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Laboratory Investigation of High RAP Content Pavement Surface Layers

Final Report

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16. Abstract

A laboratory study was undertaken to investigate the feasibility of using high (25% or more) reclaimed asphalt pavement (RAP) content warm mix asphalt (WMA) mixtures to construct the surface of highways managed by the Mississippi Department of Transportation (MDOT). The focus of the research was high RAP, with secondary emphasis on warm mix technologies used in conjunction with RAP. Three RAP sources and two warm mix technologies (Sasobit® and Evotherm 3G™) were tested. The study used all asphalt mix designs performed in the past several years by MDOT alongside field produced surface mixes as the reference for comparison/investigation of high RAP-WMA properties. The investigation included durability, cracking, rutting, and moisture damage testing as its primary components.

The study developed regression equations to estimate the amount of absorbed asphalt present in a given RAP source using the MDOT mix design database. It was shown that traditional methods of determining asphalt absorption of RAP are questionable in many situations. Durability was measured on the dense graded mixtures by the Cantabaro test, which is not a typical use of the test. Results did not indicate significant durability problems of the high RAP-WMA mixes, though they were shown to be less durable in some conditions. Mixture stiffness measured by the Bending Beam Rheometer (*BBR*) was used as a comparer to control mixes to evaluate crack resistance and produced varying results with test temperature, though no major problems were identified with the high RAP-WMA. Rutting was shown to be on par with PG 76-22 control mixes in some instances. Moisture damage was found to be a potential problem using loaded wheel testing under water. Overall, the study concluded that 25% RAP WMA was feasible and that 50% RAP WMA may be feasible for use in surface layers.

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LIST OF VARIABLES

Abs	Water absorption of aggregate by aggregate mass (%)
APA	Asphalt Pavement Analyzer
APA_7	Result of *APA* testing at 7% air voids
APA_{10}	Result of *APA* testing at 10% air voids
APT	Accelerated pavement tester
BBR	Bending Beam Rheometer
C.I.	Confidence interval
CM	Control mixture
COV	Coefficient of variation
CST	Critical stripping temperature
CTMeter	Circular Track Meter
DFTester	Dynamic Friction Tester
DFT_{20}	*DFTester* coefficient at 20 km/hr
DFT_{60}	*DFTester* coefficient at 60 km/hr
DFT_{64}	*DFTester* coefficient at 64 km/hr
$D_{b\text{-}s}$	Bulk slab density (g/cm^3)
DOT	Department of transportation
DSR	Dynamic Shear Rheometer
(d2s)	difference two-sigma limit of *ASTM C 670*
E^*	Dynamic modulus of asphalt
F60	Friction value at 60 km/hr as per *ASTM E 1960*
$F\varepsilon$	Cumulative strain at failure in *MRTCR* test
FHWA	Federal Highway Administration
FN	Flow number in *MRTCR* test
GLWT	Georgia loaded wheel tester
G-1	Crushed gravel aggregate source 1
G_b	Specific gravity of asphalt binder
G_{mb}	Bulk specific gravity of a compacted asphalt specimen
G_{mm}	Maximum theoretical specific gravity according to *AASHTO T 209*
G_{sa}	Apparent specific gravity of aggregate
G_{sb}	Bulk specific gravity of aggregate
G_{se}	Effective specific gravity of aggregate
H_F	Final height of sample measured by *SGC*
H_I	Initial height of sample measured by *SGC*
HLWT	Hamburg loaded wheel tester
HL-1	Hydrated lime source 1
HMA	Hot mixed asphalt
HT	High traffic mixture
IFI	International Friction Index
IDT	Indirect tensile test
LAC	Linear Asphalt Compactor
L-1	Limestone aggregate source 1
$LST_{+4.75}$	Amount of limestone aggregate retained on the 4.75 mm sieve as percentage of total coarse aggregate retained on the 4.75 mm sieve

$LST_{+2.36}$	Amount of limestone aggregate retained on the 2.36 mm sieve as percentage of total coarse aggregate retained on the 2.36 mm sieve
MDOT	Mississippi Department of Transportation
MEPDG	Mechanistic-Empirical Pavement Design Guide
ML	Mass loss in Cantabro durability test as percentage of original mass (%)
MPD	Mean profile depth
MRTCR	Mixture repeated torsional creep recovery test
MSU	Mississippi State University
MT	Medium traffic mixture
MTV	Material transfer vehicle
N	Term associated with *ASTM E 2157* and MPD
NCAT	National Center for Asphalt Technology
N_{des}	Number of design gyrations used in the *SGC*
NMAS	Nominal maximum aggregate size
N_p	Number of load applications
OGFC	Open graded friction course
PFC	Porous friction course
P_{200}	Percent passing No. 200 (0.075 mm) sieve
P_{AC}	Total asphalt content on mix mass basis (%)
P_b	Design asphalt content on mix mass basis (%)
$P_{b(R)}$	Total RAP asphalt content on mix mass basis (%)
$P_{ba(s)}$	Asphalt absorption of aggregate by aggregate mass (%)
$P_{ba(mix)}$	Asphalt absorption of aggregate by mixture mass (%)
$P_{ba(R)}$	Absorbed bitumen on mix mass basis (%)
P_{be}	Total effective binder on mix mass basis (%)
$P_{be(R)}$	Effective RAP binder on mix mass basis (%)
$P_{be(V)}$	Effective virgin binder content on mix mass basis (%)
$P_{bi(R)}$	Ineffective RAP binder on mix mass basis (%)
$P_{bs(R)}$	Total RAP surface asphalt on mix mass basis (%)
PG	Result of performance grading of recovered RAP asphalt
$P_{s(R)}$	RAP aggregate on mix mass basis (%)
PW	Result of PURWheel testing
R^2	Statistical coefficient of determination
R-1 to *R-5*	RAP source 1 to RAP source 5
R_M	Total rut depth measured manually (mm)
$R_{Adj.}$	Adjusted rut depth accounting for LVDT to manual measurement difference (mm)
R_T	Rut depth measured by PURWheel LVDT (mm)
QC	Quality control test specimen
QA	Quality assurance test specimen
RAP	Reclaimed asphalt pavement
RM	Recycled mixture
RVE	Representative volume element
SA	Aggregate surface area (m^2/kg)
Sat	Percent saturation of conditioned moisture damage specimen
S-1	Coarse sand aggregate source 1

SGC	Superpave Gyratory Compactor
SIP	Stripping inflection point
SN	Skid number from *ASTM E 274* with ribbed tire at 65 km/hr
S_p	Speed constant associated with *ASTM E 1960*
SR	Sand ratio
SS	State Study
ST	Standard traffic mixture
S_t	Indirect tensile strength at failure
Std. dev.	Standard deviation
T	Time to failure in IDT test
TCE	Trichloroethylene
TSR	Tensile strength ratio (%)
V	Result of viscosity testing of recovered RAP asphalt at 135 C
V_a	Air voids of compacted asphalt mixture (%)
$V_{a(T331)}$	Air voids measured specifically with *AASHTO T 331* (%)
$V_{a(T166)}$	Air voids measured specifically with *AASHTO T 166* (%)
Var.	Variance
V-def	Vertical deformation at failure in IDT test
VFA	Voids filled with asphalt
VMA	Voids in mineral aggregate
WMA	Warm mixed asphalt
a, b	Material constants
n	Number of observations or number of data points
μ	Population mean
σ	Population standard deviation
$\varepsilon(5\%)_T$	Time to 5% cumulative strain in *MRTCR* test
$(\Delta\varepsilon/\Delta T)^{-1}$	Inverse of slope in the secondary flow region in *MRTCR* test
$z_{\alpha/2}$	Statistical coefficient accounting for variability in the prediction of G_{sb}
[-24]	Result of *BBR* testing at -24 C
[-18]	Result of *BBR* testing at -18 C
[-12]	Result of *BBR* testing at -12 C
[-06]	Result of *BBR* testing at -06 C

CHAPTER 1 – INTRODUCTION

1.1 General and Background Information

Recycling asphalt was initially entertained by the pavement engineering community some 30 years ago at a time when the United States was facing an energy crisis that significantly affected the price and availability of high quality asphalt binders. The atmosphere of the energy market recently has had some similarities to the period. Mississippi DOT (MDOT) operations have been adversely affected, and they have been forced to find ways to meet the transportation needs of the state under difficult circumstances. Focus has shifted from new construction to rehabilitation in many instances.

The use of warm mix additives within warm mix asphalt (WMA) in conjunction with reclaimed asphalt pavement (RAP) was shown promising in MDOT SS 200 (Howard et al. 2009). The purpose of SS 200 was to evaluate very high RAP content (50% and greater) WMA for use in base mixtures. The study deemed very high RAP-WMA base mixtures were feasible, but no surface mixtures were studied. WMA-RAP mixes are potentially viable alternatives to assist MDOT meet the transportation needs of the state.

If shown to be feasible, high RAP-WMA could be utilized in a variety of applications. A key application is overlays used for pavement rehabilitation. These mixes could use all the RAP that is milled from the pavement. For example, milling 25 mm and overlying the pavement with 50 mm could fully replenish the producer for all RAP in the new mixture if the content were on the order of 45%. This process, though, requires a value system as the RAP milled probably isn't the same as the material used in the mix design. The process would also require large milling operations where all the RAP is returned to asphalt producers.

A second application would be using RAP mixtures with PG 67-22 binder and substituting them for lesser RAP content mixtures with PG 76-22 binder. MDOT uses HT (i.e. 85 gyration) mixtures for applications where high rut resistance is needed, though to achieve high rut resistance the mixtures become more prone to cracking due the reduced binder content. A third application could be using MT (i.e. 65 gyration) mixtures with RAP to provide sufficient rut resistance with additional binder due to less design compactive effort. The additional stiffness from the RAP could offset the need for more compaction and having more room for virgin asphalt could offset cracking problems from RAP. ST (i.e. 50 gyration) mixtures are used when rut resistance is less critical to provide crack resistance. Applications where crack resistance is the key characteristic are not the optimal application for high RAP-WMA, though they could conceivably be used. Crack resistance is optimized with ST mixes and rut resistance is optimized with HT mixes, so they should be the standard when comparing resistance to these distress mechanisms.

1.2 Objectives

The objective of the proposed research was to investigate the feasibility of moderately high (≈ 25 to 50%) RAP content WMA as surface mixes, and more specifically for overlays. To accomplish the objective, a series of tasks were undertaken. They are described below.

- Perform literature review to compliment the review performed in SS 200.
- Test the properties of 100% RAP mixtures as a function of temperature, gyratory compaction effort, virgin binder added, and warm mix additive.
- Develop regression equations using mix design data from the MDOT mix design database for use in predicting RAP properties.
- Use the 100% RAP mixture test data and regression equations from the mix design database to characterize RAP by estimating absorbed asphalt content and estimating ranges of effective and ineffective surface asphalt contents.
- Investigate suitability of Mixture Repeated Torsional Creep Recovery *(MRTCR)* test for characterization of high RAP-WMA.
- Test rut resistance using the Asphalt Pavement Analyzer (*APA*) and the PURWheel.
- Test durability using the Cantabaro test.
- Test crack resistance by sawing mixture bars from compacted specimens and testing them at different low temperatures in the Bending Beam Rheometer *(BBR).*
- Test moisture damage using the tensile strength ratio (*TSR*) and the PURWheel.
- Test dynamic modulus (E^*) for select conditions.
- Test frictional resistance and surface texture of mixtures with varying RAP content fabricated with the *Linear Asphalt Compactor (LAC)*.
- Analyze test data to evaluate performance of high RAP-WMA mixtures.

1.3 Scope

The scope of this research was a laboratory investigation to evaluate the feasibility of using recycled asphalt mixtures containing up to 50% RAP in conjunction with warm mix additives for highway surface applications. Currently MDOT allows the use of up to 15% RAP in asphalt mixtures for surface applications; therefore the focus of this study was on mixtures containing 25% RAP or more as these types of mixtures are not currently in use on the surface of MDOT roadways. While this study was not specifically restricted to either new construction or to maintenance applications of surface mixtures, the focus of this study was targeted toward maintenance overlay applications, especially in the selection of control mixtures. Surface mixes in Mississippi can be either 9.5 mm or 12.5 mm; this study focused exclusively on 9.5 mm nominal maximum aggregate size (NMAS) aggregate gradations.

CHAPTER 2 – LITERATURE REVIEW

2.1 Overview of Literature Review

This chapter provides review of literature pertinent to the work performed in this study. The information is organized by topic. Additional literature regarding RAP can be found in the SS 200 report, which was phase one of this project (Howard et al. 2009).

2.2 RAP Aggregate Properties

Prowell and Carter (2000) conducted a laboratory study of aggregate properties when recovered from the ignition oven asphalt content test. Ten asphalt mixtures were tested that utilized nine aggregate sources commonly used in Virginia. The mixtures were used to produce simulated RAP in the laboratory by loose mix short term oven aging. Aggregate samples were recovered with the ignition oven, tested for G_{sb}, and the results compared to measured virgin aggregate G_{sb}. In 8 of the 10 cases for fine aggregate, G_{sb} of extracted aggregates were lower than the known virgin aggregate G_{sb}; the average difference of the cases that were lower was 0.026. For coarse aggregate, 60% of the cases were significantly different from the known virgin aggregate G_{sb}. In all 10 cases for coarse aggregate, G_{sb} of extracted aggregates were lower than the known virgin aggregate G_{sb}; the average difference was 0.039.

Hall and Williams (1999*a*) also studied the effects of ignition oven testing on recovered aggregate properties. Eight mixtures were produced from a range of aggregate types used in Arkansas. Measurements of G_{sb} on recovered aggregate were lower than those for virgin aggregate in all eight cases, the average difference was 0.036. The authors stated that in a number of cases the differences were within the acceptable range of two test results specified by the test method.

McDaniel and Anderson (2001) stated that it can be difficult to accurately measure G_{sb} of extracted RAP aggregate because of potential changes in the aggregate properties or gradation due to the extraction process. They recommended use of one of two approaches to avoid this difficulty. The first approach was substitution of effective aggregate specific gravity for bulk aggregate specific gravity in volumetric calculations. While this approach can provide a reasonable approximation in cases where asphalt absorption by the aggregate is low, in many instances that is not the case. The second approach discussed was back-calculation of aggregate G_{sb} by measurement of RAP G_{mm} and use of an assumed value for absorbed asphalt for the RAP.

Newcomb et al. (2007) discussed the difficulty of accurately measuring G_{sb} for RAP aggregate. The authors mentioned that the ignition method could change aggregate properties and that solvent extraction methods did not always remove all of the absorbed asphalt from the aggregate pores. It was recommended to use the back-calculation method for RAP aggregate G_{sb} with measured G_{mm} data and using either known asphalt absorption values from similar aggregates or an assumed value of 1.5%.

Kvasnak et al. (2010) conducted a laboratory study of four simulated RAPs; four aggregate types and two asphalt binders were utilized. The simulated RAPs were made by following the *AASHTO R-30* aging protocol (4 hours at 135 C followed by 5 days at 85 C) on loose samples of asphalt mixture. Three methods of extracting the RAP aggregate were

examined: 1) centrifuge with TCE solvent; 2) reflux with TCE solvent; and 3) ignition oven. The researchers found that the asphalt contents determined by all three of the methods were consistently lower than the actual asphalt contents of the mixes with the ignition method generally yielding results closest to the actual value and the centrifuge method always yielding the overall lowest asphalt contents. Aggregate G_{sb} values determined with ignition oven extracted aggregate were found to be generally similar to or lower than the actual aggregate G_{sb} values determined by testing virgin aggregate. Aggregate G_{sb} values determined with solvent extracted aggregate were found to be generally similar to or higher than the actual aggregate G_{sb} values. In 47% of the comparisons (all test methods) the extracted aggregate G_{sb} values were significantly different than the virgin aggregate values; results were dependent on aggregate type. Kvasnak et al. (2010) recommended that the back-calculation approach to estimate aggregate RAP G_{sb} by measurement of RAP G_{mm} be used whenever a reasonable estimate of absorbed asphalt content is available. If an estimate of absorbed asphalt content is not available, measurement of RAP aggregate G_{sb} was recommended as the next best option but that caution should be used when selecting an extraction method for certain aggregate types.

2.3 Asphalt Absorption

Kandhal and Khatri (1992) conducted a laboratory study to investigate the absorption of asphalt binder by aggregate as part of the strategic highway research program (SHRP). Eight aggregate sources and four asphalt binders (32 mixture combinations) from the SHRP materials reference library were utilized in the study that encompassed a wide range of material properties. The aggregate types tested included granite, limestone, gravel, sandstone, and basalt; the binder grades were AC-5, AC-10, AC-20, and AC-30. The researchers found that asphalt absorption was a function of both aggregate and asphalt properties. Data from the study indicated a general relationship between aggregate water absorption and asphalt absorption. An equation was developed relating asphalt ($P_{ba(s)}$) to water (*Abs*) absorption (Eq. 2.1), where both terms reference aggregate mass. However the relatively low coefficient of determination for the relationship indicated that aggregate water absorption alone does not fully predict asphalt absorption.

$$P_{ba(s)} = 0.277\left(Abs\right) + 0.15 \qquad R^2 = 0.55 \qquad n = 96 \tag{2.1}$$

Kandhal and Khatri (1992) further found that aggregate particle shape and texture did not correlate with asphalt absorption. Measurements of aggregate pore diameter indicated that no appreciable asphalt absorption occurred in aggregate pores less than 0.05 micron in diameter though reasonable correlations were developed relating asphalt absorption to the size and quantity of aggregate pores larger than 0.05 micron. In some cases the amount of asphalt absorption of any given aggregate source varied noticeably depending on the asphalt binder source.

Analysis of the component chemistry of the asphalt binders tested provided some evidence that selective absorption of asphalt binder components might be occurring but no definitive conclusions could be drawn with regards to selective absorption. The experimental results indicated that asphalt absorption was dependent not only on the specific aggregate and asphalt binder binders tested but also on the interaction between the factors. The primary

conclusion of the study was that each type and source of asphalt binder must be treated independently (Kandhal and Khatri 1992).

2.4 Cantabro Durability Test

The Cantabro abrasion loss test is often used in design of open-graded friction course (OGFC) mixtures, also referred to as porous friction course (PFC), as a measurement of durability and of the potential for aggregate loss from mixtures (Watson et. al. 2003). An upper limit of aggregate loss for un-aged OGFC mixture specimens of 20% has been recommended (Watson et. al. 2004). Use of polymer-modified binders was found to noticeably reduce the aggregate loss compared to specimens made with an un-modified binder and the same aggregate type and gradation (Watson et. al. 2004). No information was found in the literature regarding use of the Cantabro test for dense-graded asphalt mixtures.

Alvarez et. al. (2008) found the Cantabro test to be somewhat sensitive to changes in fundamental binder properties due to aging but stated that test results might be more influenced by aggregate properties of the mixtures tested than by the binder properties. The same authors did suggest use of the Cantabro test as a tool to aid in selection of the most promising material combinations in terms of durability for OGFC mixtures. Based on a limited data set, Kraus (2008) provided evidence of a possible relationship between Cantabro aggregate loss for mixtures and results of Dynamic Shear Rheometer (DSR) testing on the polymer-modified binder components of the mixtures; testing was performed on both un-aged and laboratory aged binders and mixtures.

2.5 Mixture Testing with Bending Beam Rheometer

Zofka et al. (2005) presented a method to measure low temperature stiffness properties with the Bending Beam Rheometer (*BBR*) on thin beams of asphalt mixture made from gyratory compacted specimens. Mixture beams were prepared from 6 asphalt mixtures that contained 0, 20, or 40% RAP and either PG 58-28 or PG 58-34 virgin binder. Testing of the mixture beams was performed at -18 and -24 C. Measured stiffness of the mixtures increased as RAP was added to the mixtures for both test temperatures. A limited amount of indirect tension testing was also performed on the mixtures and results indicated that mixture stiffness at 60 seconds of loading time as measured by the two methods was fairly similar for both test temperatures.

Zofka et al. (2008) used the *BBR* mixture beam test and the indirect tension test to produce creep compliance curves for twenty asphalt mixtures. The data was then used as input for the thermal cracking module of the Mechanistic-Empirical Pavement Design Guide (MEPDG) to estimate thermal cracking of a pavement over its service life. The two test methods were observed to yield slightly different creep compliance curves, however the authors developed and presented an easy to use shifting function to transform *BBR* results to results by indirect tension testing. Comparison of thermal cracking estimates with the MEPDG using data from both test methods showed that similar data from both test methods for the same mixture resulted in similar predicted thermal cracking performance.

Marasteanu et al. (2009) evaluated use of the *BBR* mixture beam test method. Statistical analysis of dimensions of 660 mixture beams showed that test specimens of appropriate dimensions can be reliably prepared. A sensitivity analysis performed using the

Hirsch model showed that with a target mixture air void level of 4%, a range of air voids up to 4% above or below the target value (i.e. air voids ranging from 0 to 8%) would have a very small affect on measured asphalt mixture stiffness at low temperatures. The error would be 2% or less and for test loading times of about ninety seconds and longer, the error would be less than 1%. Three dimensional finite element modeling of *BBR* mixture beam testing was performed with the ABAQUS finite element code; a digital image scanning technique was utilized to base the ABAQUS models on actual mixture beam specimens. Results showed that the distribution of aggregate particles within a mixture beam was very important to measured stiffness. It was possible for distributions of aggregate to occur that produced a cross section in the beam composed entirely of asphalt mastic. For these beams the stiffness values were dramatically lower than for beams with a more uniform distribution of aggregate particles.

Marasteanu and Anderson (2001) discussed how to identify errors in rheological test data for asphalt binders (not asphalt mixtures). For *BBR* test data they recommended that a quick check of the results should be performed to verify that the slope of the m-value parameter decreases as the loading time increases. Data that did not follow this rule of thumb would likely be due to testing error. The concept could be extended to asphalt mixtures.

Velasquez (2009) investigated the sensitivity of determination of asphalt mixture stiffness at low temperatures to varying test specimen dimensions. A combination of experimental data and finite element modeling was utilized. Ten mixtures were tested at three test temperature with a variety of test specimen dimensions. Results showed that as testing temperature is decreased the disparity in binder and aggregate stiffness lessens and the mixture stiffness becomes less reliant on the size and distribution of aggregate. The consequence of this is that the minimum test specimen dimensions required to ensure that a representative volume element (RVE) of the mixture is obtained become much smaller. Experimental data suggested that the *BBR* mixture beam test method could produce representative measurements of creep stiffness for asphalt with a minimum of three test replicates even when the nominal maximum aggregate size (NMAS) of the mixtures was greater than the smallest dimension of the beam.

2.6 Relevant Pavement Density Parameters

A department of transportation (DOT) survey questionnaire reported by Linden et al. (1989) with 48 respondents provided the following information. Core samples were used by essentially all responders in some form. Twenty-one respondents used a maximum V_a density criteria (1-10%, 1-9%, 12-8%, 2-7.5%, 5-7%). One agency noted rejection below 8% V_a, while seventeen agencies reported price adjustments and thirteen additional agencies reported price adjustments or removal and replacement below their minimum density limit; a range of other options were also reported with less frequency. The average maximum in place air voids reported by state DOT's was 9.9% with a range of 5 to 15%. A summary of current in-place air voids requirements for Southeastern U.S. DOTs are provided in Table 2.1.

Table 2.1 In-Place Air Void Specification Summary of the Southeastern United States

	Specification State and V_a Requirements								
Surface Layer	**MS**	**AL**	**GA**	**FL**	**SC**	**NC**	**AR**	**LA**	**TX**
Target Air Voids	7.0	6.0	<7.8	<7.0	6.0	<8.0	6.0	<8.0	7.0
Full Pay-High	7.0	9.7	7.8	8.1	7.8	8.0	8.0	89 PWL	8.5
Full Pay-Low	4.0	2.2	3.8	2.0	4.0	---	4.0	---	4.7
Removal Required	9.0	11.2	13.5	9.5	9.4	10.8	9.1	30 PWL	10.0

Notes: All states shown specify bulk gravity of roadway cores be measured by *AASHTO T 166* or an equivalent state test method utilizing submerged specimens. For states that specify a range of target in-place density, the median of the range is reported. Louisiana utilizes a percent within limits (PWL) criteria. References to all nine DOT specifications are provided in the references chapter (Chapter 10).

Measurement of air voids using different methods poses challenges. Questions arise such as what are the issues between different test methods due to surface texture or water absorption? Another issue that has been speculated to occur is volume reduction in the specimens tested by the Corelok® method as a result of the vacuum pressure applied during removal of air from the specimen. Buchanan (2000) indicated that the Corelok® method provided the most consistent and accurate results of specimen bulk gravity for compacted mixtures with high air void contents.

As of July 2010, the Corelok® was not part of MDOT protocol for dense graded mixtures (only used for OGFC design). Typically, a core is cut at the beginning of a project and G_{mb} measured via *AASHTO T 166*. The result is used to adjust nuclear density measurements, which are used for acceptance. Periodically, the correlation between *AASHTO T 166* and the nuclear gage measurement is updated throughout the project. Paraffin coated specimens are required when excessive water absorption occurs during the laboratory test.

Cooley (2003) studied permeability of field cores from Mississippi. As part of the study G_{mb} of the cores was measured by the Corelok® method (*AASHTO T 331*) and by the submerged specimen method (*AASHTO T 166*). Twelve different mixtures (two 9.5 mm, five 12.5 mm, and five 19.0 mm NMAS) that included both fine and coarse aggregate gradations were tested for a total of 175 data points with air voids ranging from 3.8 to 12.4% via *T 166* (equivalent of 3.8 to 15.1% via *T 331*). For all twelve mixtures the two measurement methods yielded significantly different results. The author observed that similar results were obtained from both methods when the air voids were less than about 5% but that results from the two methods began to diverge noticeably as the air voids increased above 5%. The cause of the divergence in results between the two methods was stated to be likely due to the large interconnected voids present in specimens with high air void contents. The data indicated that coarse graded mixtures generally had larger differences in results than fine graded mixtures. Cooley (2003) presented a linear relationship between air voids measured according to the two methods (Eq. 2.2). According to the relationship, air voids of 7% and 10% measured by the submerged method were equivalent to air voids of 8.3% and 12.3% respectively as measured by the Corelok® method.

$$V_{a(T331)} = 1.333 V_{a(T166)} - 1.04 \qquad R^2 = 0.87 \qquad n = 175 \tag{2.2}$$

Brown and Cross (1989) measured in place density of five pavements as part of a study of rutting; the pavements had between six and sixteen years of traffic at the time of investigation. Air voids were observed to range from nearly zero to 8%. Badaruddin and White (1994) reported in place air voids of twenty-three pavements in Indiana that ranged from nearly zero to 13.2%. Lu (2005) reported that mean air voids of sixty-three pavements examined in California were about 7% and ranged from 2 to 14%. Two sets of data were used by Seo et al. (2007) to study air void reduction in service; first data set was from a study to refine gyratory compaction requirements, and the second data set was from cores taken from I-85 after two years of traffic. It was observed that 8 to 11% initial air void levels were around 6 to 8% after two years of service. Prowell and Brown (2007) measured density of forty pavements across the United States with air void levels that ranged from 5.0 to 14.5% immediately after construction. For the same pavements air voids ranged from 1.9 to 11.5% two years after construction. It was observed that about two-thirds of pavement densification due to traffic occurred in the first three months after construction.

Density specifications are often misused as discussed in Brown (1990) as mixture changes (e.g. increases in fines or asphalt content) can reduce voids when the correct way to reduce voids of a properly designed mix is through compaction. Hughes (1989) recommended using 7% air voids as the mean requirement in conjunction with 1.5% standard deviation within statistically based end result specifications. Linden et al. (1989) used 7% air voids as a baseline and reported that every 1% air void increase resulted in approximately 10% loss in pavement life. Literature review and a DOT survey questionnaire were the data sources used by Linden et al. (1989). Literature review revealed 10 to 30% fatigue life reduction and 4 to 6% penetration reduction per percent increase in air voids. Multiple studies (e.g. Huber and Heiman 1987) report air voids below 3% are a primary indicator of rutting. Brown (1990) reported that in place air voids of 3 to 8% would generally provide good performance of a surface mixture passing through or above the restricted zone.

2.7 Loaded Wheel Rut Testing

Izzo and Tahmoressi (1999) evaluated the repeatability of the Hamburg loaded wheel tester (HLWT) and stated that its use with steel wheels provided good repeatability on gravel mixes and poor repeatability for limestone mixes. Use of solid rubber wheels with the HWLT was observed to produce significantly less damage than steel wheels.

Hall and Williams (1999*b*) performed a limited evaluation of the HWLT in comparison to the Evaluator of Rutting and Stripping in Asphalt (ERSA); both field and laboratory compacted specimens of a field produced mixture were tested. Gyratory compacted specimens were observed to have significantly lower rut depths than field compacted specimens.

Sivasubramaniam et. al. (2004) compared data from the PURWheel laboratory loaded wheel tester to the Purdue accelerated pavement tester (APT) and to mixture performance on the NCAT test track. All PURWheel testing was performed at 50 C. The authors found relatively weak correlations ($R^2 = 0.35$) between PURWheel results and mixture performance at the NCAT track when PURWheel testing was performed on slab specimens cut from the APT test sections (air void range 8.0 to 11.6%). Much better correlations ($R^2 = 0.69$) were found between PURWheel results and NCAT test track results when PURWheel testing was performed on slab specimens cut directly from the NCAT test track (air void range 4.9 to

6.6%). The difference in the correlation was stated to be likely due to differences in air voids and compaction parameters.

Sivasubramaniam et. al. (2004) used a power law model given in Eq. 2.3 that was fitted to rut data for analysis; the total rut depth was considered to be the sum of specimen downward deformation in the wheel-path and any specimen uplift relative to the original surface outside of the wheel-path. The model constant *a* was stated to be related to mixture properties and initial air voids. The model constant *b* was stated to depend on test temperature as well as mixture type and to be a good indicator of mixture rutting potential.

$$\text{Total Rut} = a\left(N_p\right)^b \tag{2.3}$$

Where,

N_p = number of load applications
a, b = material constants

2.8 Moisture Sensitivity Testing

Kiggundu and Roberts (1998*b*) defined moisture damage as "the progressive functional deterioration of a pavement mixture by loss of the adhesive bond between the asphalt cement and the aggregate surface and/or loss of the cohesive resistance within the asphalt cement principally from the action of water." Kiggundu and Roberts (1988*a*) stated that the mechanisms of stripping "are likely to be asphalt-aggregate specific, environmentally specific and service conditions specific."

Moisture damage in asphalt mixtures is generally thought to be due to one of or a combination of two major causes: 1) loss of cohesion within the binder film (i.e. softening of the binder in the presence of moisture); and 2) loss of adhesion between the binder film and the aggregate particles (Hicks 1991). Loss of adhesion in a mixture is visually apparent (e.g. stripping). Loss of cohesion in a mixture is less readily observed visually but can be measured by loss of strength of the mixture.

Kandhal (1992) identified a number of factors that can lead to premature failure of pavements due to moisture damage. They include: 1) poor pavement drainage; 2) poor compaction of pavement; 3) excessive dust coating of aggregate; 4) insufficient drying of aggregate during production; and 5) use of weak aggregates. Hughes (1989) also emphasized the importance of good compaction in the field to reduce the level of permeable voids in producing pavements that are resistant to moisture damage.

Terrel and Al-Swailmi (1993) discussed a hypothesis for moisture damage in asphalt mixture that was developed during the strategic highway research program (SHRP). Laboratory test data was utilized to support the hypothesis that a range of air voids on the order of 7 to 11% in compacted mixture will produce a void structure and conditions that are favorable to occurrence of moisture damage. The range of air voids where this occurs was termed "pessium" voids (i.e. opposite of optimum). Void levels less than this range result in a relatively impermeable pavement where moisture does not intrude and void levels higher than this range result in a relatively free-draining pavement where moisture cannot remain for long periods of time (i.e. PFC or OGFC).

Williams and Breakah (2010) found the dynamic modulus test to be sensitive to moisture and that the effects of moisture were more noticeable at high temperatures and/or lower loading frequencies. A calculated *E** ratio (conditioned to unconditioned specimens) was found to be statistically no different than the conventional *TSR* ratio.

2.8.1 Tensile Strength Ratio (*TSR*) Testing

Castro-Fernandez (1996) performed moisture resistance testing with two different HMA mixtures from Nevada with RAP contents between 0 and 70%. Virgin aggregate type was not specified; PG 64-22 binder was used for the 0% RAP mix. Blends of RAP and very soft binders were selected for mixtures with RAP based on binder blending charts. When lime was included, *TSR* values were acceptable for both mixtures with any amount of RAP. When lime was not included the amount of RAP had a significant effect on *TSR* values. For both mixtures without lime and between 0 and 30% RAP the *TSR* values were below 0.50 (as low as 0.30); when the RAP content was increased to 50% the *TSR* value for one mixture was 0.60 and for the second mixture was greater than 0.80. For both mixtures with 70% RAP the *TSR* values were greater than 0.80. The results of Castro-Fernandez (1996) indicate that inclusion of RAP in moisture susceptible mixes was able to significantly improve the moisture resistance of the two mixes studied.

Zaniewski and Viswanathan (2006) reported on use of the *AASHTO T 283* test method for three mixtures of known good field performance. The 16 hour loose mix aging at 60 C required by the test method was included as part of the specimen preparation method; conditioning by vacuum saturation alone and by one freeze-thaw cycle in addition to vacuum saturation was evaluated. Results indicated that test method was not sensitive to saturation level or to inclusion of a freeze-thaw cycle as part of the conditioning protocol. The *TSR* results indicated that all three mixtures were moisture sensitive; the authors concluded that "TSR is not a reliable indicator of field performance" for the mixtures tested.

Bagampadde et al. (2006) stated that variability in moisture sensitivity test data was primarily due to aggregates and not to binder. Chen et al. (2007) studied the effect of RAP on moisture sensitivity with mixtures produced using blends of virgin binder and recovered RAP asphalt mixed with aggregate. Increasing the amount of recovered RAP asphalt was observed to have a detrimental effect on *TSR* results. Chen et al. (2007) also presented a concept of relative energy loss to analyze indirect tensile strength test results and found that the concept was capable of identifying moisture susceptibility.

Al-Qadi et al. (2009) studied HMA mixtures containing 0 to 40% RAP and found that in general *TSR* values improved as RAP was added to the mixture. PG 64-22 was used for the 0 and 20% RAP mixtures and PG 58-28 was used for the 40% RAP mixture; details of the aggregates used were not provided. The authors stated that selective absorption of binder into aggregate for RAP could potentially produce a bond that was resistant to stripping and also that incomplete blending could result in double coating of RAP particle resulting in improved TSR values.

Doyle et al. (2011) studied eight mixtures containing 0, 25, and 50% RAP (note the RAP source used was the same *R-1* RAP source investigated in this report). Both HMA and WMA mixtures were investigated with limestone and gravel aggregates with PG 67-22 binder. The authors found that increasing the amount of RAP from 0 to 25% improved the

TSR results for 75% of the mixtures studied. Increasing the amount of RAP from 0 to 50% improved the *TSR* results for 88% of the mixtures studied.

2.8.2 Loaded Wheel Testing

Aschenbrener (1995) used the HWLT to evaluate moisture damage for twenty pavement mixtures of known field performance ranging from very good to very poor. Testing was performed on slab specimen at 50 C; stripping inflection points (SIPs) were computed from the test data and used for mixture evaluation and comparison. Specific details of the mixtures tested were not provided but the test results were found to be sensitive to aggregate properties such as amount of dust coating, dust to binder ratio, and clay content. The author observed that average SIP for mixtures as determined by the Hamburg test provided an excellent correlation to field performance with respect to moisture damage. Pavements with good field performance had average SIPs generally greater than 10,000 passes and pavements with poor field performance had average SIPs less than 3,000 passes.

Additional test data presented by Aschenbrener (1995) for four aggregates (details not given) and 4 asphalt binder grades (PG 52, PG 58, PG 64, and PG 70) indicated that moisture resistance of the mixes was improved by increasing the binder grade. The amount of short term aging used in the laboratory was also found to affect HLWT results; more short term aging resulted in better performance. Aschenbrener (1995) also found not all binders graded as PG 58-22 provided the same performance; crude oil source and refining process were observed to influence HLWT results.

Pan and White (1999) conducted moisture sensitivity testing of seven mixtures and a variety of anti-strip agents with both the PURWheel loaded wheel tester and *AASHTO T 283 TSR* testing. Results indicated that in general the PURWheel provided a better indication of the stripping potential of a mixture than *TSR* testing. Results of PURWheel testing were able to demonstrate stripping in mixtures at test temperatures ranging from 25 to 60 C.

Cross et.al. (2000) performed testing of eight different mixtures with the *APA* at 40 C. Results of wet testing using one of three pre-conditioning procedures was compared to results of standard dry testing. The three pre-conditioning procedures were 1) 2 hour soak at 40 C; 2) specimen saturation and 24 hr conditioning at 40 C; and 3) specimen saturation plus one freeze-thaw cycle followed by 24 hr conditioning at 40 C. The authors found that the 2 hour soak pre-conditioning procedure produced mean rut depth results that were significantly different from the dry *APA* test data. The other two preconditioning procedures were not found to produce statistically significant differences in mean rut depths compared to dry testing. The *APA* results corresponded well with *TSR* results from standard *AASHTO T 283* testing in ranking moisture susceptibility of mixes.

Hunter and Ksaibati (2002) performed wet testing of asphalt mixtures with the Georgia loaded wheel tester (GLWT) and found that neither saturation conditioning nor saturation plus one freeze-thaw cycle conditioning prior to testing significantly affected results.

West et. al. (2004) evaluated under water testing in the *APA* for moisture sensitivity assessment of asphalt mixtures. Data was obtained for a variety of mixtures, specimen geometries, load application methods, and conditioning protocols. Initially testing was to be performed at 64 C; however that temperature was found to be too severe for steel wheel testing and therefore all testing was performed at 50 C. The results were mixed but some

general conclusions were presented by the authors. Pre-conditioning of specimens by vacuum saturation and one freeze-thaw cycle was stated to appear to be able to distinguish mixtures prone to stripping from those that were not. The steel wheel load application method was stated to be more severe than pressurized hose load application method but also appeared to be more variable. The authors further indicated that wet testing of unconditioned specimens was inadequate to cause stripping. Beam specimens were found to generally yield the most meaningful results but cylindrical specimens were stated to be more practical.

Buchanan and Smith (2005) tested 24 Mississippi mixtures with a rotary wheel tester (RWT); the test method was found to be a severe performance test for moisture susceptibility. Gravel mixtures were found to exhibit much greater deformation than gravel/limestone mixtures. A normalized rut depth parameter (specimen deformation divided by number of test cycles) was used during analysis.

Lu (2005) performed an extensive evaluation of the HLWT on pavements in California. Test parameters included 50 C test temperature and a 30 minute wait period once specimens were placed in the machine for the water bath to reach temperature. Twelve laboratory mixtures were evaluated by testing of slabs specimens (24 by 33 by 7.6 cm) prepared by rolling wheel compaction to between 6 and 8% air voids. Also cores were also taken and tested from 57 pavement sections of known performance with respect to moisture. Lu (2005) found that the HLWT did not clearly distinguish between mixes with different observed moisture sensitivities. The test method tended to overestimate performance of mixes with conventional binder and to underestimate performance of mixes with polymer-modified binder. The author provided five major recommendations to improve the HLWT: 1) vacuum saturation of specimens prior to testing; 2) pre-conditioning of specimens at the test temperature prior to testing; 3) use of different test temperatures based on binder grade; 4) performing wet and dry tests on mixtures and using a ratio of results for evaluation; and 5) that the HLWT equipment be modified with an air-heating system or environmental chamber to maintain high air temperatures during testing.

Kim and Lutif (2006) performed moisture susceptibility testing on an aggregate blend of limestone and gravel with combinations of mineral fillers and lime treatment (16 mixture combinations) with *TSR*, wet *APA*, and wet HLWT test methods. All mixes were HMA and the binder was PG 64-22. *TSR* testing according to *AASHTO T 283* was performed with six freeze-thaw conditioning cycles. Wet *APA* testing was performed at 64 C after a 16 hour conditioning period on gyratory compacted specimens with a target 4% air void content. Wet HWLT testing was performed at 70 C after a minimum 30 minute temperature equilibrium period on gyratory compacted specimens with target 7% air voids. The three test methods provided consistent rankings of aggregate blends by moisture susceptibility from high to low.

Shiwakoti (2007) compared the *APA* and HLWT for moisture sensitivity assessment for six HMA mixtures with acceptable *TSR* values (>0.80). Five of the six mixtures used PG 64-22 binder and the sixth mixture used PG 70-28 binder; details of aggregate types were not provided but were a range of materials used in Kansas. The wet HLWT was performed at 50 C on gyratory compacted specimens; a minimum 30 minute soak period was specified after the water bath reached temperature before testing commenced. Both wet and dry *APA* testing at 50 and 60 C test temperatures was performed on gyratory compacted specimens vacuum saturated then brought to the test temperature and allowed to soak for at least one hour before testing commenced. Pressurized hose load application was used for all *APA*

testing. Four of the six mixes tested exhibited visual evidence of stripping in wet *APA* testing; the *APA* did not indicate any stripping inflection point (SIP) in the test data for any of the mixes. The HLWT correctly showed SIPs for the four mixes which exhibited visual evidence of stripping and did not show a SIPs for the two mixtures without visual stripping. For *APA* testing conducted at 60 C the dry test exhibited greater rut depths than the wet test. For *APA* testing conducted at 50 C the opposite trend was observed; the wet test exhibited greater rutting than the dry.

Cooper (2009) used *TSR* and HLWT test methods to evaluate a mixture both with and without Sasobit®; the base binder was a polymer modified PG 76-22. The mixture was 75% limestone, 6% sand, and 19% RAP. Compaction temperature for the HMA was 157 C and compaction temperature for the Sasobit® mix was 143 C. Hamburg testing was performed according to *AASHTO T 324* at 50 C after 90 minutes of conditioning; 320 by 260 by 80 mm slab specimens prepared by kneading compaction were utilized for Hamburg testing. The mixture both with and without Sasobit® performed well in both *TSR* and HLWT testing and were stated to not exhibit evidence of moisture susceptibility. The mixture containing Sasobit® rutted less than the mixture without however the difference was hypothesized to be at least partly due to the lower air voids of the Sasobit® specimens.

Nielson (2010) evaluated the test temperature used in the HLWT for three asphalt binder grades and two asphalt binder sources (six combinations) on a single blend of limestone aggregate with a known history of stripping. All mixes were HMA and the binders tested were PG 70-28, PG 64-28, and PG 58-28. Slab specimens were prepared by linear kneading compaction and tested at a range of test temperatures from 45 to 60 C. The author defined a critical stripping temperature (CST) below which no stripping would occur and above which stripping would occur; the existence of a stripping inflection point (SIP) in the data was considered evidence of stripping. Based on the data, it was stated that the number of cycles required to induce stripping in the mix was highly variable and independent of the test temperature and binder grade provided the test temperature was greater than the CST for the mix. A range of CSTs was reported for each PG high temperature grade tested. For PG 58 binder grade the reported range of CSTs was 44 to 49 C. For PG 64 binder grade the reported range of CSTs was 49 to 54 C. For PG 70 binder grade the reported range of CSTs was 54 to 55 C. The author recommended that the best approach would be to select HLWT test temperatures based on anticipated environmental conditions during service including both geographic location and location within the pavement structure.

Azari (2010) conducted wet HLWT at 50 C and TSR testing of two mixtures of general low and high moisture susceptibility and observed that HLWT results were more consistent with observed field performance of the mixtures. The *TSR* results predicted that both mixes were acceptable with regards to moisture susceptibility.

2.9 Dynamic Modulus Testing with RAP

Lachance (2002) performed dynamic modulus testing on mixtures containing 0 to 40% RAP. Greater test variability was observed in specimens containing higher amounts of RAP. Mixture containing 15% RAP was observed to be stiffer than 0% RAP mixture. Stiffness of mixtures containing 20 and 40% RAP were observed to be similar to those for 0% RAP. A potential explanation for this unexpected result was provided by the author that

differences in total asphalt content and gradation may have contributed to the similar stiffness results regardless of the amount of RAP present.

Testing of mixtures containing 40% RAP was conducted by McDaniel et al. (2000) and Al-Qadi et al. (2009). Both researchers produced mixtures according to actual practice (RAP mixed with virgin materials), simulated black rock-no blending (extracted RAP aggregate mixed with virgin aggregate and virgin binder), and simulated total blending (extracted RAP aggregate mixed with virgin aggregate and blend of RAP bitumen with virgin binder). Al-Qadi et al. (2009) also produced mixtures that simulated 50% partial blending (extracted RAP aggregate mixed with virgin aggregate and blend of 50% of total RAP bitumen with virgin binder). In some cases McDaniel et al. (2000) reported dynamic modulus stiffness results for the actual practice case were higher than for either the simulated no blending or the simulated total blending cases. This is unexpected in that the amount of blending that occurs must be between 0 and 100%. Al-Qadi et al. (2009) observed that "the test results consistently showed that the dynamic modulus values for the specimens with [simulated] 100% working binder were significantly lower than those of actual practice specimens." This is an unexpected result for the same reason as the results of McDaniel et al. (2000).

2.10 Skid Resistance

Hossain et al. (1993) reported on the long term field performance of asphalt overlays containing 50% RAP placed on Interstate-8 in Arizona; all of the recycled overlay test sections experienced approximately 7 million equivalent single axle loads over their 10 year service life. Skid resistance of the recycled overlays was monitored with a Mu-meter. The overall decrease in skid resistance over the service life for all eight of the field test sections (both recycled mixtures and controls mixtures) was less than 20% of the value measured immediately post construction (Hossain et al. 1993).

The Circular Track Meter (*CTMeter*) is a device used to measure pavement surface macrotexture. Its components and use are detailed in *ASTM E 2157* and measurement results are produced in terms of Mean Profile Depth (MPD). The Dynamic Friction Tester (*DFTester*) is a device used to measure friction properties produced between a pavement surface and rubber pads mounted to the *DFTester*. Its use is detailed in *ASTM E 1911* and measurement result plots of friction versus speed are produced. Test results from *CTMeter* and *DFTester* measurements made at the same location are utilized in *ASTM E 1960* to calculate the International Friction Index (IFI).

Field measurements of four flexible pavement sections with a range of frictional skid resistance from low to high was performed by Khasawneh and Liang (2008); two of the mixtures were composed primarily of gravel aggregates and two mixes were primarily made of limestone. Between six and forty replicate measurements of both locked wheel skid trailer and *DFTester* friction estimates were made on each section. Based on a statistical analysis of the data obtained, Khasawneh and Liang (2008) recommended the correlation presented in Equation 2.4 between skid number as measured by locked wheel trailer and *DFTester* results.

$$SN = -14.99 + 139.4\left(DFT_{64}\right) \qquad R^2 = 0.70 \tag{2.4}$$

Where,

DFT_{64} = *DFTester* friction coefficient at 64 km/hr
SN = Skid Number from *ASTM E 274* with ribbed tire at 65 km/hr

Kowalski et al. (2010) conducted a laboratory study of surface skid resistance for both dense graded and stone matrix asphalt mixtures containing RAP. A total of eight mixtures were tested encompassing four levels of RAP (0%, 15%, 25%, and 40%); all mixtures were produced with a standard binder grade (PG 64-22). The RAP used by Kowalski et al. (2010) was fabricated in the lab from limestone aggregate known to exhibit poor skid resistance and a tendency to polish. Slag aggregates known to have a high resistance to skidding were combined with the artificial RAP to fabricate the test mixtures.

Kowalski et al. (2010) utilized 508 by 508 by 38 mm panels of compacted asphalt mixture for skid resistance testing. The panel fabrication process was described in more detail in Kowalski et al. (2008). Reheated asphalt mixture was compacted directly into square wooden molds using a roller mounted to a forklift. Mixture mass was used to produce a target of 7 to 8 % air voids. Based on trial compactions, the final air void range was stated to be about 9.7 to 12.3% within the slab (Kowalski et al. 2008).

Skid resistance characteristics of compacted slabs in Kowalski et al. (2010) were measured according to *ASTM E 2157* and *ASTM E 1911*. The slabs were subjected to a polishing test with a specialized device incorporating rubber tires (total 165,000 wheel passes); skid resistance was measured periodically during the polishing procedure (Kowalski et al. 2010). Skid resistance was reduced as increasing amounts of laboratory RAP were included in the mixtures; mixtures with higher RAP contents were found to be more susceptible to polishing (Kowalski et al. 2010). Based on the results with RAP containing poor skid resistance aggregate prone to polishing, Kowalski et al. (2010) recommended a maximum percentage of RAP with aggregates having a tendency to polish for surface mixtures of approximately 30% without negative effects on skid resistance.

2.11 Mixture Testing with Dynamic Shear Rheometer

Use of the dynamic shear rheometer (DSR) with mixture bar specimens was utilized by Mathy (2002) and Mathy (2003) to identify effects of rejuvenators used on the surface of pavements. Variability of the test method was observed to be high for the field core specimens tested. The test method was found to be able to determine the presence of rejuvenators in the top 10 mm of the pavement surface. Reinke and Glidden (2004) used the DSR to perform static creep testing and repeated creep recovery testing on mixture specimens. Reasonable correlations were developed between test results and field performance of mixtures at the Minnesota test road and at the FHWA test track in Virginia.

CHAPTER 3 – EXPERIMENTAL PROGRAM

3.1 Overview of Experimental Program

The purpose of this experimental program was to investigate the feasibility of using 25 to 50% RAP in WMA surface mixtures. With exception of investigating 100% RAP, all mixtures studied were 9.5 mm NMAS and met MDOT requirements for surface mixtures. Data from MDOT State Study 200 (SS 200) was used as appropriate in this investigation. Several unconventional specimen preparation and test methods were utilized during the execution of this experimental program; they are described in detail in this chapter.

Control mixtures used in this experimental program were MDOT approved mixtures from current practice. The research team felt that current practice mixtures, especially plant-mixed material, provided the most realistic reference for the mixes under investigation. Since no previous data or experience with high RAP-WMA in Mississippi was available comparison to currently acceptable mixes was appropriate.

The experimental program was carried out in three major segments: 1) testing of control mixtures containing 0 and 15% RAP; 2) testing of 100% RAP; and 3) testing of recycled mixtures containing 25 and 50% RAP. Segment one of the experimental program included both laboratory produced and plant mixed asphalt mixtures. The second segment of the experimental program was testing 100% RAP with added virgin asphalt. Results from testing 100% RAP mixtures in segment two were used to guide the investigation of recycled mixtures containing 25 and 50% RAP in segment three, which are the mixes that are under consideration for use in construction of surface layers.

3.2 Terminology

Since this study was a follow on to SS 200 (Howard et al. 2009), the same RAP and virgin aggregate sources were utilized for the majority of testing. The terminology used in this experimental program to identify materials and mixtures is organized as follows. Aggregate sources are identified with a single letter followed by a dash and a number; the letter designates what type of aggregate and the number indicates the specific aggregate of that type (e.g. *G-1* refers to gravel aggregate source one). RAP sources are identified with a unique designation beginning with the letter *R* to represent RAP source (e.g. *R-1* refers to RAP source one). For cases where other materials were used, generic terminology has been incorporated (e.g. gravel would refer to a source other than the gravel specifically referred to as *G-1*) All named aggregate and RAP sources utilized are given in the following list.

- *G-1* Crushed gravel aggregate source 1
- *L-1* Limestone aggregate source 1
- *S-1* Coarse sand aggregate source 1
- *HL-1* Hydrated lime source 1
- *R-1* RAP source 1
- *R-2* RAP source 2
- *R-3* RAP source 3
- *R-4* RAP source 4
- *R-5* RAP source 5

To identify mixtures used in this experimental program, an identification system was set up according to the general format given in Eq. 3.1. The individual components of the identification system are described as follows.

1-2/3-4 (3.1)

1: The first position in the mixture identification code designates the NMAS of the aggregate gradation. Possible values for this label are:

- 9.5: 9.5 mm NMAS gradation
- 12.5: 12.5 mm NMAS gradation (only used with 100% RAP mixtures)

2: This portion of the label indicates the percentage of RAP aggregate in the mixture as a percentage of the total aggregate. Possible values for this label are:

- 0: 0% RAP
- 15: 15% RAP
- 25: 25% RAP
- 50: 50% RAP
- 100: 100% RAP

3: This portion of the label indicates the mixture type. Possible values for this label are:

- CM: Control Mixture
- RM: Recycled Mixture

4: This portion of the label is a numeric code that indicates the specific mixture of that type. If the number is followed by a lower-case letter, the letter indicates slight changes to the same aggregate blend and mixture composition; the slight changes may include: asphalt binder grade, mixing method (e.g. plant or laboratory mixed), or design traffic level.

For example, *9.5-0/CM-1* refers to a 9.5 mm NMAS gradation with 0% RAP that is the first control mixture. Likewise, *9.5-25/RM-1* refers to a 9.5 mm NMAS gradation with 25% RAP that is the first recycled mixture.

3.3 Materials Tested

3.3.1 RAP

Five RAP sources were utilized in this experimental program. RAP sources *R-1*, *R-2*, and *R-3* were also used in SS 200 where they were referred to as *I-55*, *MS-25*, and *SP* respectively; additional information about when and where they were obtained is available in the original report. RAP source descriptions are provided in the following paragraphs.

R-1 represents a high traffic (HT) mix (85 design gyrations); the material was milled from the surface of a 22.5 km stretch of Interstate 55 near Grenada, MS. The material was

acquired from a producer's stockpile in the fall of 2007. The material was originally placed in 1992. In general the material was from a 12.5 mm binder course developed with Marshall Mix Design. Within the section milled, both polymer modified and non polymer modified binders were used, along with varying amounts of sand in the aggregate blend.

R-2 was selected to represent an intermediate traffic mix commonly used on lower volume roads and state highways. The mix was a low volume design; it would currently be categorized as an MT mix (65 design gyrations). The material was milled from State Highway 25 in Monroe County, the project was 12 km, and the maximum depth of milling was 50 mm. the material was obtained from a producer stockpile in the fall of 2007. *R-3* is representative of a typical Mississippi RAP stockpile where a variety of materials are present. In this particular stockpile nearly all of the material was acquired from MDOT highways. The material was obtained from the stockpile in the fall of 2007.

R-4 and *R-5* were only utilized for verification testing of the approach developed in Chapter 4 to estimate RAP absorbed asphalt content. *R-4* was obtained from surface milling of U.S. Highway 49 in Madison County in the summer of 2010. *R-5* was obtained from surface milling of U.S. Highway 61 in Warren County in the summer of 2010.

During this study, the gradations of extracted RAP aggregates given in Howard et al. 2009 were found to be incorrect due to a systematic operator error in the original testing. A sample of the *R-1* RAP was retested at the MSU laboratory according to *ASTM D 2172 Method A* using trichloroethylene as the extraction solvent. A washed gradation (*AASHTO T 30*) was performed on the extracted aggregate from the MSU sample. Samples of the three RAP sources were then sent to the MDOT central materials laboratory to check asphalt contents and aggregate gradations. The ignition procedure (*AASHTO T 308 Method A*) was used to determine asphalt content at MDOT. Washed gradations were performed on solvent extracted aggregate at the MDOT laboratory.

RAP properties are given in Table 3.1 and extracted RAP aggregate gradations are shown in Figure 3.1. Note the high value of sand ratio for *R-3*, this likely indicates a large percentage of natural sand is present; the MDOT specification for sand ratio is 60 or less (MDOT 2006). The re-tested washed gradation on extracted aggregate for *R-1* performed at MSU compared favorably to the results obtained by MDOT. RAP sources *R-2* and *R-3* were not re-tested for gradation at MSU; the MDOT test results were used. For the *R-1* RAP source, the washed gradation on extracted aggregate and the combined aggregate properties are average values of all valid test data from MSU and MDOT (incorrect data from Howard et al. (2009) was not included). For *R-2* and *R-3* RAP sources, the aggregate gradations and combined properties are the MDOT obtained values only. Asphalt contents determined by MSU and those determined by MDOT were within multi-laboratory precision ranges for all three RAP sources; values reported in Table 3.1 are averages of MSU and MDOT test results. Asphalt content of *R-4* and *R-5* was only determined at MDOT.

An attempt was made to extract the effective asphalt from the RAP and leave the majority of the absorbed asphalt for PG grading because it was expected that absorbed asphalt within the RAP aggregate would not contribute to blended properties of the 25 and 50% RAP mixtures. Three washes of trichloroethylene solvent were used with a 45 minute soak period for each wash. Less than all of the RAP surface asphalt was extracted using the three wash procedure. The outer portion of the binder is expected to have aged more than the absorbed asphalt so it is expected that the grade of the recovered asphalt would have been less if all of the asphalt had been extracted. For *R-1*, roughly 3.6% asphalt was extracted

from the RAP using the three wash procedure. The total asphalt content was 5.5% so approximately 1.9% asphalt remained with the RAP. Note that low temperature performance grade is a positive value for RAP sources *R-1* and *R-3* indicating very brittle asphalt.

Table 3.1 Properties of RAP Materials Tested After Asphalt Extraction

RAP ID		*R-1*[1]	*R-2*	*R-3*	*R-4*	*R-5*
Percent Passing	**25.0 mm**	100	100	100	---	---
	19.0 mm	100	100	100	---	---
	12.5 mm	96.5	99.8	92.2	---	---
	9.5 mm	90.0	98.2	82.1	---	---
	4.75 mm	60.1	73.1	55.5	---	---
	2.36 mm	41.9	52.8	43.7	---	---
	1.18 mm	34.1	40.3	38.5	---	---
	0.60 mm	29.2	33.4	33.2	---	---
	0.30 mm	19.5	22.9	20.6	---	---
	0.15 mm	11.8	13.0	11.4	---	---
	0.075 mm	8.4	9.3	7.3	---	---
G_{sb}		2.483	2.526	2.504	---	---
G_{sa}		2.600	2.597	2.577	---	---
***Abs* (%)**		1.8	1.1	1.1	---	---
$LST_{+4.75}$ (%)		8.1	28.2	24.6	---	---
$LST_{+2.36}$ (%)		8.6	32.9	24.2	---	---
P_{AC} (%)[2]		5.5	5.6	5.0	5.6	5.7
Viscosity[3] (Pa•s)		52.9	9.1	26.5	---	---
PG True Grade		117.8+1.71	105.8-3.47	112.6+4.36	---	---

1) Aggregate properties for *R-1* are average values of all valid test results obtained.
2) Average value obtained from MSU and MDOT central laboratory. *R-4* and *R-5* are MDOT results only.
3) Tested at MSU according to *AASHTO T 316,* test temperature was 135 C.

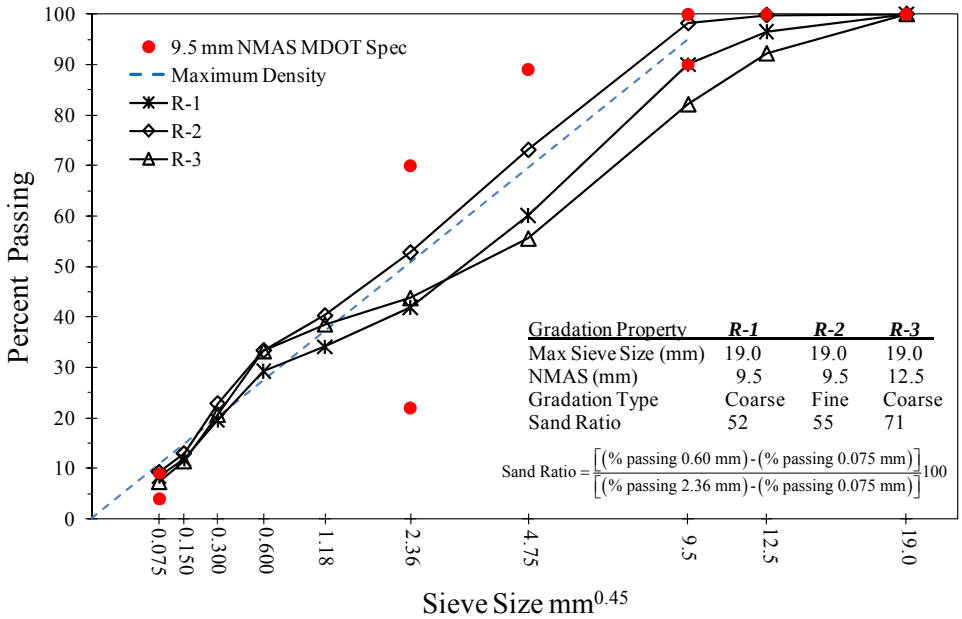
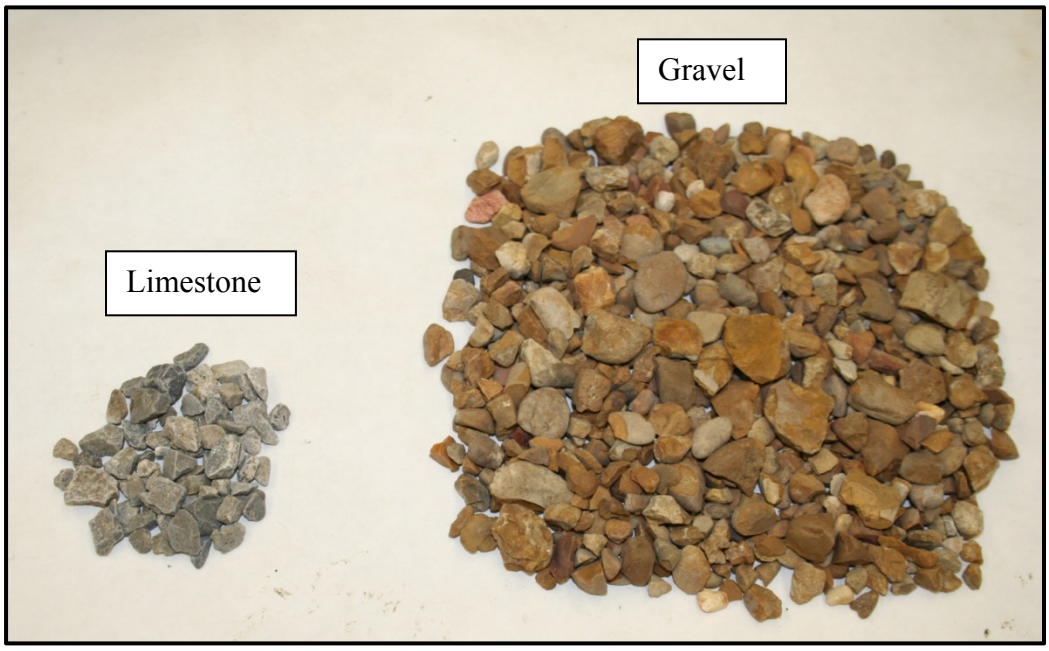
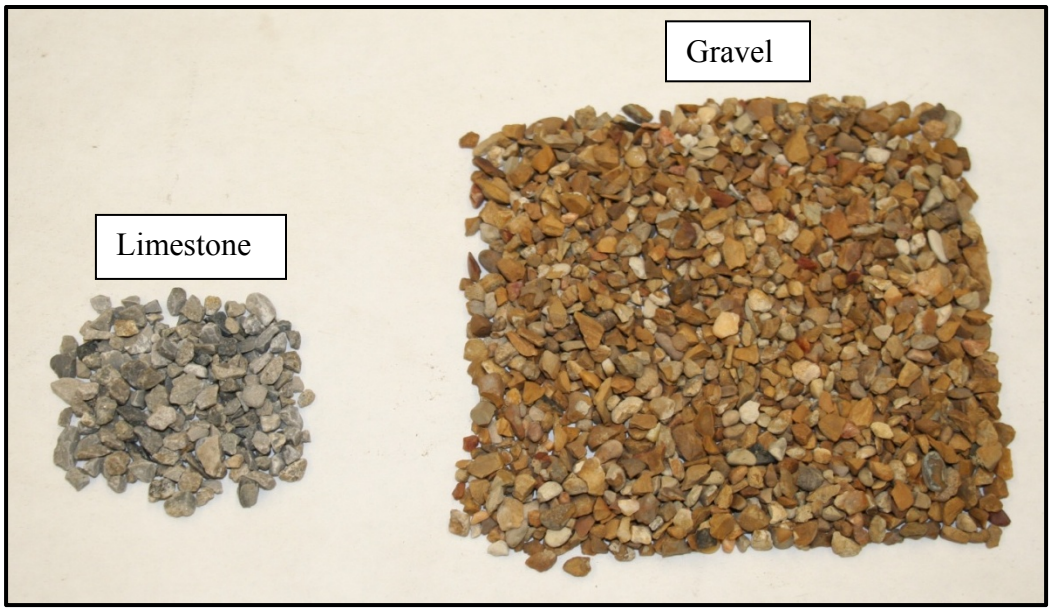


Figure 3.1 9.5 mm NMAS 0.45 Power Gradation Plot of RAP Extracted Aggregate

Crushed gravel and crushed limestone are the two primary coarse aggregate types used in Mississippi. To determine their proportions in RAP, a coarse aggregate sorting procedure was developed to estimate the amount of limestone. The procedure consists of visually inspecting and categorizing extracted RAP aggregate. Extracted aggregate washed with water is separated into two fractions: 1) retained on the 4.75 mm sieve; and 2) passing the 4.75 mm sieve and retained on the 2.36 mm sieve. Based on visual inspection the aggregate was categorized as limestone or gravel (Figure 3.2).



a) Aggregate Retained on 4.75 mm Sieve



b) Aggregate Passing 4.75 mm and Retained on 2.36 mm Sieve

Figure 3.2 RAP Aggregate Sorting Procedure (*R-1* shown)

For the aggregate retained on the 4.75 mm sieve the percentage by mass of limestone aggregate on a basis of total aggregate retained on the 4.75 mm sieve was determined; the variable $LST_{+4.75}$ is used to denote this value in Table 3.1. For all aggregate retained on the 2.36 mm sieve (including the portion retained on 4.75 mm sieve) the percentage by mass of limestone aggregate on a basis of total aggregate retained on the 2.36 mm sieve was determined; the variable $LST_{+2.36}$ is used to denote this value in Table 3.1.

For example, 1025 g of *R-1* extracted coarse aggregate was retained on the 2.36 mm sieve; of that total, 663g was retained on the 4.75 mm sieve and 362g passed the 4.75 mm sieve and was retained on the 2.36 mm sieve. The aggregate sorting procedure determined that of the material retained on the 4.75 mm sieve, 53.5g was limestone and the remainder was gravel (663g - 53.5g = 609.5g). This results in a $LST_{+4.75}$ value of 8.1% (53.5g / 663g = 8.1%). The aggregate sorting procedure determined that of the 362g of aggregate passing the 4.75 mm sieve and retained on the 2.36 mm sieve, 35g was limestone and the remainder (362g - 35g = 327g) was gravel. This results in a $LST_{+2.36}$ value of 8.6% [(53.5g+35g) / 1025g = 8.6%].

3.3.2 Virgin Aggregates

Four virgin aggregates were used for the majority of testing, which were obtained from a local asphalt producer and their properties are shown in Table 3.2. Other aggregates were tested as part of this experimental program in lesser quantities (e.g. as part of plant produced mixes). The aggregates were given generic designations. Specific details of those aggregates are not provided; only composite aggregate blend properties are provided.

Table 3.2 Properties of Virgin Aggregates Tested

Aggregate ID		***G-1***	***L-1***	***S-1***	***HL-1***
Size		< 12.5 mm	#810	---	---
Material Type		Crushed Gravel	Limestone	Coarse Sand	Hydrated Lime
Source		Scribner Pit	Vulcan	Scribner Pit	Falco
Location		Hamilton, MS	Russellville, AL	Hamilton, MS	---
Percent Passing	**25.0 mm**	100.0	100.0	100.0	100.0
	19.0 mm	100.0	100.0	100.0	100.0
	12.5 mm	100.0	100.0	100.0	100.0
	9.5 mm	92.0	100.0	100.0	100.0
	4.75 mm	47.0	92.0	95.0	100.0
	2.36 mm	26.0	68.0	82.0	100.0
	1.18 mm	16.0	53.0	72.0	100.0
	0.60 mm	11.0	41.0	55.0	100.0
	0.30 mm	8.0	27.0	21.0	100.0
	0.15 mm	7.0	19.0	2.0	100.0
	0.075 mm	5.2	14.8	0.5	100.0
G_{sb}		2.395	2.625	2.572	2.300
G_{sa}		2.625	2.711	2.644	2.300
Abs		3.66	1.21	1.06	0.00

3.3.3 Virgin Binders and Warm Mix Additives

Three virgin binders were used for laboratory prepared mixtures; two PG 67-22, and one PG 76-22. The PG 76-22 and the primary PG 67-22 virgin binder were supplied by Ergon Asphalt and Emulsions, Inc. from Vicksburg, MS. The secondary PG 67-22 virgin binder was sampled from the asphalt plant that produced one of the control mixtures; it was originally supplied by Hunt Refining Company from Tuscaloosa, AL. The primary PG 67-22 binder was used for production of all laboratory mixed asphalt with the following two exceptions. The secondary PG 67-22 binder source was used for the control mixture *CM-4b*, and the PG 76-22 binder was used for control mixture *CM-4c*.

Virgin binder was heated to a mixing temperature of 154 C for PG 67-22 and not held at the mixing temperature for more than six hours; the number of re-heat cycles was minimized to ensure that properties of the binder were not adversely affected. The mixing temperature for PG 76-22 virgin binder was 188 C; once the mixing temperature was achieved, the binder was mixed for one hour with a high shear mixer before use. The polymer-modified virgin binder was not held at mixing temperature for more than six hours and any remaining binder at the end of the day was discarded.

Two warm mix additives were used in this experimental program: 1) Sasobit®; and 2) Evotherm 3G™. Sasobit® was used at a dosage rate of 1.0% based on total binder weight. Evotherm 3G™ was used at a dosage rate of 0.5% based on total binder weight. The Sasobit® or Evotherm 3G™ added to compensate for the RAP binder was added based on the total extracted asphalt cement content of the RAP.

Sasobit® was added to binder according to manufacturer recommendations. The binder was heated to 127 C and a paddle mixer was used to mix in the pellets that were slowly added into the binder. If all the pellets are added at once even dispersion might not have occurred. Once added and mixed, the Sasobit® will not settle in the binder. To compensate for the RAP binder, additional Sasobit® pellets were added immediately before mixing as described in Section 3.4.1.

Evotherm 3G™ was premixed with virgin binder before use according to manufacturer recommendations. Binder was first heated to mixing temperature (154 C) before the liquid Evotherm 3G™ was added and then mixed with a high shear mixer until fully incorporated into the binder (approximately 10 minutes based on manufacturer's recommendations). To compensate for the RAP binder, the virgin binder was overdosed with Evotherm 3G™ so that the final dosage rate once samples were mixed would be 0.5% by total asphalt cement weight. This necessitated separate containers of binder be prepared for each intended asphalt content, but the procedure resulted in the most accurate Evotherm 3G™ dosage rate possible.

3.4 Preparation of Test Specimens

For laboratory asphalt production, samples of aggregate were batched according to aggregate stockpile gradations. RAP was batched according to the aggregate stockpile gradations given in Howard et al. (2009); this resulted in the RAP extracted aggregate gradations given in Table 3.1. For all moisture damage testing (i.e. *TSR* and PURWheel), the virgin aggregate and hydrated lime were mixed with approximately 2% water to ensure adequate coating of the aggregate by the hydrated lime.

For the recycled mixtures in this experimental program, the percentage of RAP in the mixture was determined on the basis of percentage of extracted RAP aggregate contributed to the total aggregate in the mixture. This approach was simple to use for batching material in the laboratory during mix design and for practical purposes was the same value as percentage of the RAP in the final mixture (e.g. a 50% RAP mixture on an extracted aggregate to total aggregate basis might be 49.7% RAP on a RAP to total mixture basis).

The virgin aggregate and RAP were heated separately and then combined during mixing. Prior to mixing, virgin aggregate was heated for a minimum of 240 minutes in a forced draft oven; typical heating time was overnight. Prior to mixing, RAP was heated for 120 minutes in a forced draft oven at the mixing temperature. After heating, the materials were mixed as described in Section 3.4.1. Total heating time for the RAP was 210 minutes prior to compaction (i.e. 120 minutes heating before mixing plus 90 minutes of heating during short term aging of the mixture).

In addition to the laboratory preparation method, two preparation methods for plant produced asphalt mixture were utilized: 1) field sampled and prompt compaction prior to heat loss; and 2) plant sampled that was reheated prior to compaction. The first plant production method involved sampling of plant mixed material at the paving location, either from an asphalt paver or a material transfer vehicle (MTV). The samples were quickly brought to the laboratory in insulated containers and then compacted promptly without any additional heating. For compaction of multiple specimens from one sampling trip, the mix was kept in an oven set to the measured field mix temperature for not more than one hour. The second plant production method consisted of sampling the plant mixed material at the asphalt plant and bringing it back to the laboratory; the mixture was allowed to cool. At a later time, the asphalt mixture was reheated to compaction temperature before specimen compaction.

3.4.1 Laboratory Mixing

For control mixtures, the target mixing and compaction temperatures were either taken from the appropriate MDOT mix design or from temperature-viscosity charts for the asphalt binder. For recycled mixtures, target mixing, short term aging and compaction temperatures were the same. The purpose of using the same mixing and compaction temperatures for recycled mixtures was to attempt to isolate the contribution of RAP bitumen at a specific temperature to the overall mixture properties. For all laboratory produced mixtures, the standard MDOT short term aging time of 90 minutes was used at the compaction temperature.

All laboratory mixing of asphalt was performed with a bucket mixer; two capacities of bucket mixer were utilized depending on the size of mixture sample required: 1) conventional 19 L capacity; and 2) large 38 L capacity. The conventional 19 L capacity mixer was used for preparation of all asphalt mix for G_{mm} and *SGC* compacted specimens. The large 38 L capacity mixer was used for preparation of all asphalt mix for compaction in the *LAC*.

The mixing procedure was the same regardless of the mixer was used. A heated mixing bucket was placed on a scale and the pre-heated virgin aggregate and RAP were added to the bucket. A well was created in the center of the hot aggregate and the appropriate amount of virgin binder was weighed into the mixing bucket. When required,

Sasobit® was added to compensate for RAP binder by heating it to just below its melting temperature, and placing it into the pool of liquid asphalt formed inside the mixing bucket (Figure 3.3). The bucket was placed in the mixer and the asphalt components were mixed continuously for 60 to 90 seconds. Care was taken to ensure the components were fully blended and the aggregate was coated.

The quantity of asphalt mixture needed for compaction of slab specimens in the *LAC* (~ 30 kg) could not all be mixed at the same time in the 38 L mixer. The aggregate and RAP for slab specimens was batched in two equal parts (~ 15 kg) and handled separately during heating and mixing. The first part was mixed according to the procedure described above then placed in a 19 L steel pail for short term aging. The mixing bucket was placed back into an oven for about 5 minutes to reheat and then the second batch was mixed using the same procedure. The second part was added to the same 19 L steel pail as the first part of the sample for short term aging. During the compaction process care was taken to prevent segregation of the mix by mixing the first and second parts of the asphalt mixture sample in the *LAC* compaction mold.

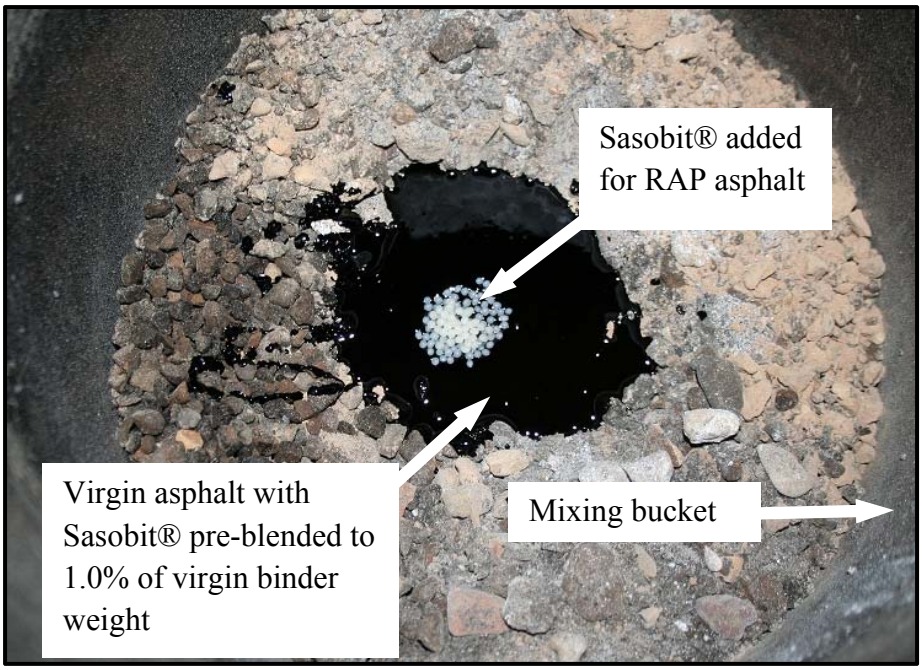


Figure 3.3 Addition of Sasobit® for RAP to Mixture

3.4.2 Compaction of Test Specimens

Two types of asphalt compaction equipment were utilized: 1) Superpave Gyratory Compactor (*SGC*); and 2) Linear Asphalt Compactor (*LAC*). The *SGC* was used to compact standard 150 mm and 100 mm diameter cylinder specimens either with a specified compactive effort (i.e. number of gyrations) or to a target height and density. All *SGC* compaction was performed with a Pine Instrument brand compactor that was calibrated to 1.25 ± 0.02° by the external angle method.

Salient features and an overview of operation of the *LAC* in use at MSU is described briefly herein, further details can be found in Doyle and Howard (2010). Figure 3.4 shows the *LAC* and its major components. The *LAC* produces rectangular slabs of asphalt mixture that are 29.3 by 62.4 cm that can be any target thickness between 3.8 and 10.2 cm. For this study, two target slab thickness were utilized: 1) nominal 3.8 cm thickness for skid resistance test specimens; and 2) nominal 7.6 cm thickness for PURWheel test specimens.

During the *LAC* compaction process, the compaction mold is moved backward and forward beneath a roller attached to the upper frame (Figure 3.4). Compactive effort is applied by a hydraulic cylinder attached to one end of the upper frame; the hydraulic pressure is regulated to provide a constant downward force on the upper frame of the compactor. The compactive force of the roller is transmitted to the asphalt mixture through a series of vertically aligned steel plates (not shown in Figure 3.4); this results in a kneading action during compaction similar to that produced by a static steel wheel roller.

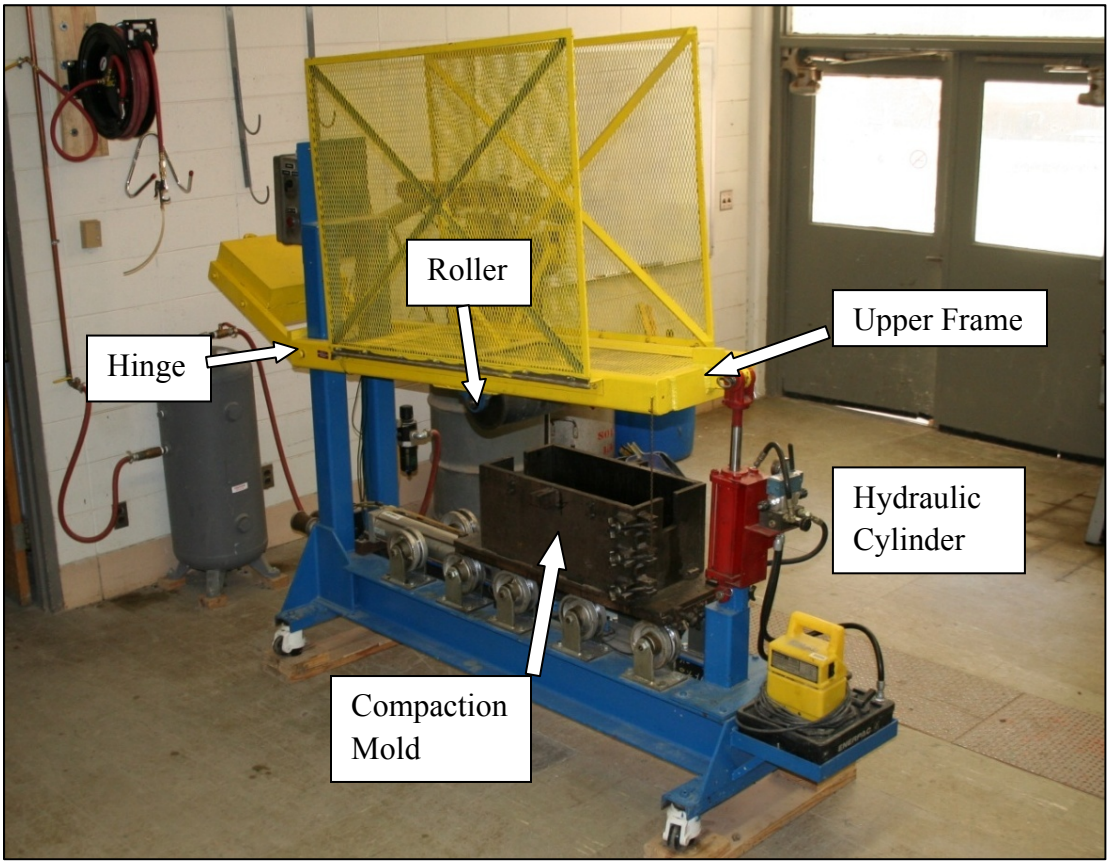


Figure 3.4 Linear Asphalt Compactor (*LAC*)

The level of compactive effort exerted by the *LAC* can be varied by adjusting the hydraulic system pressure used to operate the hydraulic ram and by varying the number of passes of the compaction mold beneath the roller. For all slabs of nominal 3.8 cm thickness produced for skid resistance testing, the compactive effort parameters were 12 passes and 1379 kPa hydraulic system pressure. For all slabs of nominal 7.6 cm thickness the compactive effort parameters were 18 passes and 2413 kPa hydraulic system pressure.

The general compaction process for slabs produced in the *LAC* is shown in Figure 3.5. At the conclusion of the short term aging period, the mixture is loaded into the pre-heated compaction mold as shown in Figure 3.5*a*. The asphalt mixture is spread evenly in the mold while taking care to prevent segregation (Figure 3.5*b*) before a sheet of release paper is placed on top followed by a thin steel sheet; the purpose of the steel sheet is to distribute the weight of the compaction plates and ensure a smooth surface to the final compacted slab. Next, the vertically aligned compaction plates are carefully lowered on top of the loose asphalt mixture. The upper frame of the *LAC* is brought down and pinned to the hydraulic cylinder (Figure 3.5*c*). After compaction is complete, the upper frame is unpinned, the vertical plates are removed, and the detachable portion of the compaction mold is removed to allow easy removal of the compacted slab. An example of the final compacted slab is seen in Figure 3.5*d*; the exposed corner of each slab is marked and used as a reference corner for all further testing to identify the slab's orientation during compaction.



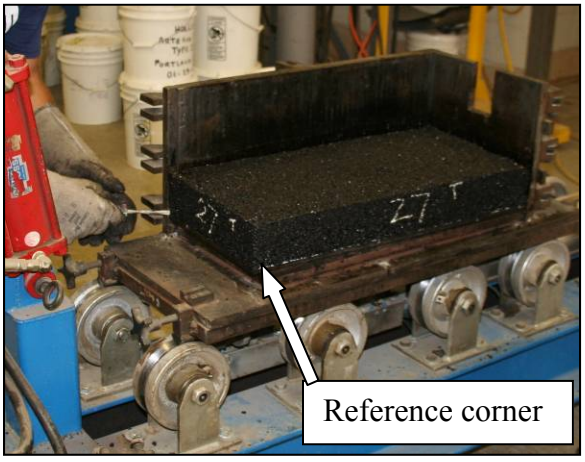
a) Loading Mix into Compaction Mold



b) Leveling of Mix in LAC



c) LAC Ready for Compaction

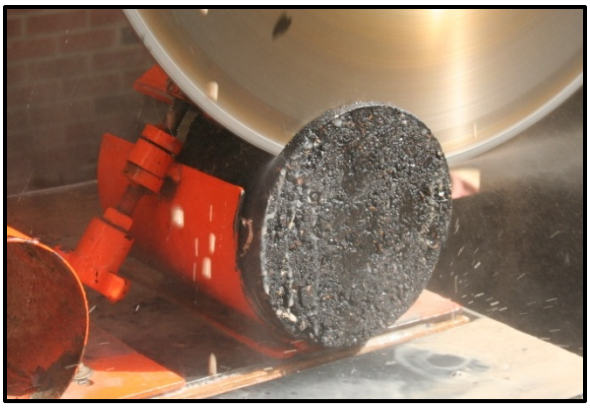


d) Compacted Slab

Figure 3.5 *LAC* Slab Compaction Process

3.4.3 Sawing of Test Specimens

Specimens compacted to 150 mm diameter and nominal 115 mm height with the *SGC* were sawn to produce test specimens for *BBR* and *MRTCR* mixture testing. Two major steps were performed to produce test specimens: 1) sawing into rectangular blocks; and 2) sawing of rectangular blocks into final test specimens. The sawing procedures produced test specimens from the interior of *SGC* compacted specimens, and step 1 was the same for *BBR* and *MRTCR* beam or bar production as seen in Figure 3.6.



a) Cutting of 12.5 mm thick slice



b) Top and bottom slices removed



c) Marking for vertical perimeter cuts



d) Cutting vertical slices around perimeter



e) 115-mm x 115-mm rectangular block



f) Final 115 mm x 115 mm x 50 mm blocks

Figure 3.6 Rectangular Block Preparation-Step 1 of *BBR* or *MRTCR* Production

A masonry saw was used to remove horizontal slices 12.5 mm thick (top and bottom) as seen in Figure 3.6*a* and 3.6*b*; these slices were discarded. Four vertical cuts were then made to produce a rectangular block approximately 115 mm square (Figure 3.6*c* to Figure 3.6*e*). The resulting block was then sliced horizontally into two blocks approximately 50 mm thick; the final product is seen in Figure 3.6*f*. The final blocks were marked such that the face that was originally the interior of the compacted specimens was evident.

During step 2 *BBR* mixture beams 6 mm by 12 mm by 115 mm were produced as illustrated in Figure 3.7 and 3.8 (left to right). Prepared rectangular blocks from the first sawing step were cut with a Buehler Delta AbrasiMet® precision abrasive saw utilizing a 25 cm diameter 2 mm thick diamond blade. Six vertical cuts were made in the block such as to produce five slices 12 mm wide (Figure 3.7*a* and Figure 3.7*b*). Each of the 12 mm wide vertical slices was then turned on its side and cut to produce 6 mm thick beams (Figure 3.7*c*). Two cuts were taken to produce two mixture beams per vertical slice. A final prepared mixture beam specimen is shown in Figure 3.7*d*. Twenty mixture beams can be cut from one gyratory specimen. The 6 mm thickness of the mixture beam corresponds to a vertical dimension in the original compacted specimen. The 12 mm width of the mixture beam corresponds to a horizontal dimension in the original compacted specimen.



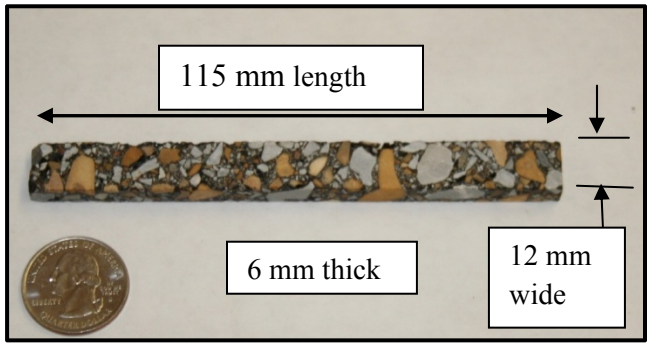
a) *Vertical cuts*



b) Five vertical 12 mm wide slices



c) Horizontal cuts



d) Final mixture beam specimen

Figure 3.7 Preparation of *BBR* Specimens from Rectangular Blocks

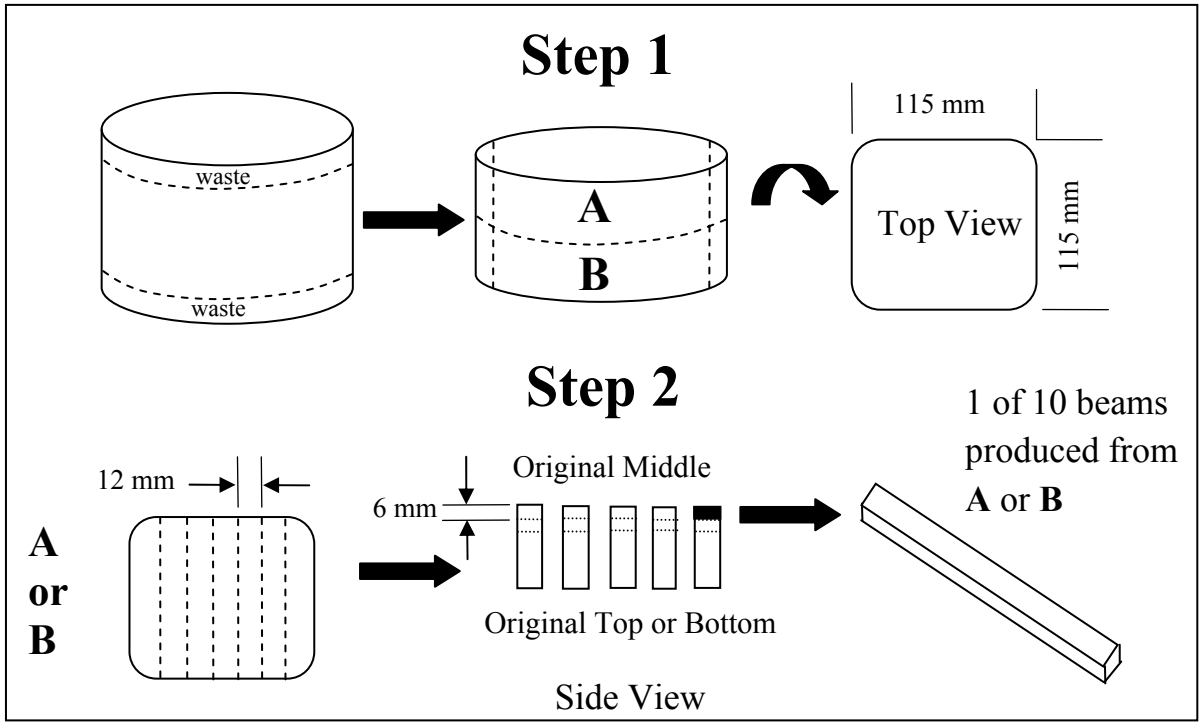


Figure 3.8 Schematic of *BBR* Specimen Preparation Method (Not to Scale)

During step 2 the procedure to produce 10 mm by 12 mm by 50 mm mixture bars for *MRTCR* testing was similar to that for *BBR* specimens. Five vertical 12 mm wide slices were created (Figure 3.7*b*) from rectangular blocks. Horizontal cuts were then taken across the slices such that 10 mm thick bars were created (Figure 3.9*a*). Several of the bars were then clamped together and the bars were cut to the final 50 mm length (Figure 3.9*b*). Twenty *MRTCR* mixture bar specimens can be cut from one gyratory specimen. The 10 mm dimension corresponds to a vertical dimension in the original compacted specimen and the 12 mm dimension corresponds to a horizontal dimension.



a) 12 mm x 10 mm x 115 mm bar *b) Cutting bars to final 50 mm length*

Figure 3.9 Preparation of *MRTCR* Specimens from Rectangular Blocks

3.5 Test Methods

3.5.1 Fundamental Properties

Theoretical maximum specific gravity (G_{mm}) was tested according to *AASHTO T 209*. A sample of asphalt mixture was mixed and short term aged according to Section 3.4.1 and at the conclusion of the short term aging period, the loose sample was cooled. The sample was divided into two portions with a sample splitter; *AASHTO T 209* was performed on each split portion of the sample and the results were averaged to produce one G_{mm} result.

Bulk specific gravity (G_{mb}) was measured according to *AASHTO T 331* (Corelok®) as it was in SS 200. Exceptions were for moisture damage (*TSR*) and dynamic modulus (E^*) testing, where G_{mb} was measured according to *AASHTO T 166* (submerged specimen method) in accordance with test method requirements.

Density of compacted slabs used for PURWheel and skid resistance testing were estimated by measurement of the slab mass and slab thickness at six locations around the perimeter. A bulk slab density value was computed from this data ($D_{b\text{-}s}$); this density value was used in conjunction with the mixture G_{mm} to compute an estimate of air voids for the slab. To correlate this estimate of air voids with *AASHTO T 331*, a correlation equation from Doyle and Howard (2010) was utilized. Eq. 3.2 is the combined equation relating air voids to bulk slab density and G_{mm}. The equation was developed based on coring of 61 slabs (total of 366 cored specimens) compacted in the *LAC* and measurement of their air voids by *AASHTO T 331*.

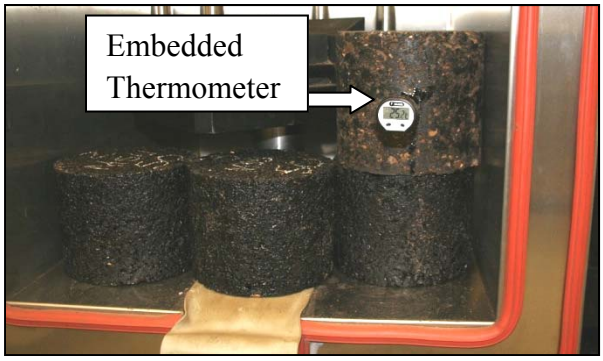
$$V_{a(T331)} = 89\left(\frac{G_{mm} - D_{b-s}}{G_{mm}}\right) \qquad (R^2 = 0.96) \qquad (3.2)$$

Where,

$V_{a(T\,331)}$ = air voids measured according to *AASHTO T 331*
$D_{b\text{-}s}$ = bulk slab density (g/cm^3)

3.5.2 Indirect Tensile Strength

Indirect tensile strength and time to failure were determined on *SGC* compacted specimens; testing was performed with an Interlaken universal soil and asphalt test system. Before testing, specimens were brought to thermal equilibrium of 25 C by placing them in the Interlaken environmental chamber where they were ultimately tested (Figure 3.10*a*). A specimen of comparable mass with an embedded thermometer was placed in the chamber with the test specimens to ensure sufficient conditioning had taken place prior to testing. The length of each specimen was measured, load-time data was recorded from the test at a frequency of 30 Hz; the loading rate was 50 mm/min. This information was used to calculate the indirect tensile strength at failure (S_t). Figure 3.10*b* is a photo of testing.



a) Conditioning Samples



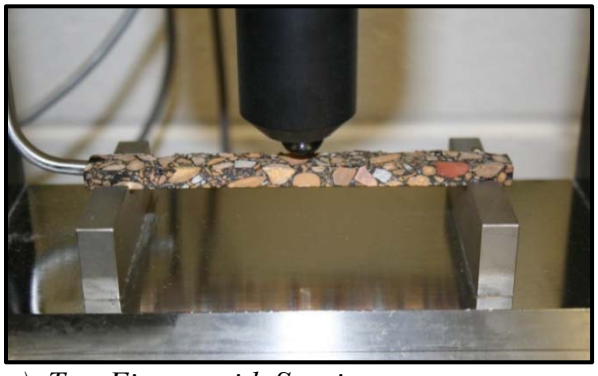
b) Indirect Tensile Strength Testing

Figure 3.10 Indirect Tensile Strength Testing

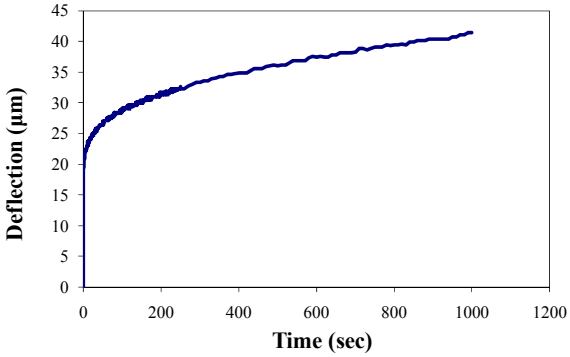
3.5.3 Bending Beam Rheometer Mixture Test

To investigate low temperature mechanical properties, flexural creep testing was performed with a *BBR* on mixture beam specimens prepared according to Section 3.4.3. For control mixtures and 100% RAP, five replicates were tested at each test temperature from each *SGC* specimen. During the course of this study, information was identified through literature review that indicated that three replicate specimens was likely adequate. Literature review in combination with analysis of test method variability conducted as part of this report led to a reduction in the level of replication for 25 and 50% RAP mixtures; three replicate specimens were tested from each *SGC* specimen for those mixtures.

Dimensions of the beam specimens were measured and recorded prior to testing. A CANNON Thermoelectric *BBR* was used for all testing. Beam specimens were immersed in the cooling bath containing methanol of the *BBR* for 60 ± 5 minutes before testing to ensure they reached thermal equilibrium at the desired test temperature. The test parameters were different than those for the standard binder test; the specific test parameters for the mixture test were a 4.9 N constant load and 1000 second test duration. Specimen deflection at the center of the mixture beam was recorded by the test equipment throughout the test. Figure 3.11*a* shows the test fixture with a mixture beam specimen while removed from the coolant bath. Figure 3.11*b* is an example of deflection data from the *BBR* mixture test.



a) Test Fixture with Specimen



b) Example Deflection Data

Figure 3.11 *BBR* Mixture Testing

Deflection data obtained during the *BBR* test is used to compute two test parameters: 1) mixture stiffness as a function of time; and 2) instantaneous slope of the mixture stiffness curve (m-value). Values of each parameter are calculated at eight discrete loading times over the period of the test. The time points are 8, 15, 30, 60, 120, 240, and 960 seconds.

3.5.4 Cantabro Durability

The Cantabro abrasion loss test procedure used in this study is essentially the same as the Mississippi test method for open graded friction course abrasion loss (*MT-85*) for un-aged specimens and is described as follows. Standard 150 mm diameter gyratory compacted specimens of nominal 115 mm height were compacted of each mixture. The design compactive effort was utilized for all Cantabro specimens. Compaction of specimens to a target density was not utilized since the goal of this line of testing was to develop a test that could be performed in day to day operations with the types of specimens that are already being made for measurement of volumetric properties. Figure 3.12 allows for a visual comparison of tested Cantabro specimens with varying binder contents and subsequently varying levels of mass loss (*ML*).

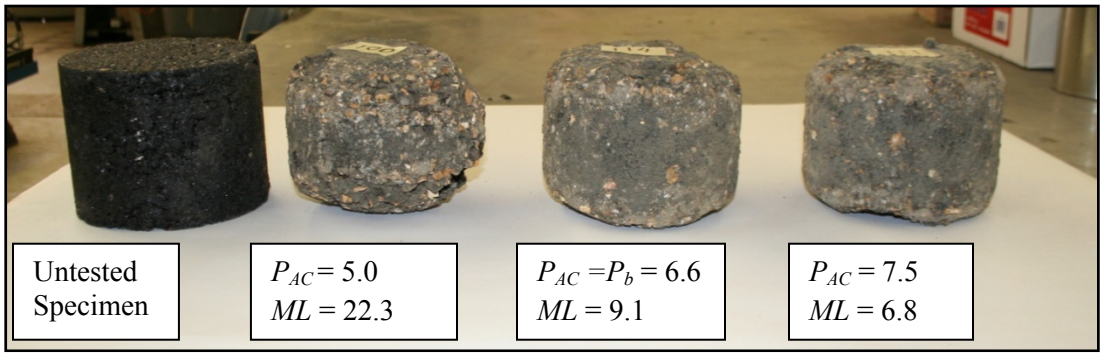


Figure 3.12 Tested Cantabro Specimens with Varying Total Asphalt Content (P_{AC})

Prior to testing, specimens were conditioned in an environmental chamber overnight (minimum of twelve hours) at 25 C. A dummy specimen of similar properties with an embedded thermocouple was exposed to the same conditions to verify that the internal temperature of all samples equilibrated to 25 C. The temperature of the LA Abrasion drum was checked before every test and was required to be 25 ± 2 C before testing. A specimen was placed in the drum of an LA Abrasion testing machine without the charge of steel spheres and subjected to 300 revolutions. The mass of the specimen was recorded before and after the test and the loss in specimen mass as a percentage (*ML*) during the test was reported as a percentage of the original mass. All debris leftover from the previous test was removed from the LA Abrasion drum before each test to ensure that there was no variability introduced to the results due to cushioning of the test sample.

A limited amount of testing was included to evaluate the effects of laboratory aging methods on *ML*. Two laboratory aging protocols were selected: 1) the long term conditioning protocol for compacted test specimens of *AASHTO R-30*; and 2) the aging protocol specified in Mississippi test method *MT-85*. The *R-30* protocol was 120 ± 0.5 hours (5 days) in a forced draft oven set to 85 ± 3 C. The *MT-85* protocol was 168 hours (7 days)

in a forced draft oven set to 64 C. The *MT-85* test method does not specify time and temperature tolerances, so the tolerances from *R-30* were utilized. Specimens were subjected to the desired aging protocol then allowed to cool overnight before being tested for *ML* according to the same procedure as was used for the un-aged specimens.

3.5.5 Moisture Damage (*TSR*)

Moisture damage testing was performed according to *ASTM D 4867* on 62.5 mm tall by 100 mm diameter gyratory compacted specimens. In accordance with *ASTM D 4867*, target air voids of specimens compacted for moisture damage testing was 7 ± 1% as measured by *ASTM D 2726* (submerged specimen method) As previously mentioned in Section 3.4, virgin aggregate batches were mixed with approximately 2% water prior to heating to ensure coating of the aggregate by the hydrated lime.

3.5.6 Rutting (*APA*)

For *APA* rut testing, a test temperature of 64 C was used according to *MDOT* recommendations. The wheel load was 445 N (100 lb) and the hose pressure was 690 kPa (100 psi) according to *AASHTO TP 63*. The wheel load and hose pressure was verified once per day and adjusted if necessary. Specimens were preconditioned at the test temperature prior to testing for a minimum of 6 hours but not more than 24 hours.

Two different methods for creating *APA* specimens were employed: 1) compaction to a target height (75 mm) and density in the *SGC*; and 2) trimming of 115 mm gyratory specimens to test height. Preparation of compacted specimens for the first method is described in Section 3.4.2; the target air voids were 7 ± 0.5% or 10 ± 0.5% measured according to *AASHTO T 331* (Corelok®) and the target height was 75 ± 5 mm. The purpose of testing two different air void levels for *APA* rutting was to evaluate rutting rate of the mixtures independent of the air void level. Use of the second method was limited to 100% RAP mixture specimens in the expanded RAP compaction experiment described in Section 3.6.2.2. Standard compacted specimens of nominal 115 mm height were cut to target test height of 75 ± 5 mm. A specific air void level was not specified for method two; rather air voids were dictated by mixture and compaction variables.

3.5.7 PURWheel

PURWheel testing was performed on specimens created by sawing *LAC* compacted slab specimens in half; specimens were approximately 29 cm wide and 31 cm long. Two PURWheel specimens corresponding to the halves of a compacted slab were tested at the same time in the left and right tracks of the PURWheel to be a single replicate PURWheel test. The basic features and test parameters of the PURWheel in use at MSU are given here, additional details can be found in Howard et al. (2010).

Test specimens are grouted in place with Plaster of Paris during testing. The test temperature for the PURWheel is 64 C (same test temperature as the *APA*). Once the test chamber reaches the target temperature, the specimens are conditioned for six hours, not to exceed 24 hours, to ensure the specimen reaches thermal equilibrium. Two independently controlled wheel carriages mounted with 4-ply pneumatic tires are used to load the specimens during the test. The tire inflation pressure is 862 kPa and the wheel load is 178.6

kg, resulting in a gross contact pressure at the beginning of the test of approximately 630 kPa. The travel speed of the wheel over the specimen during testing is 33 cm/sec. A full test consists of 20,000 passes of the wheel over the test specimen or a cumulative rut depth of 15 mm measured by the software (corresponds to a physical specimen deformation of 23 mm), whichever comes first. Eq. 3.3 is the correlation equation used to convert rut depths measured by the LVDT's on the PURWheel to rut depths that would be measured by manual methods.

$$R_M = R_{Adj.} = 0.0153\left(R_T\right)^2 + 1.3R_T \qquad R^2 = 0.96 \qquad (3.3)$$

Where,

R_M = total rut depth measured manually (mm)
$R_{Adj.}$ = adjusted rut depth accounting for LVDT and manual measurement difference (mm)
R_T = rut depth measured by PURWheel LVDT's (mm)

During testing the rut depth of the test specimen is measured over the central 20 cm and recorded by the PURWheel control software. In addition to the electronic measurement of specimen rut depth during the test, manual measurements of the final specimen rut depth are also recorded for each PURWheel test.

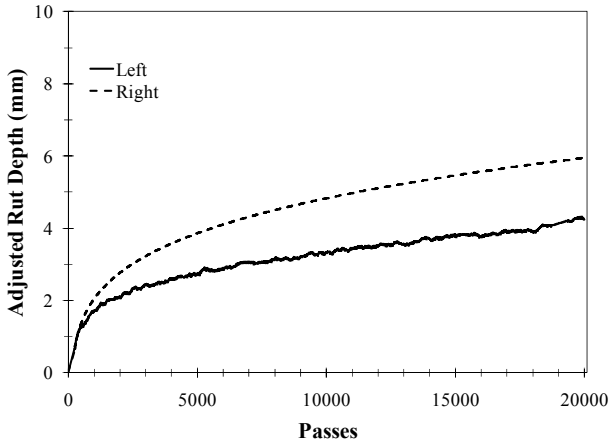
Air voids of slabs tested in the PURWheel were on the order of 8 to 10% on a Corelok® (*T 331*) basis or 6.8 to 8.3% on a submerged (*T 166*) basis for most mixtures though the voids varied somewhat in a few cases. The compactive effort of all slabs was constant at 18 passes and 2413 kPa hydraulic system pressure. The void levels experienced by most slabs is in line with the Table 2.1 DOT specifications where average target, full pay maximum, and removal void levels were approximately 7, 8, and 10% measured via *T 166*.

A maximum air void criteria for slabs was established as 10% measured via *T 166* or 12.3% via *T 331* (Eq. 2.2 used to correlate *T 166* to *T 331*). This criteria is in line with the average air void level warranting removal in the southeast US. This criteria allows air voids to be in the range stated by Terrel and Al-Swailmi (1993) to be favorable to moisture damage (7 to 11%). Testing slabs at air void levels representing the higher end of permissible values is more indicative of cases likely to be susceptible to moisture damage in service. If a mixture performs adequately at the upper end of allowable voids, it should in turn perform well at the lower end of allowable voids with the same aggregate blend and asphalt content.

3.5.7.1 PURWheel Dry Protocol

Slabs were tested in a dry condition at 64 C for rutting evaluation. An example of a tested slab from the PURWheel dry protocol test is seen in Figure 3.13*a*. An example set of test data for a PURWheel dry protocol test is seen in Figure 3.13*b*, note the smooth progression of rutting in both left and right test specimens and that Eq. 3.3 was used to determine adjusted rut depths.





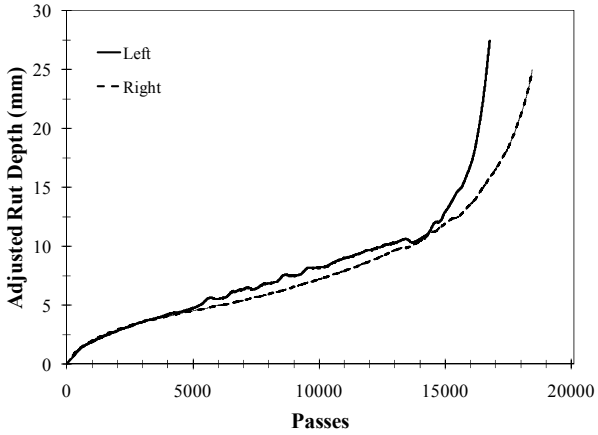
a) Tested PURWheel Dry Test Specimen *b) Example PURWheel Data for Dry Test*

Figure 3.13 PURWheel Dry Protocol Rutting Test

3.5.7.2 PURWheel Wet Protocol

For combined asphalt mixture rutting and moisture damage evaluation using the PURWheel, test specimens were tested underwater at 64 C after 6 hr of conditioning. An example of a tested PURWheel specimen for moisture damage evaluation is seen in Figure 3.14*a*, note the loss of aggregate coating in the wheel path. An example set of test data for a PURWheel wet protocol test is seen in Figure 3.14*b*, note the quick progression of damage and early failure of the test specimens. Early failure occurred more frequently using wet testing but did not occur in all instances.





a) Tested PURWheel Wet Specimen *b) Example PURWheel Data for Wet Test*

Figure 3.14 PURWheel Wet Protocol Moisture Damage Test

3.5.8 Skid Resistance

For evaluation of skid resistance of laboratory produced asphalt mixtures, five replicate panels were prepared of each mixture; the process is documented in Figure 3.15.

Panels were made from slabs of nominal 38 mm thickness compacted in the *LAC*. Two slabs were cut to size (Figure 3.15*a*) and then joined to create one test panel. Shallow wooden box frames were used to securely hold the slabs in place (Figure 3.15*b*). To assemble the panels a thin layer of sand-cement mortar was first spread across the inside of the wooden frame (Figure 3.15*c*), then the slab pieces were placed and leveled (Figure 3.15*d*).



a) Trimming Slabs to Size



b) Slabs and Frame Pre-assembly



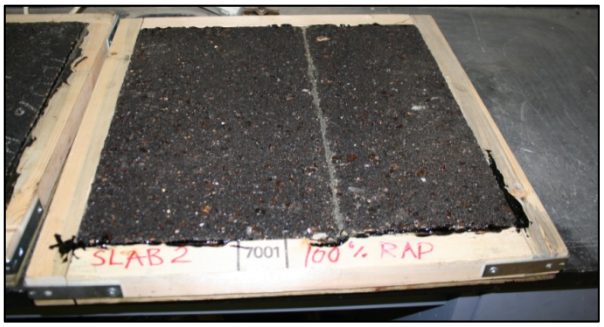
c) Placing Mortar Layer



d) Leveling Slab Pieces



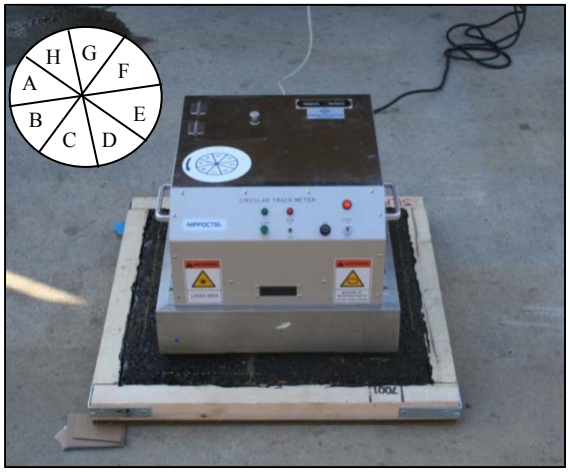
e) Placing Hot Sand on Seam



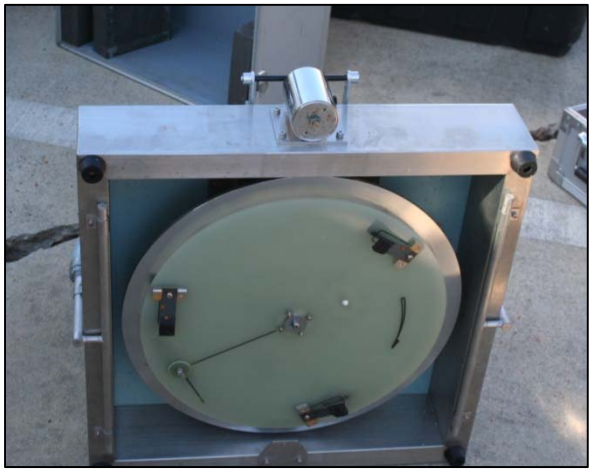
f) Completed Test Panel

Figure 3.15 Fabrication of Skid Resistance Panels

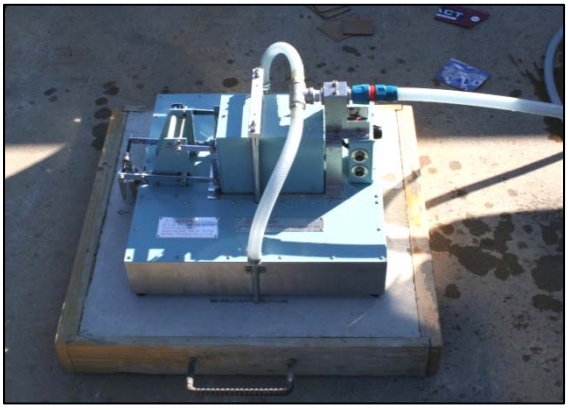
To fill the joint between slab pieces hot asphalt binder was carefully poured into the crack flush with the surface and any excess removed. Hot sand was embedded in the binder (Figure 3.15*e*) and any excess was brushed away once the binder had cooled. Binder was also used to fill any gaps between the edge of slabs and the frame; the surface dimensions of the asphalt mixture testing surface for each completed panel were 50.8 by 50.8 cm (Figure 3.15*f*). The panel dimensions used for skid resistance measurements in this study were smaller than the recommended dimensions for laboratory fabricated panels in *ASTM E 2157* and *ASTM E 1911* of 60 by 60 cm; however the panels were larger than the footprint of both the *CTMeter* and the *DFTester* (Figure 3.16*a*, 3.16*d*) and edge effects were felt to be minimal.



a) CTMeter Testing



b) DFTester Slider Detail



c) Verifying the DFTester



d) DFTester Testing

Figure 3.16 Testing of Skid Resistance Panels

Skid resistance testing of the panels was performed at Burns Cooley Dennis, Inc. Conditions were sunny with temperature near 0 C at the beginning of testing and approximately 16 C when testing was completed. Panels were stored indoors prior to testing so their temperature was higher than ambient conditions. Panels were leveled before testing;

Figure 3.16 shows the panels being tested. Surface texture measurement of the panels was first performed on all fifteen panels in no particular order while dry by *CTMeter* testing according to *ASTM E 2157*. The *CTMeter* was placed in the center of each panel and oriented so that the seam always fell in segments C and G (Figure 3.16*a*). Segments C and G are diametrically opposite each other in a north-south orientation in Figure 3.16*a*. Eight texture measurements were made of each panel.

Friction coefficient measurement was then performed on all panels in no particular order by the *DFTester* according to *ASTM E 1911* (Figure 3.16*d*). Before testing panels, *DFTester* output results were verified by measuring a reference concrete panel of previously established friction properties (Figure 3.16*c*). Each set of rubber sliders (Figure 3.16*b*) was used for 12 runs before replacement to limit degradation. Five friction measurements were made of each panel.

3.5.9 Mixture Repeated Torsional Creep Recovery (*MRTCR*) Test

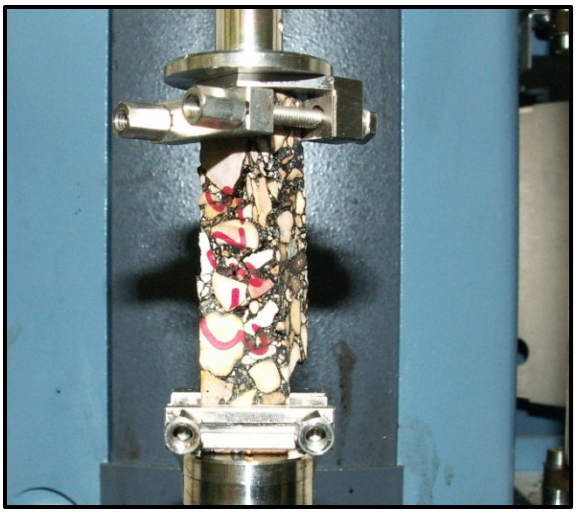
Mixture repeated torsional creep recovery (*MRTCR*) testing was performed on nominal 10 mm by 12 mm by 50 mm mixture bars prepared from gyratory compacted specimens according to the procedure given in Section 3.4.3. The test was performed with a dynamic shear rheometer (DSR) that had been modified to perform the mixture test (Figure 3.17*a*). The true dimensions of a mixture bar specimen were measured and recorded before it was clamped into the test fixture (Figure 3.17*b*). The test temperature was 64 C, and a 15 min temperature equilibration period prior to testing was used. The loading sequence consisted of repeated cycles of 1 second of loading followed by 9 seconds of recovery. The DSR control software computed the appropriate force required to produce a desired torsional stress level based on the measured dimensions of the test specimen; the control software recorded the strain history experienced by the test specimen. The specific stress level used during the test was dependant on the mixture properties; a stress level was selected to produce failure in the test specimen within a reasonable amount of total test time (minimum of 100 cycles and a maximum of 990 cycles). For control mixture testing the stress level utilized was 68kPa. For testing of 100% RAP the stress levels utilized were 272 kPa and 544 kPa depending on mixture parameters. The loading sequence was repeated until failure was reached. An example of test data from the *MRTCR* test is shown in Figure 3.17*c*; the residual strain at the end of each test cycle is plotted versus global test time.

Figure 3.17*c* is divided into three regions: primary flow, secondary flow, and tertiary flow. Primary flow is the region in which strain rate decreases with loading time. The secondary flow region is where the strain rate becomes constant with loading time. The tertiary flow region occurs after the failure point and is differentiated from the secondary flow region in that the strain rate increases with time instead of remaining constant. Throughout the tertiary flow region the specimen starts to fail quickly and experience large permanent deformations.

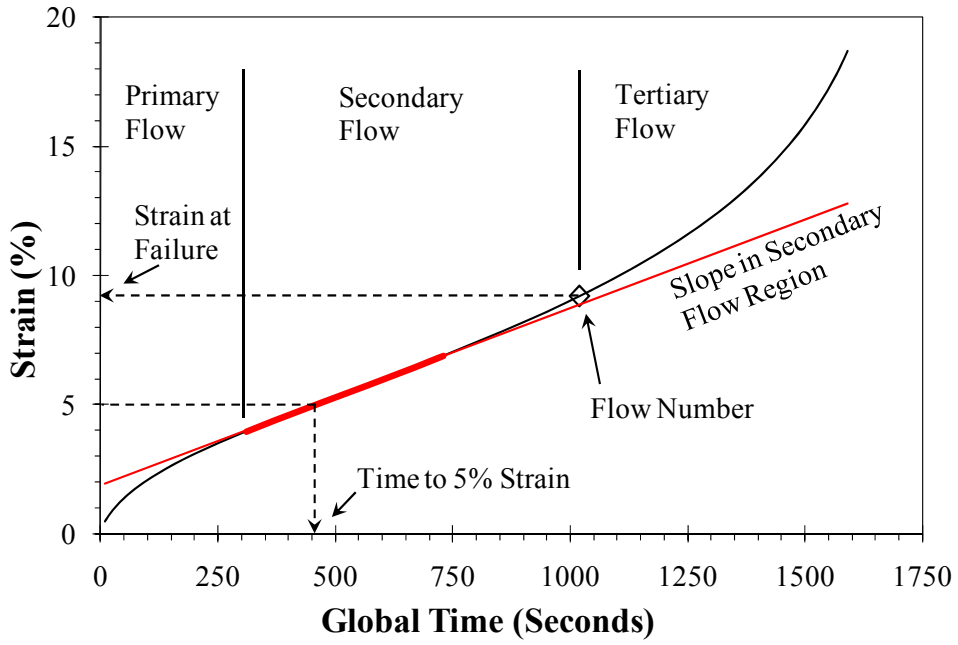
Four response variables are utilized to describe the behavior of tested *MRTCR* specimens shown in Figure 3.17*c*. They are: 1) time to 5% cumulative strain (denoted $\varepsilon(5\%)_T$); 2) inverse of slope in the secondary flow region (expressed as an inverse for convenience and denoted $(\Delta\varepsilon/\Delta T)^{-1}$); 3) flow number (number of cycles to failure denoted *FN*); and 4) cumulative strain at failure (denoted F_ε).



a) DSR Test Equipment



b) Tested Specimen



c) Example of Test Data

Figure 3.17 *MRTCR* Mixture Testing

3.5.10 Dynamic Modulus

Dynamic modulus testing was performed according to *AASHTO TP 62*. Testing was not performed at -10 C due to equipment limitations. Specimen air voids were 7 ± 0.5%. Test specimens were cored from 150 mm diameter by 170 mm tall gyratory compacted pills. Testing was performed with an IPC Global universal testing machine.

3.6 Mixtures Tested and Experimental Designs

3.6.1 0 to 15% RAP Control Mixtures

This segment was concerned with performance testing of control mixtures for comparison to high RAP recycled mixtures. Control mixture properties are given in Table 3.3. A decision was made to use current practice MDOT approved mixtures as the primary control; the majority of 9.5 mm MDOT approved surface mixtures contain 10 to 15% RAP. The research team felt that using current practice mixtures containing 15% RAP for performance comparisons instead of producing 0% RAP mixtures in the laboratory was a pragmatic compromise between the experimental rigor of a 0% RAP control mixture and the realism of current practice 15% RAP mixtures for control comparison.

Initially a 0% RAP control mixture was developed having a virgin aggregate gradation matching that of the high RAP mixtures as closely as possible. This mixture is identified in Table 3.3 as *9.5-0/CM-1*. VMA and dust to effective binder ratio values for this mixture are out of MDOT allowable ranges due to the high dust content of the gradation.

Generally speaking, the relative performance boundaries of asphalt in Mississippi are represented by ST and HT mixtures. ST mixtures have the highest effective asphalt content for a particular gradation; this results in a flexible pavement that is resistant to cracking but also results in a pavement that can be susceptible to rutting under heavy traffic. HT mixtures have the lowest effective asphalt content for a particular gradation; this results in stiff pavements that are resistant to rutting but can also result in an increased potential for cracking. The goal when selecting control mixtures was to encompass the range of potential cracking and rutting resistance of current practice mixtures to the best extent possible. This allowed evaluation of the recycled mixtures in terms of the range of current practice.

Three current practice control mixtures were obtained and tested as part of this experimental program; they were selected to encompass a performance range of current practice rehabilitation mixtures. One ST mixture and two HT mixtures were selected. One of the HT mixtures contained neat binder and the other contained polymer-modified binder. Properties of MDOT approved control mixtures *9.5-15/CM-2*, *9.5-15/CM-3*, and *9.5-15/CM-4a* are provided in Table 3.3 and were taken directly from the mix design sheets.

A standard traffic (ST) control mixture (*9.5-15/CM-2*) was obtained from a city street overlay project in Starkville, MS. All mix was sampled on consecutive days in June 2010. The ST control was conventional hot mix and the target overlay thickness was 3.8 cm.

To investigate the properties of current practice HT mixtures containing polymer-modified binder, control mixture *9.5-15/CM-3* was obtained. This mixture was sampled directly from the asphalt plant in September 2010, placed in metal buckets and returned to the MSU laboratory; the mix was then re-heated and compacted at a later date. The mix with polymer-modified PG 76-22 binder was being produced at the plant as warm mix using foaming technology; the material exited the plant at approximately 132 C and was field compacted at approximately 121 C. Typical MDOT procedure for compaction of reheated mix that was originally produced as foamed warm mix is to compact at a temperature near what would be the hot mix compaction temperature for the mix. This procedure was followed for compaction of reheated *9.5-15/CM-3* mixture; a temperature of 138 C was utilized. The mix was being used for isolated sections of mill and repair near Tupelo MS; the placement thickness was approximately 3.8 cm.

For the second control mixture a high traffic (HT) mix where PG 67-22 was being substituted for polymer-modified binder was selected. This mix (*9.5-15/CM-4a*) was being used for an overlay project on U.S. Highway 45 near West Point, MS. All the mix was sampled on consecutive days, in November 2009 from the paving location. The HT mix with neat PG 67-22 binder was conventional hot mix and the target overlay thickness was 5 cm.

Table 3.3 Properties of 9.5 mm NMAS Control Mixtures

Mixture ID	*9.5-0/ CM-1*	*9.5-15/ CM-2*	*9.5-15/ CM-3*	*9.5-15/ CM-4a*	*9.5-15/ CM-4b*	*9.5-15/ CM-4c*	*9.5-0/ CM-5*	*9.5-15/ CM-6-29*
Prep Method[a]	1	2	3	2	1	1	1	2 or 3
Design Traffic	MT	ST	HT	HT	HT	HT	MT	varied
N_{des}	65	50	85	85	85	85	65	varied
Binder Grade	67-22	67-22	76-22	67-22	67-22	76-22	67-22	varied
WMA	none	none	foam[b]	none	none	none	3G 0.5%	none
Mix Temp (C)	154	157	132	160	154	166	116	varied
Comp Temp (C)	146	field	138	field	146	154	116	varied
Percent Passing								
25.0 mm	100	100	100	100	100	100	100	100
19.0 mm	100	100	100	100	100	100	100	100
12.5 mm	100	100	100	100	100	100	96.3	varied
9.5 mm	94.6	92.4	95.9	96.1	96.1	96.1	89.7	varied
4.75 mm	62.2	---	---	---	---	---	62.1	varied
2.36 mm	41.6	40.1	41.0	37.1	37.1	37.1	42.2	varied
1.18 mm	30.6	---	---	---	---	---	32.3	varied
0.60 mm	22.9	---	---	---	---	---	25.5	varied
0.30 mm	14.4	---	---	---	---	---	14.0	varied
0.15 mm	10.1	---	---	---	---	---	6.6	varied
0.075 mm	7.8	5.5	6.1	6.0	6.0	6.0	2.3	varied
***G-1* Gravel (%)**	67	75	43	37	37	37	61	varied
***L-1* LST (%)**	22	0	31	37	37	37	28	varied
***S-1* Sand (%)**	10	9	10	10	10	10	10	varied
***HL-1* Lime (%)**	1	1	1	1	1	1	1	varied
RAP (%)	0	15	15	15	15	15	0	varied
$P_{b(R)}$ **(%)**	0	4.6	5.5	5.6	5.6	5.6	0	varied
G_{sb}	2.458	2.533	2.480	2.518	2.518	2.518	N/A	varied
G_{sa}	2.642	2.634	2.591	2.658	2.658	2.658	N/A	varied
***Abs* (%)**	2.82	1.52	1.73	2.08	2.08	2.08	N/A	varied
$P_{AC} = P_b$ **(%)**	5.70	6.25	5.80	5.80	5.80	5.80	5.40	varied
$P_{be(V)}$ **(%)**	5.70	5.57	4.98	4.96	4.96	4.96	5.40	varied
G_{mm}	2.339	2.362	2.332	2.367	2.367	2.367	2.342	varied
G_{se}	2.533	2.585	2.526	2.569	2.569	2.569	2.526	varied
VMA	14.5	16.0	15.0	15.0	15.0	15.0	N/A	varied
P_{200}/P_{be}	1.7	1.0	1.2	1.2	1.2	1.2	N/A	varied

a: Preparation methods were as follows:
1. Laboratory mixed and short term aged according to standard procedure.
2. Plant mixed, field sampled, transported in insulated containers, compacted immediately.
3. Plant mixed, plant sampled, brought to laboratory, reheated prior to compaction.

b: Original mixture was foamed but it was re-heated prior to compaction.

At the same time *9.5-15/CM-4a* was being produced, aggregate and RAP was sampled from the stockpiles for later use in producing laboratory specimens of the same mix for comparison to the plant mixed asphalt. Neat PG 67-22 asphalt binder was also sampled from the plant for use in mixture *9.5-15/CM-4b* as previously mentioned in section 3.2.3 of this report. A stock PG 76-22 was used to produce mixture *9.5-15/CM-4c* in the laboratory.

For skid resistance investigation, mixture *9.5-0/CM-5* was produced in the laboratory with no RAP. No other testing was performed with this mixture. Individual sieve fractions of the fine aggregate gradation were adjusted to meet a target overall gradation; combined aggregate properties weren't determined. The virgin binder contained 0.5% Evotherm 3G™.

The test matrix performed on control mixtures as part of this experimental program is provided in Table 3.4; the values in each row for a mixture indicate the number of replicates tested for each test type and condition. For PURWheel testing, four tests (two wet and two dry) were performed on each plant mixed material and two tests (one wet and one dry) were performed on each of the laboratory mixed versions of the *9.5-15/CM-4* control mixture.

BBR testing of each *SGC* compacted specimen produced one replicate of five beams at each of the four test temperatures. At any temperature one replicate was the average of five beams. The baseline replication level was two, which required two *SGC* specimens. Additional replicates were tested for control mixes 1, 4*a* and 4*b* to evaluate variability.

Since the Cantabro durability test has not been used previously for dense-graded asphalt mixtures to the knowledge of the authors, additional data was required to establish both the expected variability of the test method and a range of test results representative of current practice Mississippi mixtures. To achieve this goal, quality control (QC) specimens of plant produced mixtures were obtained from a local asphalt plant and tested at MSU. Additionally, quality assurance (QA) specimens of a range of asphalt mixture types from around the state prepared at the MDOT central materials laboratory were tested at MDOT. Details of these mixtures are given in Table 3.5.

To measure test method variability, plant mixed QC specimens of two mixtures were obtained and tested (*9.5-15/CM-6* and *9.5-15/CM-7*). Both were composed of the same 9.5 mm gradation as control mixture *9.5-15/CM-4a*. The only differences were the design traffic levels and therefore the total asphalt contents of the mixtures. In contrast to the 5.8% total design asphalt content of control mixture *9.5-15/CM-4a*, the design total asphalt content of the ST mixture *9.5-15/CM-6* was 6.2% and the design total asphalt content of the MT *9.5-15/CM-7* mixture was 6.0%. Thirty un-aged specimens each of *9.5-15/CM-6* and *9.5-15/CM-7* were tested to establish variability of the test method. Based on the investigation of test variability, the baseline number of replicates for Cantabro testing was reduced from five to three for all additional testing (the only control mixture affected was *9.5-15/CM-4c*).

For mixture *9.5-15/CM-6*, three aged Cantabro specimens were tested per aging protocol. Based on the results, data for the aging protocol resulting in the greatest *ML* increase (*R-30*) was then supplemented to reach 30 total replicates. The data was used to evaluate variability of aged specimens and to establish a baseline of aged test results.

To evaluate the range of expected performance of typical Mississippi mixtures with respect to un-aged Cantabro results, QA specimens were tested. Twenty-two mixes were compacted and tested at the MDOT central laboratory, and properties of these mixtures are given in Table 3.5 (control mixtures 8 to 29). Two replicates were typically tested per mix based on availability, though in a few cases multiple sets of the same mix were available from different projects and were tested resulting in four to eight replicates.

Table 3.4 Experimental Test Matrix and Replication for 9.5 mm NMAS Control Mixtures

Compaction Type	Test Parameters		Mixture							
			9.5-0/ CM-1	***9.5-15/ CM-2***	***9.5-15/ CM-3***	***9.5-15/ CM-4a***	***9.5-15/ CM-4b***	***9.5-15/ CM-4c***	***9.5-0/ CM-5***	***9.5-15/ CM-6 to 29***
SGC	***APA***	**7% V_a**	0	3	3	3	3	2	0	0
	APA	**10% V_a**	0	3	3	3	0	0	0	0
	TSR	**7% V_a**	1	1[MDOT]	1[MDOT]	1[MDOT]	0	0	0	0
	Cantabro	**Un-aged**	5	5	5	5	5	3	0	116[Table 3.5]
	Cantabro	***R-30***	0	3	3	0	0	0	0	30[Table 3.5]
	Cantabro	***MT-85***	0	3	3	0	0	0	0	3[Table 3.5]
	BBR	**-06 C**	3	2	2	4	3	2	0	0
	BBR	**-12 C**	3	2	2	4	3	2	0	0
	BBR	**-18 C**	3	2	2	4	3	2	0	0
	BBR	**-24 C**	3	2	2	4	3	2	0	0
	MRTCR	**64 C**	3	0	0	0	0	0	0	0
	E*	**7% V_a**	0	0	0	1	0	0	0	0
LAC	**PURWheel**	**Dry**	0	2	2	2	1	1	0	0
	PURWheel	**Wet**	0	2	2	2	1	1	0	0
	Skid Resistance		0	0	0	0	0	0	5	0

APA	A replicate consisted of a single track in the test equipment composed of two 150 mm diameter specimens.
TSR	A replicate consisted of six specimens tested according to *ASTM D 4867* or information taken from MDOT mix design.
Cantabro	A replicate consisted of one *SGC* compacted specimen.
BBR	A replicate consisted of five mixture beams at one temperature from an *SGC* specimen.
MRTCR	A replicate consisted of six mixture bars with three each tested at two stress levels from an *SGC* specimen.
PURWheel	A replicate consisted of two specimens cut from a single *LAC* compacted slab and tested side by side at the same time.
Skid Resistance	A replicate consisted of a single skid resistance panel.
*E**	A replicate consisted of two specimens.

Table 3.5 Detailed Experimental Matrix for Cantabro Plant Mixed Control Mixtures 6 to 29

	Binder	$P_{AC} = P_b$		Aggregate Components (%)				Cantabro Specimens Tested		
Mixture ID	**Grade**	**(%)**	N_{des}	**Gravel**	**Limestone**	**Sand**	**RAP**	**Un-aged**	***R-30***	***MT-85***
9.5-15/CM-6	67-22	6.2	50	37	37	10	15	30	30	3
9.5-15/CM-7	67-22	6.0	65	37	37	10	15	30	0	0
9.5-15/CM-8	76-22	5.4	85	29	50	5	15	2	0	0
9.5-15/CM-9	76-22	5.1	85	29	50	5	15	2	0	0
9.5-10/CM-10	76-22	5.5	85	79	5	5	10	4	0	0
9.5-15/CM-11	76-22	5.5	85	50	24	10	15	2	0	0
9.5-15/CM-12	76-22	6.2	85	40	34	10	15	4	0	0
9.5-15/CM-13[1]	76-22	5.4	85	75.5	0	7	15	2	0	0
9.5-15/CM-14	76-22	5.8	85	45	7	32[2]	15	2	0	0
9.5-15/CM-15	76-22	5.5	85	61	20	3	15	2	0	0
9.5-15/CM-16	67-22	6.0	85	68	9	7	15	2	0	0
9.5-15/CM-17	67-22	6.1	65	37	37	10	15	2	0	0
9.5-15/CM-18	67-22	5.6	65	52	6	26[2]	15	2	0	0
9.5-15/CM-19	67-22	5.3	65	50	18	16[2]	15	2	0	0
9.5-15/CM-20	67-22	5.5	65	31	50	3	15	2	0	0
9.5-15/CM-21	67-22	6.4	65	40	20	24[2]	15	2	0	0
9.5-10/CM-22	67-22	5.7	65	34	46	9	10	2	0	0
9.5-15/CM-23[1]	67-22	5.8	65	74	0	8	15	2	0	0
9.5-0/CM-24	67-22	5.8	50	40	50	9	0	2	0	0
9.5-10/CM-25	67-22	5.6	50	64	10	10	10	2	0	0
9.5-10/CM-26	67-22	5.4	50	29	45	10	10	2	0	0
9.5-6/CM-27	67-22	5.3	50	28	50	6	6	8	0	0
9.5-10/CM-28	67-22	6.4	50	37	37	10	10	4	0	0
9.5-10/CM-29	67-22	5.2	50	49	25	10	10	2	0	0

Notes: All mixtures contained 1% hydrated lime. CM-6 and CM-7 were prepared with method 2 and CM-8 to CM-29 with method 3.

1) Contained dust.

2) Contained manufactured sand.

3.6.2 100% RAP Mixtures

A large amount of 100% RAP with no additional virgin asphalt or virgin aggregate was compacted in SS 200; the effects of heating temperature and duration as well as warm mix additives on compaction of RAP were investigated therein. Some testing was also conducted in SS 200 of 100% RAP with additional virgin binder added; the effects of warm mix additive and amount of virgin asphalt were investigated. As a continuation of the previous research a considerable amount of additional testing was performed on 100% RAP mixtures with additional virgin asphalt to better understand the effects of RAP when incorporated into recycled mixtures. This was performed in an attempt to reduce the number of variables involved by removing the effects of virgin aggregate; the purpose was not to design or evaluate mixtures of 100% RAP for use in paving.

From an experimental standpoint, recycled mixtures have four major factors or variables: 1) aggregate contributed from RAP; 2) virgin aggregate; 3) aged asphalt bitumen contributed from RAP; and 4) virgin asphalt. A statistical analysis of an experiment containing four variables has eleven interactions between variables that must be checked and either eliminated or included in the analysis before the four major variables of interest can be evaluated. In the case of a statistical analysis of three major factors there are only four interactions to be checked before the main effects can be evaluated. In the case of a statistical analysis of two major factors there is only one interaction to be checked before the main effects can be evaluated. While the effects of the four factors concerning recycled mixtures can never be fully isolated and measured separately, the number of total variables can be lowered in an attempt to reduce the overall complexity. The purpose of this work is to allow for the development of a better understanding of the fundamental behaviors occurring in recycled asphalt mixtures.

R-1, R-2, and *R-3* RAP sources were utilized in mixtures containing 100% RAP; 100% RAP mixtures were designed to 4% air voids according to the conventional Superpave design method. As noted in Section 3.3.1, the sand ratio for the *R-3* RAP aggregate gradation is especially high and would not be permitted as a standalone gradation. This mixture was investigated to determine the effect of testing a mixed RAP source that would not have been functioning in a pavement in the proportions of the stockpile. Properties of the designed 100% RAP mixtures are given in Table 3.6. The experimental test matrix for 100% RAP mixtures is given in Table 3.7. The data from 100% RAP testing was analyzed to determine if the performance of 100% RAP mixtures can be used to estimate the performance of a recycled mixture containing a percentage of the same RAP source (e.g. 50% RAP mixture).

Table 3.6 Properties of 100% RAP Recycled Mixtures with 4% Air Voids

Mixture ID	***9.5-100/RM-1***	***9.5-100/RM-2***	***12.5-100/RM-3***
Design Traffic	MT	MT	MT
N_{des}	65	65	65
Binder Grade	PG 67-22	PG 67-22	PG 67-22
WMA	Sasobit® 1.0%	Sasobit® 1.0%	Sasobit® 1.0%
Mix Temp (C)	116	116	116
Comp Temp (C)	116	116	116
NMAS	9.5 mm	9.5 mm	12.5 mm
RAP (%)	100	100	100
RAP Source	*R-1*	*R-2*	*R-3*
$P_{AC} = P_b$ **(%)**	7.4	6.8	6.4
$P_{b(R)}$ **(%)**	5.4	5.6	5.0
$P_{be(V)}$ **(%)**	2.0	1.2	1.4
G_{mm}	2.317	2.370	2.381
G_{se}	2.574	2.619	2.614

3.6.2.1 RAP Relative Heating Experiment

A small experiment was performed with the *9.5-100/RM-1* mixture to investigate the effects of relative heating time on RAP compaction behavior. The RAP was placed in pre-heated steel trays in a layer approximately 5 cm thick and heated in a forced draft oven at 177 C for 15 minutes. The goal was to approximate, albeit crudely, the relatively short period of heating at high temperature that RAP experiences in an asphalt plant during production. The RAP was then removed and mixed with the appropriate amount of virgin binder in the standard manner before being placed in pans for short term aging at 146 C. Five different short term aging times were utilized: 60, 90, 180, 360, and 1440 minutes. At the conclusion of short term aging, specimens were compacted in the *SGC* with the design compactive effort (65 gyrations). Three replicate specimens were produced for each short term aging time and were tested with the Cantabro test. Two G_{mm} replicates were produced as part of this experimental program to evaluate long term asphalt absorption potential of RAP mixture, one with 60 minutes of aging and one with 1440 minutes of aging.

Table 3.7 Investigation of 100% RAP Mixtures Compacted with *SGC* Designed Asphalt Content from Table 3.6

Compaction Type	Test Parameters		Mixture		
			9.5-100/RM-1	***9.5-100/RM-2***	***12.5-100/RM-3***
SGC	***APA***	**7% V_a**	2	2	2
	APA	**10% V_a**	2	2	2
	TSR	**7% V_a**	1	1	1
	Cantabro	**Un-aged**	3	3	3
	BBR	**-06 C**	1	1	1
	BBR	**-12 C**	1	1	1
	BBR	**-18 C**	1	1	1
	BBR	**-24 C**	1	1	1
	E*	**7% V_a**	1	1	0
LAC	**PURWheel**	**Dry**	2	2	2
	PURWheel	**Wet**	2	2	2
	Skid Resistance		5	0	0

APA	A replicate consisted of a single track in the test equipment composed of two 150 mm diameter specimens.
TSR	A replicate consisted of six specimens tested according to *ASTM D 4867*.
Cantabro	A replicate consisted of one *SGC* compacted specimen.
BBR	A replicate consisted of five mixture beams at one temperature from an *SGC* specimen.
PURWheel	A replicate consisted of two specimens cut from a single *LAC* compacted slab and tested side by side at the same time.
Skid Resistance	A replicate consisted of a single skid resistance panel.
*E**	A replicate consisted of two specimens.

3.6.2.2 Expanded RAP Compaction Experiment

To evaluate mixture parameter effects on the behavior of RAP and virgin binder in the absence of virgin aggregate, additional 100% RAP testing was conducted with an expanded number of experimental variables and a reduced level of replication. To accomplish this, a 3^4 factorial designed experiment was created encompassing factors of compaction temperature, compactive effort, warm mix additives, and amount of virgin binder. Based on results of the testing performed with the *R-1* RAP source at compaction temperatures of 116 and 138 C, the number of factors examined and the amount of testing performed was greatly reduced for the other RAP sources. Over 300 specimens of 100% RAP with virgin binder were compacted in this portion of the research.

The amount of virgin binder added and total asphalt contents selected for use in this part of the experimental program were based on work in SS 200 (Howard et al. 2009). Three levels of added virgin binder (low, medium, and high) were investigated corresponding to on the order of 0.5, 1.5, and 2.5% virgin binder. The true amount of virgin binder, RAP asphalt, and total asphalt (P_{AC}) is shown in Table 3.8 on a mix mass basis. The concept was to have three different virgin binder contents that would bound 4% air voids when compacted.

An experimental test matrix detailing the specific factor-level combinations that were tested and the categories of testing performed is provided in Table 3.9. *BBR* testing of RAP source specimens at the low total asphalt content could not be performed on some of the mixture combinations due to an excessively brittle mixture. *MRTCR* testing could not be performed on some of the mixture combinations due to excessively brittle mixture. Based on the results of *MRTCR* testing, the test method was not found to be an optimal method to meet the goals of this project and the test method was not utilized in this rest of this experimental program. As a result only a limited number of mixture combinations were tested.

Table 3.8 Asphalt Contents For 100% RAP at Varying Conditions

RAP Source	P_{AC} Range	P_{AC} (%)	$P_{be(V)}$ (%)	$P_{b(R)}$ (%)
R-1	High	8.1	2.8	5.3
	Med	7.1	1.7	5.4
	Low	6.0	0.6	5.4
R-2	High	8.2	2.7	5.5
	Med	7.2	1.7	5.5
	Low	6.2	0.6	5.6
R-3	High	7.4	2.5	4.9
	Med	6.4	1.5	4.9
	Low	5.5	0.5	5.0

Table 3.9 Investigation of 100% RAP Mixtures at Varying Conditions

RAP Source	Comp Temp (C)	N_{des}	Warm Mix Additive and Total Asphalt Content[Table 3.8] None High	None Med	None Low	Evotherm 3G™ 0.5% High	Evotherm 3G™ 0.5% Med	Evotherm 3G™ 0.5% Low	Sasobit® 1.0% High	Sasobit® 1.0% Med	Sasobit® 1.0% Low
R-1	116	50	Є § Ä▲♣	Є § Ä▲	Є § Ä▲	Є § Ä▲♣	Є § Ä▲	Є § Ä▲	Є § Ä▲♣	Є § Ä▲	Є § Ä▲
	116	65	Є § Ä▲♣	Є § Ä▲	Є § Ä▲	Є § Ä▲♣	Є § Ä▲	Є § Ä▲	Є § Ä▲♣	Є § Ä▲	Є § Ä▲
	116	85	Є § Ä▲♣	Є § Ä▲	Є § Ä▲	Є § Ä▲♣	Є § Ä▲	Є § Ä▲	Є § Ä▲♣	Є § Ä▲	Є § Ä▲
	138	50	Є § Ä▲♣	Є § Ä▲	Є § Ä▲	Є § Ä▲♣	Є § Ä▲	Є § Ä▲	Є § Ä▲♣	Є § Ä▲	Є § Ä▲
	138	65	Є § Ä▲♣	Є § Ä▲	Є § Ä▲	Є § Ä▲♣	Є § Ä▲	Є § Ä▲	Є § Ä▲♣	Є § Ä▲	Є § Ä▲
	138	85	Є § Ä▲♣	Є § Ä▲	Є § Ä▲	Є § Ä▲♣	Є § Ä▲	Є § Ä▲	Є § Ä▲♣	Є § Ä▲	Є § Ä▲
	154	65	Є ▲	Є ▲	Є▲	Є ▲	Є ▲	Є▲	Є ▲	Є ▲	Є▲
R-2	116	65	Є ▲	Є ▲	Є ▲	Є	Є	Є	NT	NT	NT
	138	65	Є ▲♣	Є ▲♣	Є ▲	Є ▲♣	Є ▲♣	Є ▲	Є ▲♣	Є ▲♣	Є ▲
	154	65	Є ▲	Є ▲	Є ▲	Є	Є	Є	NT	NT	NT
R-3	116	65	Є ▲	Є ▲	Є ▲	Є ▲	Є ▲	Є ▲	Є	Є	Є
	138	65	Є ▲♣	Є ▲♣	Є ▲♣	Є ▲♣	Є ▲♣	Є ▲♣	Є ▲♣	Є ▲♣	Є ▲♣
	154	65	Є ▲	Є ▲	Є ▲	Є ▲	Є ▲	Є ▲	Є	Є	Є

Legend:

Є	Cantabro	1 replicate which consisted of a single *SGC* specimen.
§	IDT	1 replicate which consisted of a single *SGC* specimen.
Ä	*APA*	1 replicate which consisted of a single 150 mm diameter specimen.
▲	*BBR*	1 replicate (5 mixture beams) each at -18 and -24 C from a single *SGC* specimen.
♣	*MRTCR*	1 replicate (3 mixture bars) from a single *SGC* specimen.
NT	Not Tested	

3.6.2.3 RAP Absorbed Asphalt Experiment 1

To investigate the potential for additional absorption of asphalt by RAP aggregate an experiment was performed that consisted of two factors: 1) additional virgin asphalt content (high, medium, and low); and 2) RAP heating and compaction temperature (116 and 138 C). The factors and levels were the same as in Table 3.8 and 3.9; three G_{mm} replicates were prepared of each factor level combination. The first replicate was only virgin binder, the second replicate contained Sasobit® and the third replicate contained Evotherm 3G™. Based on results of this experiment with the *R-1* source, only the factor of additional virgin asphalt content was examined for the *R-2* and *R-3* sources.

3.6.2.4 RAP Absorbed Asphalt Experiment 2

Another experiment was performed on the *R-1* and *R-3* RAP sources to investigate absorption of asphalt by RAP aggregate; it consisted of testing four G_{mm} replicates from two samples of RAP. The first sample of RAP was split; one half was used to determine G_{mm} and the other half was heated for 120 minutes at 171 C then cooled and used to determine G_{mm}. The second sample of RAP was heated for 120 minutes at 171 C then mixed with 2% additional virgin binder. The second sample was split; one half was immediately cooled and the other half was placed in an oven at the hot mix compaction temperature (146 C) for four hours before it was removed and cooled. G_{mm} was determined for each half of the second sample. A four hour short term age was chosen as being conducive to producing a maximum potential for asphalt absorption; hot mix temperatures were chosen in favor of warm mix temperatures as they are more favorable to asphalt absorption.

3.6.3 25 and 50% RAP Mixtures

Five recycled mixtures containing either 25 or 50% RAP were designed and tested (Table 3.10). Based on results of the 100% RAP mixture testing, RAP source *R-3* was not utilized for 25 or 50% RAP mixtures. When determining virgin aggregate gradations, minimum aggregate stockpile percentages of 5% were used to align with cold feed limitations of asphalt plants. For the primary four recycled mixtures, the same virgin aggregate stockpile percentages were used with each RAP source at the 25% and 50% RAP contents to control the effects of virgin aggregate gradation. Virgin PG 67-22 binder with Sasobit® was used for all mixtures.

Recycled mixture *9.5-50/RM-1b* was only tested for skid resistance. For the recycled mixtures, a suite of testing was performed as detailed in Table 3.11. Cantabro testing of aged specimens was only performed for mixtures containing RAP source *R-1*. Dynamic modulus testing was only performed for mixtures containing RAP source *R-2*. The VMA for mixture *9.5-25/RM-2* is below MDOT requirements.

Table 3.10 Properties of 9.5 mm NMAS 25 and 50% RAP Recycled Mixtures

Mixture ID	*9.5-25/ RM-1*	*9.5-25/ RM-2*	*9.5-50/ RM-1*	*9.5-50/ RM-1b*	*9.5-50/ RM-2*
Design Traffic	MT	MT	MT	MT	MT
N_{des}	65	65	65	65	65
Binder Grade	PG 67-22	PG 67-22	PG 67-22	PG 67-22	PG 67-22
WMA	Sasobit 1.0%	Sasobit 1.0%	Sasobit 1.0%	3G 0.5%	Sasobit 1.0%
Mix Temp (C)	116	116	116	116	116
Comp Temp (C)	116	116	116	116	116
Percent Passing **25.0 mm**	100	100	100	100	100
19.0 mm	100	100	100	100	100
12.5 mm	99.1	100	98.3	96.4	99.9
9.5 mm	93.0	95.1	91.8	89.8	95.9
4.75 mm	59.2	62.5	58.4	61.2	64.9
2.36 mm	39.7	42.4	39.7	42.0	45.2
1.18 mm	29.9	31.5	30.9	33.2	34.0
0.60 mm	23.2	24.3	25.0	27.3	27.1
0.30 mm	14.6	15.5	15.8	16.7	17.5
0.15 mm	9.6	9.9	9.9	9.2	10.5
0.075 mm	7.2	7.5	7.3	5.3	7.8
***G-1* Gravel (%)**	56	56	40	31	40
***L-1* LST (%)**	8	8	0	13	0
***S-1* Sand (%)**	10	10	9	5	9
***HL-1* Lime (%)**	1	1	1	1	1
RAP (%)	25	25	50	50	50
RAP Source	*R-1*	*R-2*	*R-1*	*R-1*	*R-2*
$P_{b(R)}$ **(%)**	5.5	5.6	5.5	5.5	5.6
G_{sb}	2.450	2.460	2.453	---	2.473
G_{sa}	2.624	2.623	2.610	---	2.609
***Abs* (%)**	2.70	2.52	2.46	---	2.10
$P_{AC} = P_b$ **(%)**	6.1	5.6	6.5	6.5	6.2
$P_{be(V)}$ **(%)**	4.7	4.2	3.7	3.7	3.4
G_{mm}	2.306	2.334	2.311	2.344	2.338
G_{se}	2.508	2.524	2.530	2.572	2.552
VMA	15.2	14.0	15.4	N/A	14.9
P_{200}/P_{be}	1.4	1.6	1.4	N/A	1.6

Table 3.11 Experimental Test Matrix and Replication of 25 and 50% RAP Recycled Mixtures

Compaction Type	Test Parameters		Mixture				
			9.5-25/RM-1	***9.5-25/RM-2***	***9.5-50/RM-1***	***9.5-50/RM-2***	***9.5-50/RM-1b***
SGC	***APA***	**7% V_a**	2	2	2	2	0
	APA	**10% V_a**	2	2	2	2	0
	TSR	**7% V_a**	1	1	1	1	0
	Cantabro	**Un-aged**	3	3	3	3	0
	Cantabro	***R-30***	3	0	3	0	0
	BBR	**-06 C**	2	2	2	2	0
	BBR	**-12 C**	2	2	2	2	0
	BBR	**-18 C**	2	2	2	2	0
	BBR	**-24 C**	2	2	2	2	0
	E*	**7% V_a**	0	1	0	1	0
LAC	**PURWheel**	**Dry**	2	2	2	2	0
	PURWheel	**Wet**	2	2	2	2	0
	Skid Resistance		0	0	0	0	5

APA	A replicate consisted of a single track in the test equipment composed of two 150 mm diameter specimens.
TSR	A replicate consisted of six specimens tested according to *ASTM D 4867*.
Cantabro	A replicate consisted of one *SGC* compacted specimen.
BBR	A replicate consisted of five mixture beams at one temperature from an *SGC* specimen.
PURWheel	A replicate consisted of two specimens cut from a single *LAC* compacted slab and tested side by side at the same time.
Skid Resistance	A replicate consisted of a single skid resistance panel.
*E**	A replicate of dynamic modulus consisted of two specimens.

CHAPTER 4 – CHARACTERIZATION OF RAP PROPERTIES

4.1 Overview of RAP Characterization

A rational yet practical approach to mix design incorporating reclaimed asphalt pavement (RAP) in high quantities (e.g. over 25%) needs methods that can account for more than just the total asphalt content and gradation of the RAP. Two RAP sources with the same total asphalt content and gradation could perform very differently in a mixture depending on factors including the amount of absorbed bituminous material and the condition of the bituminous material on the surface of the aggregate. Initially the bitumen of these two sources could have been very different, moderately different, or the same depending on factors including the application and mix design method (Superpave, Marshall, or Hveem). In service, the aging of these two sources could have been very different, moderately different, or the same depending on factors including compaction, traffic, distresses, and environmental conditions. These two RAP sources should not be treated equally in a new mixture unless they are characterized such that it is justifiable to do so, and current practice does not have methods in place to make such an assessment.

In current practice, none of the factors that led to the amount of bituminous material or its condition (e.g. mix design method, field aging) for a given RAP source would be known to the designer of the new mixture. The amount of absorbed bitumen relative to the amount of total bitumen would be a function of the mix design method, and the grade of the bitumen on the surface of the aggregates would be a function of many variables. A method that focuses on the current properties is appropriate, as what led to the current properties of the bitumen is secondary to the properties themselves.

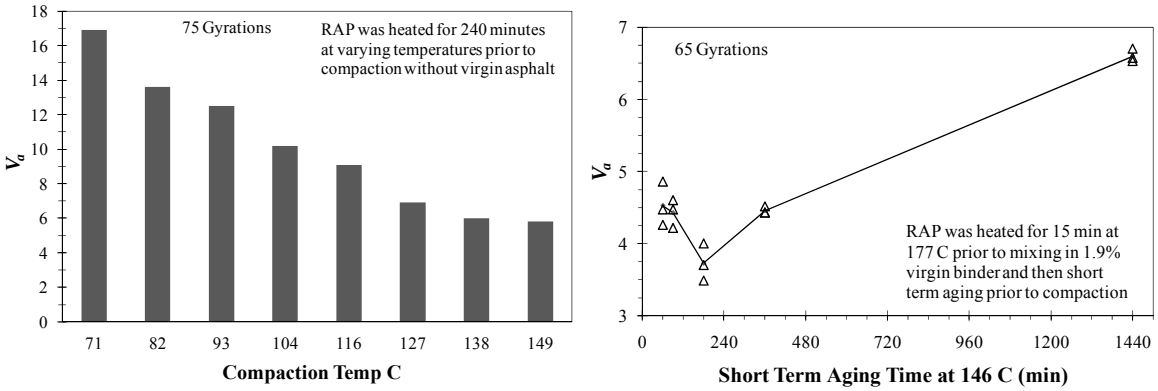
The debate over RAP properties has intensified in recent years due to decreasing budgets coupled with rising raw material prices. Key aspects of RAP behavior that have been debated include if and to what extent the bituminous material within RAP re-livens and contributes to compaction and performance of the new mixture. Figure 4.1 provides evidence that two of the key aspects of the RAP debate (heating temperature and heating time) affect the extent the bituminous material re-livens in a new mixture. Warm mix technologies are the key issue related to heating temperature, and asphalt production methods are the key issue related to heating time.

Figure 4.1*a* investigates the effect of heating temperature by compacting 100% *R-1* RAP without virgin binder at varying temperatures. Raw data is found in Howard et al. (2009). Better compaction occurred as the temperature was increased.

Figure 4.1*b* was intended to crudely approximate RAP heating during plant production (i.e. investigate effects of heating time) using *9.5-100/RM-1* (Raw data provided in Table A.1). Typical methods of introducing RAP during plant production result in a short but intense level of heating; arguably this will heat the surface of RAP particles but may not fully heat the RAP before virgin binder is added. After mixing and before compaction, RAP has time to absorb additional heat from the virgin aggregate while in storage silos or during transport. Two G_{mm} samples were prepared according to the same procedure; one was aged for 60 minutes and the other was aged for 1440 minutes. Results of testing the two G_{mm} samples were nearly identical and were averaged for calculation of air voids.

Average air voids decreased as the short term aging time increased up to 180 minutes and thereafter average air voids increased. The maximum compaction occurred at 180

minutes of short term aging time (195 minutes total heating time). These results indicate that the addition of heat to the RAP after coating with virgin binder is beneficial to compaction, but that longer aging times are likely stiffening the virgin binder coating the RAP and ultimately hindering compaction relative to lesser aged virgin binder. It is unclear what effects longer storage times might have on high RAP mixes during plant production since asphalt storage silos limit exposure to oxygen in contrast to the forced-draft oven aging performed herein. The total heating time that resulted in optimum compaction for this experiment was approximately 195 minutes; this is close to the total heating time for RAP used for the rest of this experimental program of 210 minutes (see Section 3.4).



a) Heating Temperature *b) Heating Time*

Figure 4.1 Effect of Heating Temperature and Heating Time on RAP

The Figure 4.1 data shows that RAP bitumen on the aggregate surface is affected by the conditions encountered and that a portion of the bitumen remains inert (i.e. acts as aggregate) while the rest is effective and re-livens (i.e. facilitates compaction and then acts as binder though perhaps differently than when originally used). The remainder of the RAP bitumen is absorbed in the aggregate pores. A total of three types of bituminous materials are present within RAP: effective surface, inert surface, and absorbed.

Compaction is arguably the key characteristic of mix design and the lubrication provided by bituminous material is arguably the key characteristic that facilitates compaction of a given aggregate structure. The approach taken in this paper is not able to consider the relative effects of compaction between bituminous material with different lubrication characteristics. This is a limitation as Figure 4.1b shows the effects of different amounts of binder aging on compaction.

A meaningful discussion related to lubrication effects of aged RAP bituminous material and virgin asphalt is premature until an estimate of the quantity of aged bituminous material is available. Bituminous material that was originally absorbed into the aggregate pores is not available to lubricate aggregates during compaction. Some of the bituminous material that was originally part of the lubricating material is believed to be inert in many conditions when used as RAP in a new mixture. The reminder of the bituminous material that was part of the original lubricating material would aid in lubrication in the new mixture but would be stiffer and as a result would not lubricate as much in the new mixture.

The component diagram of RAP provided in Figure 4.2 builds on the results of Figure 4.1 and is the focus of the rest of the analysis. The first issue addressed was prediction of

absorbed bitumen, $P_{ba(R)}$, within RAP pores as prediction of this parameter has not previously been possible on a large scale such as within the operations of a state DOT. The second issue was characterization of the RAP surface asphalt and decoupling ineffective and effective surface asphalt ($P_{bi(R)}$ and $P_{be(R)}$, respectively). All terms are defined on a mixture mass basis and as a result do not necessarily have the same numerical value. For example, adding virgin binder ($P_{be(V)}$) would change the numerical value of absorbed bitumen ($P_{ba(R)}$) even though the mass of bitumen absorbed has not changed.

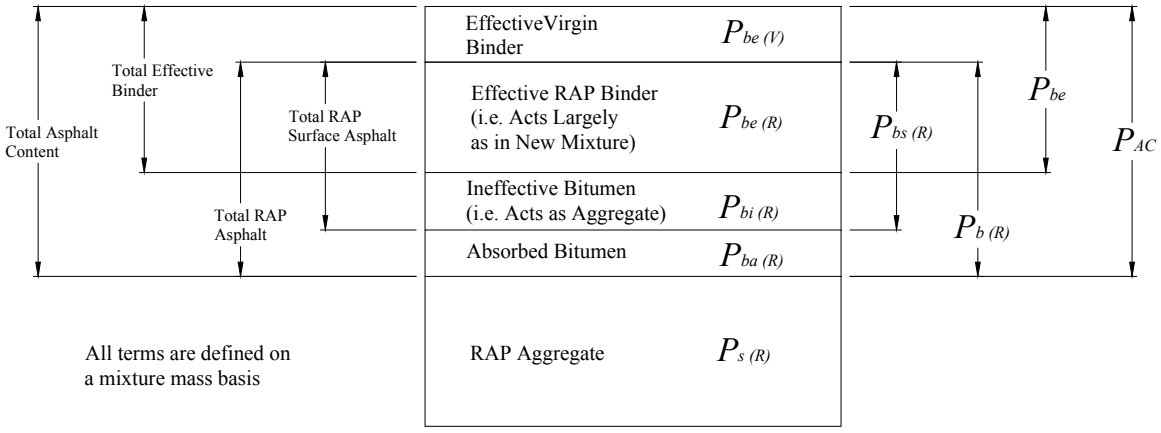


Figure 4.2 Component Diagram for RAP Mixtures

Many approaches have been taken with regard to RAP characterization, but an approach relying on a large mixture database coupled with testing of 100% RAP has not been attempted to the knowledge of the authors. This chapter presents the results of such an analysis using data from all MDOT approved mix designs over the past several years alongside testing of 100% RAP with added virgin binder. The database of mix designs was used to develop regression equations for prediction of properties that have previously posed difficulty. The approach was developed in a manner that does not require inputs that have been shown problematic to measure on extracted RAP aggregates (e.g. G_{sb}). The analysis assumes RAP in Mississippi is fully represented by the database used to develop the regression equations. Testing of 100% RAP was used to compliment the database regression in some instances, while other 100% RAP testing was used to verify quality of the regression. The analysis uses extraction only to measure total asphalt content.

The analysis was developed in a manner focused on practical implementation. Key items of consideration were that: 1) it is difficult to accurately measure G_{sb} on RAP aggregates after bitumen is extracted; 2) it is difficult to accurately measure G_{mm} of RAP as received from a producer stockpile due to dust on the surface of the particles, micro cracks in aged bitumen allowing water absorption, and similar; and 3) it is not difficult to accurately measure G_{mm} of RAP when coated with sufficient virgin asphalt. Justification of this approach is provided throughout the chapter.

4.2 MDOT Asphalt Mixture Database

Properties of all mix designs approved by MDOT between January 2005 and March 2010 were provided by the Materials Division and used for analysis. Data obtained for each asphalt mixture included combined properties of the aggregate blend, compactive effort, asphalt binder grade, and mixture volumetric properties. Also included were individual aggregate stockpile proportions, aggregate types, aggregate water absorptions, and stockpile gradations. For mixtures that contained RAP, the RAP total asphalt content, extracted aggregate gradation, and extracted aggregate water absorption were included. The data needed for the analysis is maintained by MDOT in a database where all approved mix designs are in a standard format, making the approach feasible. The approach could probably be implemented by other state DOT's as they likely maintain similar information in some type of organized fashion.

The raw data was arranged by nominal maximum aggregate size (NMAS) and design traffic level (i.e. ST, MT, and HT). These design traffic levels correspond to design compactive efforts of 50, 65, and 85 gyrations, respectively. The database contained a total of 837 entries; 369 were 9.5 mm, 244 were 12.5 mm, and 224 were 19.0 mm NMAS.

Not all 837 database entries were unique in terms of volumetric properties. In a number of cases there were two mixes with identical aggregate and volumetric properties. In most instances these duplicate cases resulted from re-approvals of existing mix designs with different binder grades or different binder sources. The duplicate cases were removed from the dataset as they do not represent unique volumetric mixture combinations, which reduced the number of mixes to 590.

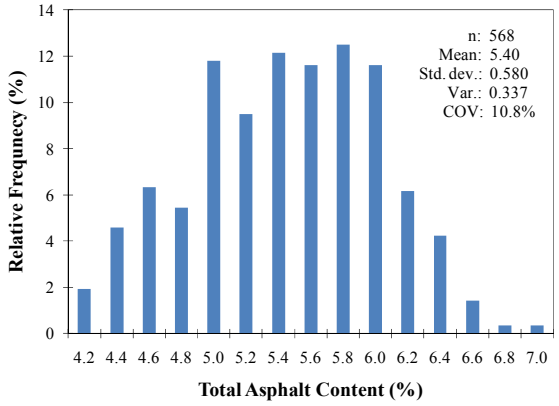
The overwhelming majority of mixtures contained combinations of gravel, limestone, sand, and RAP though not all mixtures contained all these aggregate types. Twenty-two mixtures (3.7% of the total) were removed from the data set since they contained other aggregate types. The unusual aggregate types removed were: granite (19 mixes), slag (1 mix), sandstone (1 mix), and crushed concrete (1 mix). Removal of these 22 mixes left 568 for use in analysis. Of the 568 mixes, 93% or 529 contained RAP.

The dataset was considered to be the population of asphalt properties in Mississippi. This is a reasonable approach with all the approved mixtures statewide over a period in excess of five years. A key component of the investigation is the assumption that asphalt placed within the past five years represents the RAP being used in present day. This is a reasonable assumption for Mississippi within the jurisdiction of the Mississippi DOT.

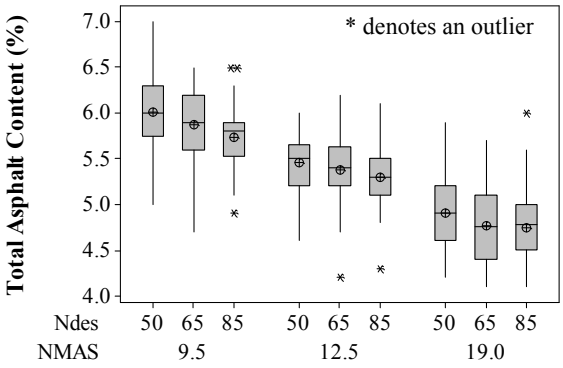
4.2.1 Asphalt Contents of Mississippi Mixtures

Figure 4.3 presents relative frequency histograms and boxplots of total, effective, and absorbed asphalt contents for the mixtures. Examination of the relative frequency histograms of total and effective asphalt content (Figure 4.3*a* and Figure 4.3*c*) reveals a relatively wide spread of values and no clearly defined peak. The effective asphalt content standard deviation is lower than the total asphalt content standard deviation. The coefficients of variation (COV) for the two populations are nearly the same (approximately 10%). From the boxplot of total asphalt content (Figure 4.3*b*) it can be observed that as the NMAS of the aggregate gradation increases, the total asphalt content decreases as expected.

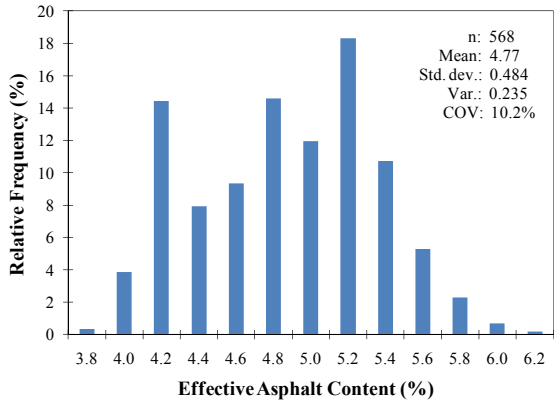
The same observation can be made from the effective asphalt boxplot (Figure 4.3*d*). It is evident that an increase in compactive effort during mix design results in a decrease in effective asphalt content. This is expected since a greater compactive effort during mix design requires less effective asphalt to achieve a target level of air voids.



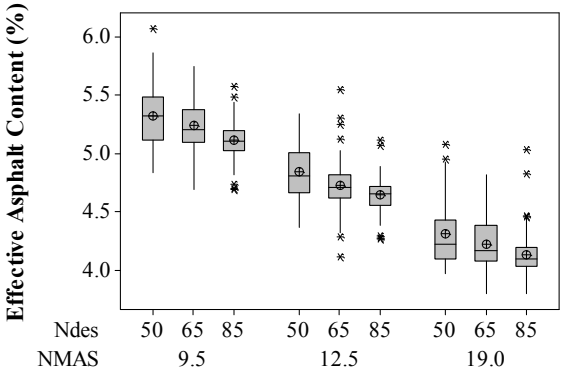
a) Relative Frequency Histogram of P_b



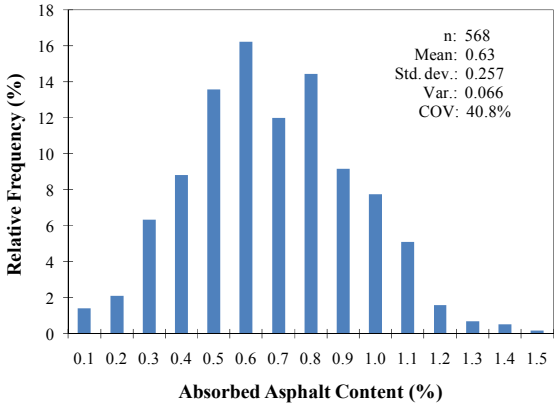
b) Boxplot of P_b



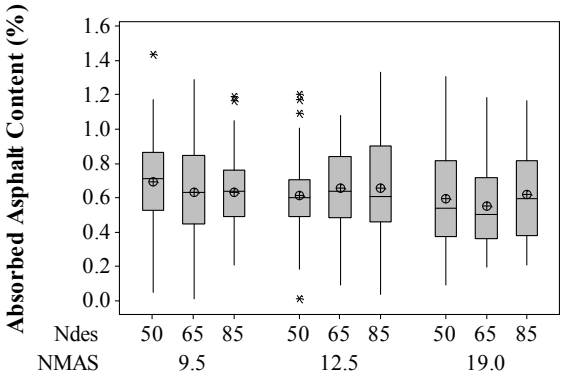
c) Relative Frequency Histogram of P_{be}



d) Boxplot of P_{be}



e) Relative Frequency Histogram of $P_{ba(mix)}$



f) Boxplot of $P_{ba(mix)}$

Figure 4.3 Summary Asphalt Content Results

Examination of the absorbed asphalt relative frequency histogram (Figure 4.3*e*) indicates a general peak and an approximately normal distribution that is in contrast to the distributions of total and effective asphalt. The COV is approximately four times higher for the absorbed asphalt distribution. The boxplot of effective asphalt contents (Figure 4.3*f*) reveals little difference in mean absorption values with changes in compactive effort. The lack of change in mean absorbed asphalt content for changing compactive effort is expected since compactive effort does not affect aggregate absorptive capacity. It is interesting to note that the differences in absorbed asphalt content for different NMAS are quite small. One reason could be crushing the same base aggregate source to produce different gradations, since absorption is a general characteristic of the gravel or stone source.

Table 4.1 summarizes the mixtures contained in the dataset as well as the ranges of their total, effective, and absorbed asphalt contents. A few observations are indicated in the boxplots of total and effective asphalt content as potential outliers. While unusual, these observations were left in the dataset because they represent real mixtures and are part of the population of asphalt mixtures in Mississippi. These mixtures, however, were not shown in Table 4.1 as they detract from the point of the table.

The total asphalt content range over the five year period covered by this dataset was 4.1 to 7.0%. Note the wide range in absorbed asphalt in Table 4.1; absorbed asphalt content is seen to range from 0.03 to 1.33%. By defining $P_{ba(mix)}$ as a percentage of the total mixture, total asphalt content is the sum of absorbed and effective asphalt contents. MDOT uses this definition of absorbed asphalt for their mix designs.

Table 4.1 Summary of 568 Unique Mixtures in MDOT Mixture Dataset

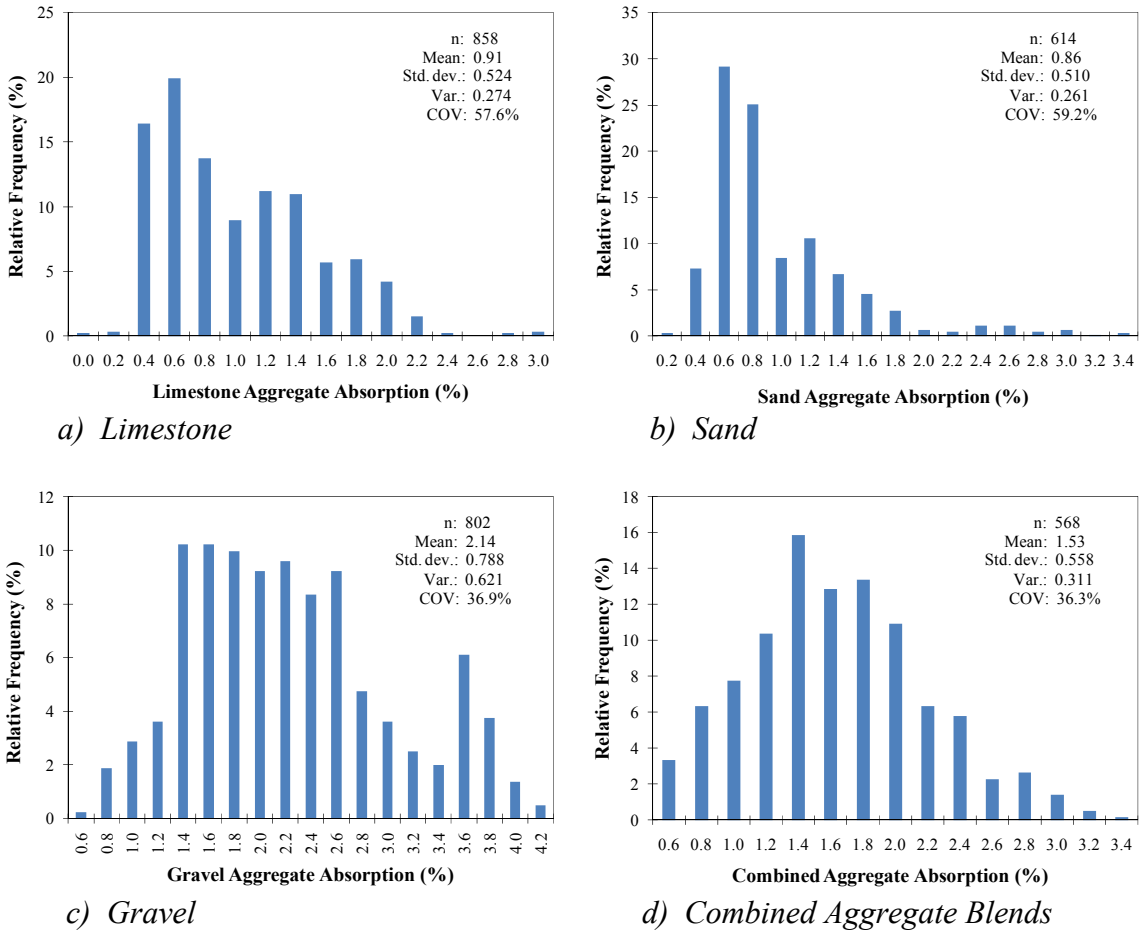
NMAS	Traffic Level	N_{des}	No. of Mixtures	Range of P_b		Range of P_{be}		Range of $P_{ba(mix)}$	
				max	min	max	min	max	min
9.5 mm	HT	85	80	6.30	5.10	5.57	4.69	1.05	0.21
	MT	65	75	6.50	4.70	5.74	4.69	1.29	0.06
	ST	50	73	7.00	5.00	6.07	4.83	1.17	0.04
9.5 mm Mixes			**228**	**7.00**	**4.70**	**6.07**	**4.69**	**1.29**	**0.04**
12.5 mm	HT	85	73	6.10	4.80	5.11	4.27	1.33	0.03
	MT	65	49	6.20	4.70	5.13	4.28	1.08	0.09
	ST	50	45	6.00	4.60	5.34	4.36	0.94	0.18
12.5 mm Mixes			**167**	**6.20**	**4.70**	**5.34**	**4.27**	**1.33**	**0.03**
19.0 mm	HT	85	68	5.60	4.10	4.94	3.80	1.17	0.20
	MT	65	54	5.70	4.10	4.81	3.80	1.19	0.19
	ST	50	51	5.90	4.20	4.46	3.97	1.31	0.08
19.0 mm Mixes			**173**	**5.9**	**4.10**	**4.94**	**3.80**	**1.31**	**0.08**
All Mixes			**568**	**7.00**	**4.10**	**6.07**	**3.80**	**1.33**	**0.03**

Note: The term $P_{ba(mix)}$ is defined on the basis of total mass of asphalt mixture and not on aggregate mass.
Note: Outliers have been removed from the data provided in this table.

4.2.2 Water Absorption of Mississippi Aggregate Sources

Aggregate stockpile data was sorted into limestone, sand, and gravel categories based on identifying information in the database. Water absorption relative frequency histograms for the three aggregate categories as well as the combined aggregate blends are provided in Figure 4.4. Discussion of each of the aggregate types and the aggregate blends follows.

The limestone histogram (Figure 4.4*a*) has a distribution with a mean of 0.91%, no clear peak value, and a slight right skew. A possible explanation is that Mississippi has no substantial native sources of limestone so essentially all limestone aggregate is imported from areas such as Kentucky and Alabama. The data could be a reflection of important quantities from different locations as they likely have different absorption properties. Overall, 80% of the limestone water absorption values fall in a range of about 0.35 to 1.75%.



a) Limestone *b) Sand*

c) Gravel *d) Combined Aggregate Blends*

Figure 4.4 Summary Water Absorption Results

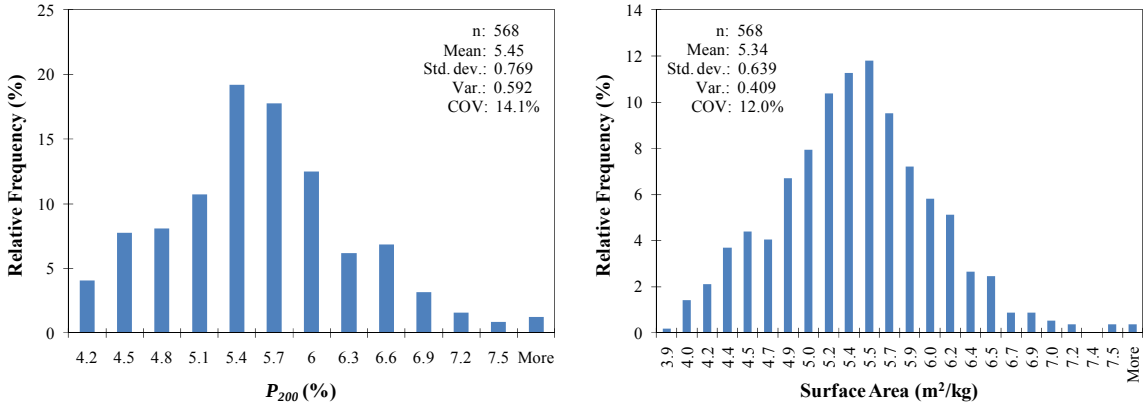
The Figure 4.4*b* sand distribution has a peak that is near the mean value of 0.86% but is severely right skewed. The MDOT database does not have a clear definition of what constitutes sand, which could explain some of the skew. The aggregate identified as sand could be naturally occurring aggregate (i.e. clean but un-crushed) or contain manufactured materials (i.e. crushed aggregate) that could have very different water absorption values. Overall, 80% of the sand water absorption values fall in a range of about 0.40 to 1.55%, which is similar to the limestone data.

The crushed gravel histogram (Figure 4.4*c*) reveals a wide distribution with no clear peak. This is likely due to variations in geology between aggregate sources from around the state. Overall, 80% of the gravel water absorptions fall in a range of about 1.25 to 3.45%.

Figure 4.2*d* plots composite aggregate blend water absorption results. In contrast to the individual aggregate sources, the distribution is approximately normal with a peak near the mean value of 1.53%. Overall, 80% of the aggregate blend water absorption values fall in a range of about 0.80 to 2.25%.

4.2.3 Gradation of Mississippi Aggregate Sources

Figure 4.5 plots percent fines and surface area for all aggregate blends. The percent fines distribution appears generally normal in shape with a mean of 5.45% but with a slightly higher proportion of values below the mean than above. The surface area distribution appears normal in shape with a mean of 5.34 m^2/kg and a few extreme values to the far right of the distribution.



a) Gradation Passing 0.075 mm Sieve *b) Surface Area*

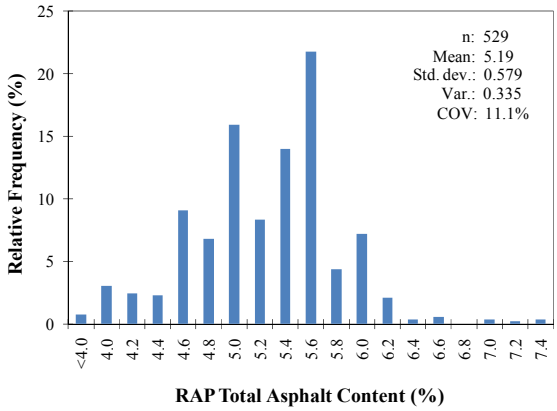
Figure 4.5 Summary Aggregate Blend Results

4.2.4 Mississippi RAP Properties

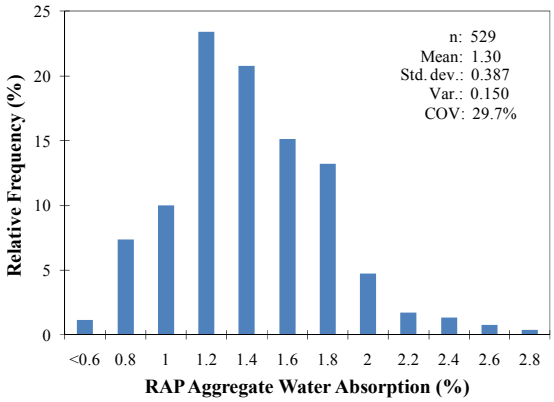
Figure 4.6 plots RAP properties used in new mixtures. The total RAP asphalt content distribution (Figure 4.6*a*) is generally normal in shape but contains several values that are much higher and lower than the central distribution. The high values are likely due to testing error since they are above the highest total asphalt content of 7.0% contained in Table 4.1. Potential causes of error that would over estimate RAP asphalt content include aggregate degradation in an ignition test, loss of fine material, or incomplete recovery of mineral fines from extraction solvent. The low values may be due to testing error, be from RAP sources with stripped aggregate, or be from RAP mixed with base material during reclaiming.

The water absorption histogram (Figure 4.6*b*) is fairly normal aside from one abnormally low value that is likely testing error. The RAP fines histogram (Figure 4.6*c*) is also fairly normal and has a wide distribution with a range of 3 to 13% and a relatively high standard deviation. The extracted RAP aggregate surface area distribution (Figure 4.6d) has a mean value of 7.86 m^2/kg and two peaks on either side of the mean value. In a few cases, surface area exceeded 10.0 m^2/kg, and these cases were those in Figure 4.6c with a high fines (i.e. passing 0.075 mm sieve) content.

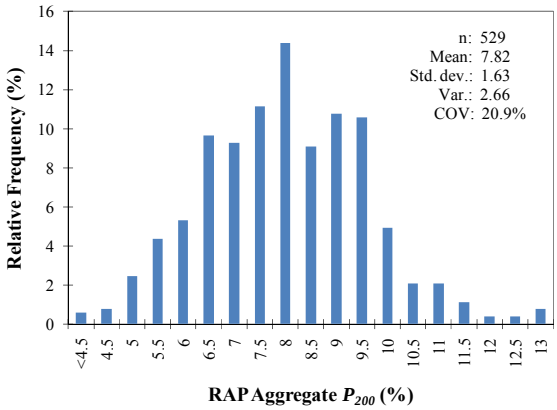
Since RAP was formerly new asphalt mixture it is informative to compare the distributions of RAP and current MDOT mixture properties. Table 4.2 presents the results of unequal variance *t*-test comparisons between RAP and current mixture properties. The mean RAP total asphalt content is significantly lower than the mean total asphalt content for MDOT mixtures; the difference is 0.21%. The variances of the two distributions are nearly identical which suggests that the distributions are quite similar except for their mean values. Possible reasons for the lower RAP asphalt contents include testing error resulting in lower total asphalt contents (e.g. incomplete extraction of RAP asphalt), loss of asphalt volatiles during service life, or actual loss of asphalt during the reclaiming process (e.g. during milling and handling). Another potential explanation for this result is that mixtures designed according to earlier versions of MDOT specifications (i.e. higher design compactive effort) resulted in generally lower asphalt contents than the current mix design specifications.



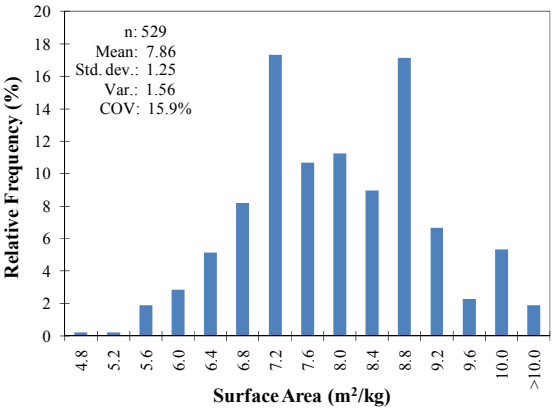
a) Total Asphalt Content



b) Extracted Aggregate Water Absorption



c) Percent Passing 0.075 mm Sieve



d) Extracted Gradation Surface Area

Figure 4.6 Summary RAP Results

The mean water absorption of extracted RAP aggregate is significantly lower than the mean combined aggregate blend water absorption values of current MDOT mixtures; the difference is 0.24%. Lower aggregate absorption values for RAP imply that values of RAP aggregate G_{sb} values are also lower. This aligns with the results found in several sources cited in the literature review that aggregate G_{sb} is often lower for extracted aggregate than for

virgin aggregate. The mean percent passing the 0.075 mm sieve (i.e. fines) for RAP aggregate is significantly higher than for current MDOT mixtures; the difference is about 2.4%. The increased fines are likely due to aggregate degradation (milling in particular).

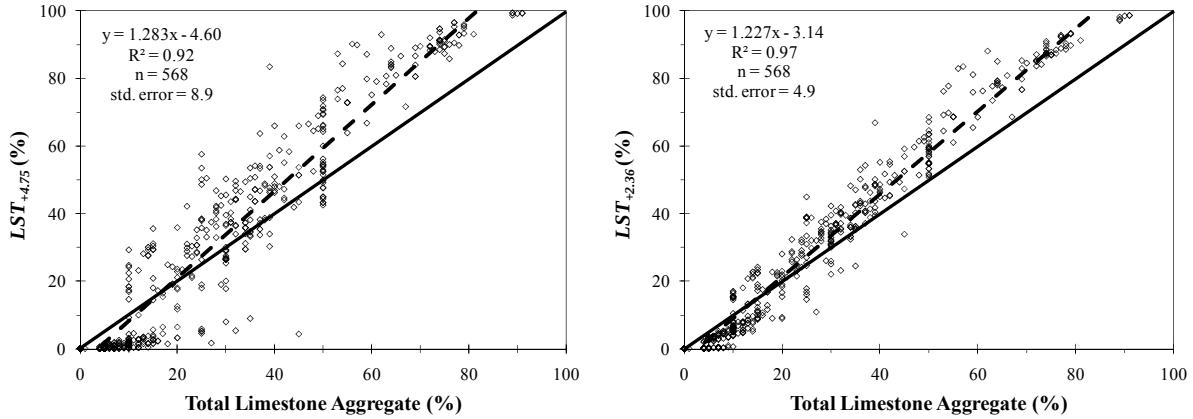
Table 4.2 Unequal Variance *t*-test Test Comparison of RAP to Mixture Properties

Category	Material	*n*	Mean	Var.	*t*-stat	*t*-crit	Significantly Different?
Asphalt Content	RAP	529	5.19	0.335	5.82	±1.96	Yes
	Mixtures	568	5.40	0.337			
Abs	RAP	529	1.30	0.150	-8.19	±1.96	Yes
	Mixtures	568	1.54	0.311			
P_{200}	RAP	529	7.82	2.662	30.49	±1.96	Yes
	Mixtures	568	5.45	0.592			

Note: Significance testing performed at the 95% confidence level.

4.3 Results of RAP Aggregate Sorting Procedure

To evaluate the usefulness of the aggregate sorting procedure for extracted RAP aggregate described in the experimental program, two regression equations were developed using the aggregate data in the mixture database. The first regression was of $LST_{+4.75}$ to total limestone aggregate in the mixture (Figure 4.7*a*). The correlation is reasonable ($R^2 = 0.92$) but there is some scatter in the data.



a) Retained on *4.75 mm Sieve* *b) Retained on 2.36 mm Sieve*

Figure 4.7 Correlation of Coarse Limestone Aggregate to Total Limestone Aggregate

The second regression was of $LST_{+2.36}$ to total limestone aggregate in the mixture; this is shown in Figure 4.7*b*. The correlation is better ($R^2 = 0.97$) than for the regression developed for coarse aggregate retained on the 4.75 mm sieve. A very reasonable estimation of the percentage of total limestone aggregate in an aggregate blend can be determined by using the aggregate sorting procedure developed as part of this research project. This procedure is used later in the chapter as an input for regression equations for prediction of RAP properties.

4.4 Correlation of Water and Asphalt Absorption

A regression equation was developed relating absorbed asphalt to aggregate water absorption, which is shown in Figure 4.8. A correlation does exist as asphalt absorption is on the order of one third of aggregate water absorption. However, there is a noticeable amount of scatter in the data ($R^2 = 0.51$). The relationship is similar to that found by Kandhal and Khatri (1992) discussed in the literature review. Prediction of absorbed asphalt using water absorption would require measurement of water absorption on aggregates extracted from RAP, which was found to be variable during literature review. This does not appear to be the optimal approach to estimate absorbed asphalt in RAP.

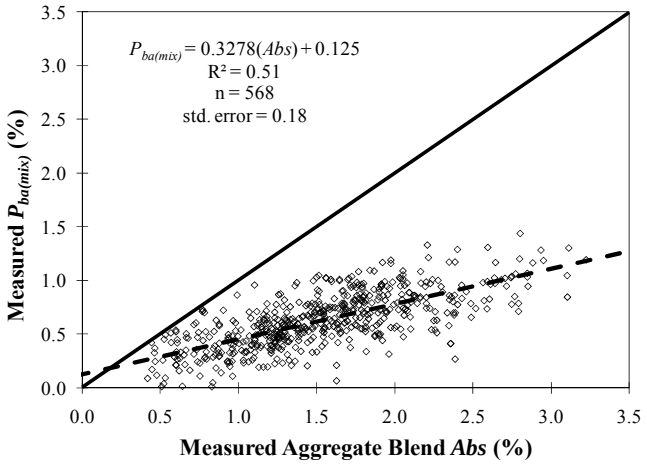


Figure 4.8 Use of Aggregate Water Absorption to Estimate Asphalt Absorption

4.5 RAP Absorbed Asphalt

Evidence is provided in this section that G_{se} can be reliably and efficiently determined by measuring G_{mm} on RAP coated with additional virgin binder. The evidence is supported by data showing RAP does not absorb noticeable amounts of virgin asphalt. The evidence is also supported by discussion related to the difficulty of conducting G_{mm} on RAP versus the ease of determining G_{mm} on RAP coated with virgin binder.

4.5.1 RAP Absorbed Asphalt Experiment 1

The propensity of RAP to absorb additional virgin asphalt was investigated using the methods described in Section 3.6.2.3. *R-1* RAP was heated and short term aged at 116 C and 138 C in conjunction with three total asphalt contents (P_{AC}) as given in Table 3.8. Raw data is provided in Table A.2, and the raw G_{mm} values were used to calculate G_{se} values. Asphalt binder specific gravity (G_b) of 1.03 was assumed for all calculations.

A pooled variance *t*-test was used to compare replicates containing Sasobit® and Evotherm 3G™ to the replicates without warm mix additives (Table 4.3). Results indicated no significant difference in the mean values for either comparison. In that there were no statistical differences in the data, all the data with and without warm mix additives at a given temperature and asphalt content was grouped together for the next step in the analysis.

An ANOVA test was then performed on the G_{se} data and the results are provided in Table 4.4. The interaction of temperature and total asphalt content was not significant. Also, RAP heating and short term aging temperature were not found to be significant parameters. Likewise, RAP total asphalt content was not found to be a significant parameter.

Temperature and warm mix additives were not considered for the two remaining RAP sources. The three total asphalt contents tested are given in Table 3.8. The raw data is provided in Tables A.3 and A.4; the data was used to calculate G_{se}. Tables 4.5 and 4.6 provide results of ANOVA analyses and based on the results, RAP total asphalt content was not found to be a significant parameter for G_{se} results for the *R-2* and *R-3* RAP sources.

Table 4.3 Pooled Variance *t*-test Test for G_{se} of *R-1* RAP

Comparison	*n*	Mean	Var.	*t*-stat	*t*-crit	Significantly Different?
None	12	2.581	1.02×10^{-4}	1.56	±2.30	No
Sasobit®	12	2.575	4.36×10^{-5}			
None	12	2.581	1.02×10^{-4}	1.48	±2.30	No
Evotherm 3G™	12	2.574	1.39×10^{-4}			

Note: Significance testing performed at the 95% confidence level.

Table 4.4 ANOVA Test for G_{se} of *R-1* RAP

Source	df	SS	MS	F_{calc}	P_{value}	Significant?
Temp	1	0.0002609	0.0002609	3.04	0.091	No
P_{AC}	2	0.0005409	0.0002705	3.15	0.057	No
Temp * P_{AC}	2	0.0000590	0.0000295	0.34	0.712	No
Error	30	0.0025735	0.0000858			
Total	35	0.0034344				

Note: Significance testing performed at the 95% confidence level.

Table 4.5 ANOVA Test for G_{se} of *R-2* RAP

Source	df	SS	MS	F_{calc}	P_{value}	Significant?
P_{AC}	2	0.0000418	0.0000209	0.80	0.525	No
Error	3	0.0000779	0.0000260			
Total	5	0.0001197				

Note: Significance testing performed at the 95% confidence level.

Table 4.6 ANOVA Test for G_{se} of *R-3* RAP

Source	df	SS	MS	F_{calc}	P_{value}	Significant?
P_{AC}	2	0.0001409	0.0000705	3.92	0.145	No
Error	3	0.0000539	0.0000180			
Total	5	0.0001948				

Note: Significance testing performed at the 95% confidence level.

The results indicate that the warm mix temperatures tested did not induce any additional asphalt absorption for the *R-1* RAP source. Warm mix additives did not induce any additional absorption of asphalt for the *R-1* RAP source. The amount of virgin asphalt added did not affect determination of aggregate G_{se} for the *R-1*, *R-2*, or *R-3* RAP sources.

4.5.2 RAP Absorbed Asphalt Experiment 2

The potential for asphalt absorption to be affected in RAP under varying conditions was investigated using the *R-1* and *R-3* RAP sources. Details are provided in Section 3.6.2.4. Table A.5 contains the raw data and Table 4.7 provides the results of this experiment.

The as received (un-heated) data provided a baseline measurement of the RAP aggregate absorbed asphalt. The data after 120 minutes of heating provided a measurement of whether any additional RAP asphalt was absorbed by the RAP aggregate. The sample without short term aging provided a baseline measurement of new asphalt absorption for the mixture. The 4 hour short term aging period at standard hot mix temperature (146 C) was selected to be very favorable to new asphalt absorption and to represent the best possible opportunity for additional asphalt absorption by the RAP aggregate.

Table 4.7 Results of Absorbed Asphalt Experiment 2

Material Tested	Condition	P_{AC} (%)	G_{mm} [1]	G_{se}
R-1 + 0% $P_{be(V)}$	As received	5.5	2.382	2.579
R-1 + 0% $P_{be(V)}$	2 hr heat at 171 C	5.5	2.373	2.567
R-1 + 2% $P_{be(V)}$	2 hr heat at 171 C, no aging	7.4	2.315	2.571
R-1 + 2% $P_{be(V)}$	2 hr heat at 171 C, 4 hr aging at 146 C	7.4	2.319	2.577
	***R-1* G_{se} Summary: Average 2.574**			**Range 0.012**
R-3 + 0% $P_{be(V)}$	As received	5.0	2.415	2.599
R-3 + 0% $P_{be(V)}$	2 hr heat at 171 C	5.0	2.422	2.608
R-3 + 2% $P_{be(V)}$	2 hr heat at 171 C, no aging	6.9	2.351	2.598
R-3 + 2% $P_{be(V)}$	2 hr heat at 171 C, 4 hr aging at 146 C	6.9	2.358	2.608
	***R-3* G_{se} Summary: Average 2.603**			**Range 0.010**

1) Average of two measurements.

The difference in G_{se} results for the two tested conditions is 0.012 for *R-1* and 0.010 for *R-3*. Both differences are less than the allowable range of 0.014 for four determinations of G_{mm} by a single operator. The results indicate that a negligible amount of additional asphalt (aged or virgin), if any, is absorbed by the *R-1* or *R-3* RAP aggregates during laboratory heating and short term aging.

For uncoated RAP there is a tendency for fine material to be lost during the test as evidenced by the dark cloud that appears in the water bath while obtaining the submerged mass of the sample. Also, broken RAP aggregate surfaces produced during the milling process could affect test results. It is much easier to obtain accurate G_{mm} measurements for G_{se} calculation with RAP coated with an additional 2% virgin asphalt on a mixture mass basis than with only the RAP. Table 4.7 provides evidence the approach is also accurate. Figure 4.9 illustrates the differences between as received RAP and that coated with virgin asphalt. *R-3* RAP was shown as it had the most uncoated aggregates of the sources tested. Some aggregate had stripped during service, but test data showed the asphalt remained in the aggregate pores leading to consistent G_{se} measurements. RAP that has been contaminated with base material that has never been coated with asphalt would cause difficulty, whereas stripped aggregate does not appear to cause difficulty.

The data presented in this section shows that the asphalt absorbed and measured during the mix design process ($P_{ba(mix)}$) is equivalent to absorbed RAP asphalt ($P_{ba(R)}$) for practical purposes. The numerical value of either $P_{ba(mix)}$ or $P_{ba(R)}$ will vary depending on the amount of $P_{be(V)}$ being considered since they are defined on a mixture mass basis. As $P_{be(V)}$ increases $P_{ba(R)}$ decreases. Numerically, $P_{ba(R)}$ is a maximum when $P_{be(V)}$ is zero, but it should be understood that the amount of asphalt absorbed in the RAP is not changing rather the total mix mass is increasing and making the amount of absorbed asphalt less of the total mix mass. The remainder of the chapter uses $P_{ba(R)}$ to define asphalt absorbed into RAP pores since it is one of the key parameters under investigation.

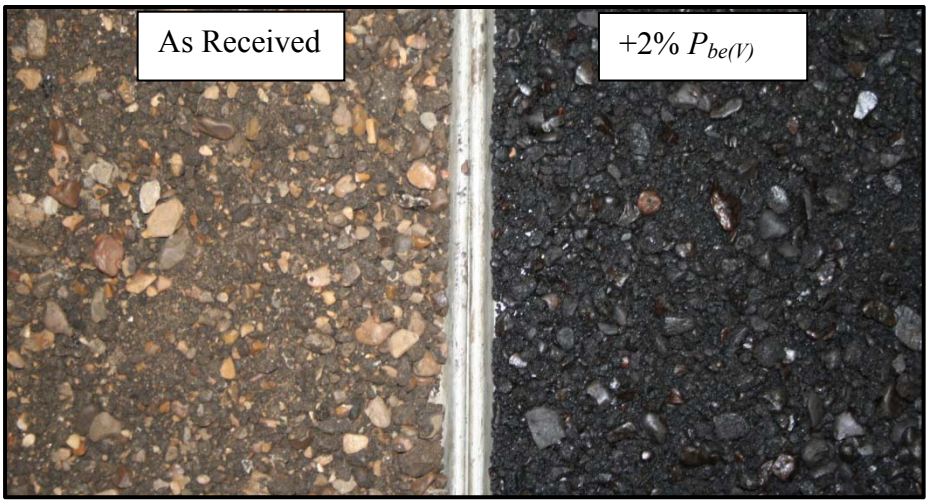


Figure 4.9 Loose *R-3* RAP Samples With and Without Virgin Binder

4.6 Prediction of RAP Absorbed Asphalt

Regression equations were developed to relate the measurable properties of a RAP source (either directly or indirectly) to absorbed asphalt. The measurable properties of a RAP source for purposes of this analysis were: G_{se}, $P_{b(R)}$, SA, $LST_{+2.36}$, and similar properties that can be determined knowing only the total asphalt content and having extracted RAP aggregate. Surface area (SA) can be computed based on the percent passing each sieve size and standard surface area factors according to the method presented in Roberts et al. (1991). Figure 4.7 was used to select $LST_{+2.36}$ to represent the percentage of limestone in the mixture. The remaining terms are conventional. Development of regression equations that required inputs not available within current practice or that required inputs shown problematic in literature (e.g. G_{sb}) were not attempted since they are less practical than equations that can be developed with practically measured inputs.

The most desirable approach was to be able to predict $P_{ba(R)}$ directly from regression, and the next most desirable approach was to be able to predict G_{sb} and use volumetric relationships to calculate $P_{ba(R)}$. Regression equations were developed in a step-wise fashion where all input variables under consideration were used to predict the output of interest. Input variables that did not affect the prediction were removed until all variables remaining affected the calculated output variable. Direct $P_{ba(R)}$ calculation could not produce R^2 values greater than approximately 0.6. The best regression equation for calculation of G_{sb} is

provided in Eq. 4.1. Eq. 4.2 is the standard volumetric equation used in conjunction with the values calculated in Eq. 4.1 to determine $P_{ba(R)}$.

$$G_{sb\min,\max} = 1.111 G_{se} - 0.329 \pm z_{\alpha/2}(0.0156) \qquad R^2 = 0.94 \qquad n = 568 \qquad (4.1)$$

$$P_{ba(R)} = P_{ba(mix)} = \left(100 - P_{b(R)}\right)\frac{\left(G_{se} - G_{sb}\right)}{G_{sb}G_{se}}G_b \qquad (4.2)$$

Where,

G_{sb} = oven dry bulk specific gravity of RAP aggregate from Eq. 4.1
G_{se} = effective specific gravity of RAP aggregate measured on coated particles
G_b = specific gravity of asphalt binder (assumed to be 1.03)
$P_{b(R)}$ = total RAP asphalt content measured by ignition or extraction methods (%)
$P_{ba(R)}$ = absorbed asphalt in the RAP source by mixture mass (%)
$P_{ba(mix)}$ = absorbed asphalt by mixture mass from the MDOT database (%)
$z_{\alpha/2}$ = statistical coefficient accounting for variability in the prediction of G_{sb}

The prediction method does not require sophisticated inputs, and its correlation is very reasonable. Figure 4.10 provides a visual representation of the prediction ability of Eq. 4.1 within the activities of MDOT; values were computed with $z_{\alpha/2}$ equal to zero. The data in Figure 4.10 is distributed closely and evenly around the line of equality indicating no consistent errors associated with the prediction. A $z_{\alpha/2}$ value of 1.96 representing a 95% confidence level was used to compute the prediction interval band shown in Figure 4.10.

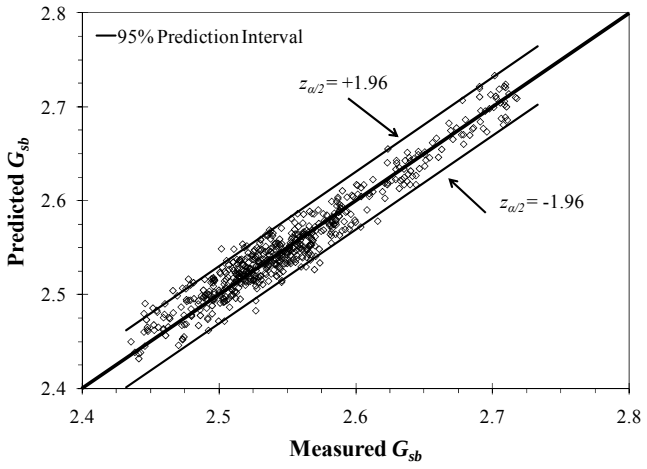


Figure 4.10 Comparison of Measured and Predicted G_{sb}

The uncertainty term in Eq. 4.1 represents variability in the fundamental properties of the asphalt mixtures that cannot be accounted for by any statistically significant and physically meaningful properties that can be readily and reliably measured for RAP in current practice. For practical purposes the 95% prediction interval of Figure 4.10 is equivalent to the single operator repeatability (d2s) index for measurement of G_{sb} on fine

aggregate as given in both *AASHTO T 84* and *ASTM* C 128 (0.031 vs. 0.032). The prediction interval range of 0.031 is slightly wider than the coarse aggregate (d2s) repeatability index of 0.025 given in both *AASHTO T 85* and *ASTM* C 127. Overall the ability of the equation to explain the relationship of G_{se} to G_{sb} is on the order of the accuracy of G_{sb} measurement.

Figure 4.11 provides pertinent data in terms of the increase in G_{se} relative to G_{sb} and how that behavior equates to measured $P_{ba(R)}$ values in the database. Interestingly G_{se} never exceeds G_{sb} by more than 0.10. Based on Figure 4.11 increasing G_{se} by 0.01 corresponds to an approximate increase in $P_{ba(R)}$ of 0.15 to 0.20% indicating small errors in G_{sb} or G_{se} result in considerable errors in $P_{ba(R)}$.

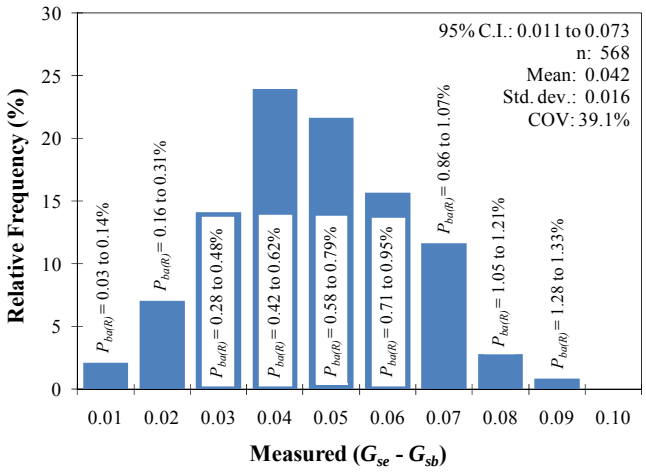


Figure 4.11 Relative Frequency Histogram

The error associated with the Eq. 4.1 prediction can be seen using Figure 4.11 and Figure 4.12. Figure 4.12 plots the data used to develop Eq. 4.1, and shows the best fit trend line (i.e. $z_{\alpha/2} = 0$) and the 95% prediction interval (i.e. $z_{\alpha/2} = \pm 1.96$). The minimum, median, and maximum G_{se} values are 2.485, 2.584, and 2.756 respectively. Using Eq. 4.1 with $z_{\alpha/2}$ of zero, G_{se} minus G_{sb} terms are 0.053, 0.042, 0.023 respectively. As seen in Figure 4.11, Eq. 4.1 does not encompass the 95% confidence interval of measured G_{se} minus G_{sb} which is 0.011 to 0.073. Eq. 4.1 and Eq. 4.2 with $z_{\alpha/2}$ of zero are only capable of predicting $P_{ba(R)}$ of 0.30 to 0.86% while the 95% confidence interval of $P_{ba(R)}$ was 0.13 to 1.13% and the total interval with outliers removed was 0.03 to 1.33%.

Error in the prediction using 95% confidence interval data coupled with the approximate increases of $P_{ba(R)}$ with increases of G_{se} minus G_{sb} results in approximately 0.4% increase in $P_{ba(R)}$ that cannot be explained by the Figure 4.12 trend line. Likewise, approximately 0.25% decrease in $P_{ba(R)}$ cannot be explained by the Figure 4.12 trend line. When error in the prediction is considered the distribution of $P_{ba(R)}$ is fully encompassed. Error of 0.25% below the interval and 0.40% above the interval is not out of line with the differences that would occur in calculation of absorbed asphalt due to measurement error of G_{sb} according to (d2s) limits.

The approach provided in this section is not capable of predicting an exact value of $P_{ba(R)}$, though it can provide a reasonable value and a range that is very unlikely to be exceeded. The approach also bounds the problem and does not allow $P_{ba(R)}$ values to be used that cannot be correct. The next section provides verification information that shows this

approach is reasonable to predict $P_{ba(R)}$ and that the values predicted are better than current practice for many situations. The next section also shows that current practice reports $P_{ba(R)}$ values that are almost certainly incorrect.

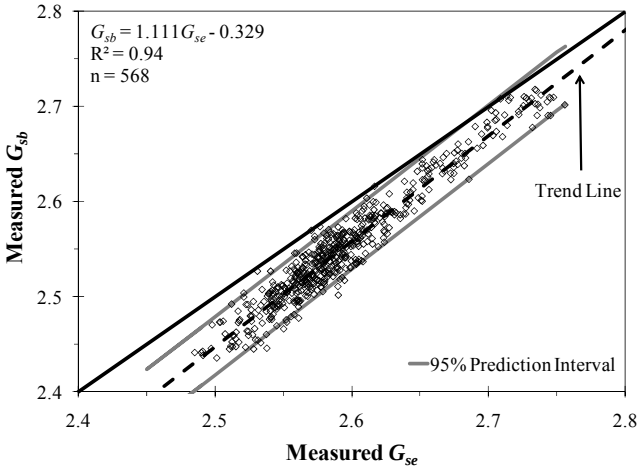


Figure 4.12 Comparison of G_{se} and G_{sb} Values From Database

4.7 Evaluation of RAP Absorbed Asphalt Prediction

The approach developed from the MDOT mixture database for determining G_{sb} and $P_{ba(R)}$ are evaluated in this section. Five RAP sources were used in the evaluation, and the input values and resulting outputs from Eq. 4.1 and 4.2 are provided in Table 4.8. Conventionally measured G_{sb} via *AASHTO T 84* and *T 85* on extracted RAP aggregate was also used to calculate $P_{ba(R)}$ according to standard protocol.

Table 4.8 Evaluation of G_{sb} and $P_{ba(R)}$ Prediction Equations

RAP	G_{se}			Eq. 4.1, 4.2 Predicted[1]			Conventionally Measured	
Source	Type	*n*	Value	G_{sb}	G_{se} - G_{sb}	$P_{ba(R)}$	G_{sb}	$P_{ba(R)}$
R-1	Avg.	48	2.577	2.534	0.043	0.18, 0.64, 1.11	2.483	1.43
	Max	48	2.599	2.559	0.040	0.14, 0.59, 1.05		
	Min	48	2.557	2.512	0.045	0.21, 0.68, 1.16		
R-2	Avg.	6	2.605	2.565	0.040	0.13, 0.58, 1.03	2.526	1.17
	Max	6	2.608	2.569	0.039	0.12, 0.57, 1.03		
	Min	6	2.596	2.555	0.041	0.14, 0.59, 1.06		
R-3	Avg.	14	2.608	2.569	0.039	0.12, 0.57, 1.03	2.504	1.66
	Max	14	2.626	2.589	0.037	0.09, 0.54, 0.99		
	Min	14	2.596	2.555	0.041	0.15, 0.60, 1.06		
R-4	Avg.	2	2.596	2.555	0.041	0.14, 0.59, 1.05	---	---
R-5	Avg.	2	2.620	2.582	0.038	0.10, 0.54, 0.99	---	---

Note: $P_{ba(R)}$ values shown in this table coincide with $P_{be(v)}$ of zero.
1: G_{sb} and G_{se} - G_{sb} values shown are for $z_{\alpha/2}$ of 0 and $P_{ba(R)}$ is for $z_{\alpha/2}$ of -1.96, 0, and 1.96, respectively.

Table 4.8 G_{sb} values differ substantially between Eq. 4.1 and *T 84*, *T 85* measured values, with Eq. 4.1 predicting higher values in all cases. This observation is supported by literature. The G_{sb} values from conventionally measured techniques are very likely too low

based on the database information as $P_{ba(R)}$ values were 1.13% or less for the 95% confidence interval for all Mississippi mixes over the last five years. The likelihood of three RAP sources known to come from Mississippi and known to be from different pavements exceeding the 95% confidence interval while no data was within the 95% confidence interval of such a comprehensive data set is near impossible.

The variability of the method described by Eq. 4.1 and 4.2 can be seen in Table 4.8. *R-1* RAP with average G_{se} values has been used for the purposes of discussion, though the same concept applies to all RAP sources. It should be understood that the most likely $P_{ba(R)}$ with Mississippi materials for G_{se} equal to 2.577 is 0.64% and that values as low as 0.18% and as high as 1.11% are possible but unlikely. In a good number of cases the actual value for a randomly sampled RAP source would be say 0.52% if lower or 0.77% if higher. In a smaller number of cases, the actual value would be say 0.38% if lower or 0.83% if higher. In a fairly small number of cases, the actual value would be say 0.21% if lower or 1.06% if higher. In any instance, the maximum error in the prediction would be either 0.64 minus 0.18, or 0.46% if lower or 1.11 minus 0.64, or 0.47% if higher. The maximum error is not 1.11 minus 0.18, or 0.93%.

The method to predict $P_{ba(R)}$ using G_{se} on RAP coated with virgin binder was shown to be stable using the Table 4.9 data. *R-1* was measured 48 times and the $P_{ba(R)}$ value predicted with $z_{\alpha/2}$ equal to 0 varied at most 0.09%. Figure 4.11 indicated this level of $P_{ba(R)}$ variation could occur with less than 0.01 difference in measurement of G_{se} minus G_{sb}, which is well within between operator precision in standard test protocols.

The G_{se} minus G_{sb} values shown are reasonable when viewed in terms of the relative frequency histogram provided in Figure 4.11. No RAP was tested with G_{se} values in the upper or lower portions of the Figure 4.11 distribution. *R-4* and *R-5* were on hand in the laboratory and used for verification, but upon testing it was observed they too fall in the central portion of the distribution. Ideally dozens of RAP sources could have been obtained throughout Mississippi and tested with the proposed and conventional methods for comparison.

4.8 Effect of Additives and Temperature on RAP Volumetrics

Three-hundred and ninety-four 100% RAP specimens were mixed with virgin binder and compacted according to the procedures described in Section 3.4.2; bulk density and air voids were determined as described in Section 3.5.1. The experimental design is discussed in Section 3.6.2.2. The compaction data is presented in terms of P_{AC} and each data point represents the average of all replicates for that experimental treatment combination.

Results of the *R-1* RAP compaction data at 116 and 138 C are shown in Figure 4.13 organized by compaction temperature and warm mix additive; the raw data can be found in Tables A.6 to A.23. The effect of compactive effort is observed in all cases. As the compactive effort is increased, the air voids generally decrease for a given asphalt binder content. This result is expected in new mixtures and was also observed in the 100% RAP mixtures.

Figure 4.14 presents the *R-1* data for 65 gyrations organized by compaction temperature and warm mix additive. The 154 C compaction temperature raw data is located in Table A.24. For a specific compaction temperature and compactive effort combination the effect of warm mix additives is minimal although minor differences are observable at the 138

C temperature. Note how an increase in compaction temperature noticeably reduces the air voids level for the same asphalt content and combination of compactive effort and warm mix additive. Also note that the lowest total asphalt content (highest contribution of RAP bitumen) in combination with 154 C temperature resulted in air voids near 4%.

Results of the *R-2* RAP compaction data with 65 gyrations are presented in Figure 4.15 organized by compaction temperature; the raw data is presented in Tables A.25 to A.27. The data exhibits similar trends to the *R-1* compaction data. Almost no difference is seen in air voids with the addition of warm mix additives except at the 154 C compaction temperature where Evotherm 3G™ is observed to improve compaction somewhat. Increasing the compaction temperature reduces the air voids. Note that the lowest total asphalt content resulted in air voids near 4% at compaction temperatures of 138 C and 154 C.

Results of the *R-3* RAP compaction data with 65 gyrations are presented in Figure 4.16 organized by compaction temperature. The raw data is presented in Tables A.28 to A.30. The addition of warm mix additives is again seen to have little effect on compaction.

The effects of warm mix additives on *R-1* RAP with 50 and 85 gyrations are observed to be minimal based on Figure 4.17. In general warm mix additives are observed to have very little effect on compaction of 100% RAP. This could be due to the difficulty of mixing small dosage levels of warm mix additives into the thin film of aged RAP bitumen already coating the RAP aggregates.

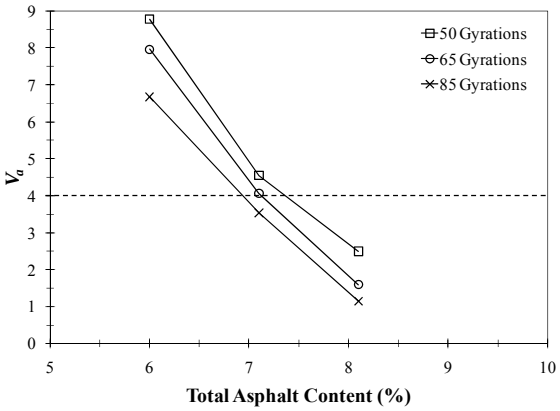
Linear regression was performed using the data in Figures 4.13 through 4.17 using the average V_a values for each of the three total asphalt contents. The results are provided in Table 4.9. For each combination of gyrations, warm mix additive, and compaction temperature, the total asphalt content (P_{AC}) that would produce 4% air voids in a compacted specimen was calculated from the regressions and tabulated in Table 4.9.

In most cases the addition of warm mix additives resulted in small or no changes in the P_{AC} estimates for the combination of RAP mixture and compaction parameters. No consistent trends of either additive with respect to the control were apparent. In some cases Evotherm 3G™ resulted in the lowest P_{AC}, in other cases Sasobit® resulted in the lowest P_{AC}, and in other cases the control treatment resulted in the lowest P_{AC} estimate but the overall the differences were generally small. The average P_{AC} value in Table 4.9 is recommended for use.

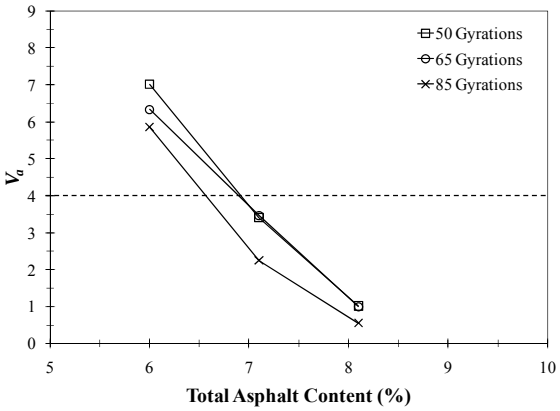
The data in Figures 4.13 through 4.17 is also useful for predicting the effect temperature has on any RAP source. Figure 4.18 illustrates the effect reducing the temperature has on the need for virgin asphalt; 65 gyration data used. The total amount of asphalt needed at 154 C was taken as zero to provide a clearer picture of the additional virgin asphalt demand that could be attributed to temperature reduction. *R-1* had the stiffest binder so it would be expected that more virgin asphalt would be needed as the temperature decreased, which did happen. Interestingly, *R-2* had a higher virgin asphalt demand at 116 C than *R-3*. The key observation is that all three RAP sources were affected by temperature and to different extents. Using RAP in WMA should consider trends of this nature as behaviors at hot mix temperatures (e.g. 154 C) probably won't translate to warm mix temperatures in a consistent fashion over a range of RAP sources.

An extra virgin binder to temperature curve can be generated for a RAP source by compacting eighteen specimens (3 virgin binder contents [0.5%, 1.5%, 2.5%], three temperatures [116, 138, 154 C], and two replicates). For RAP sources available in large quantities, this level of effort would allow much more informed decisions such as whether to

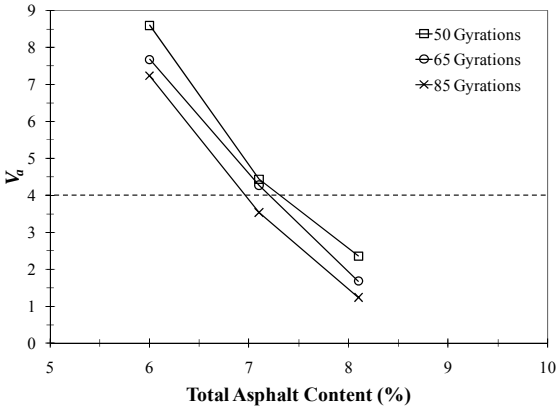
use the material in hot mix or warm mix asphalt. RAP sources that have high extra virgin binder at low temperatures would be more appealing in hot mix asphalt, and vice versa, all other factors being equal.



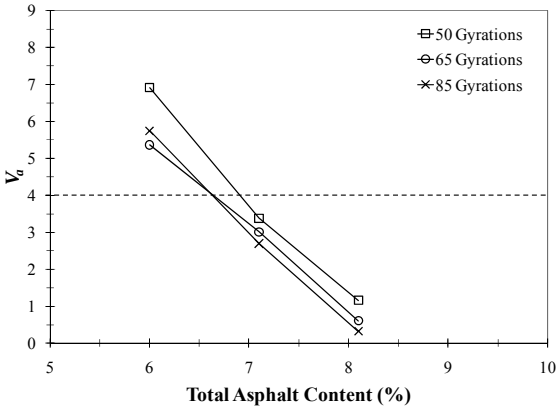
a) 116 C Compaction, No Additive



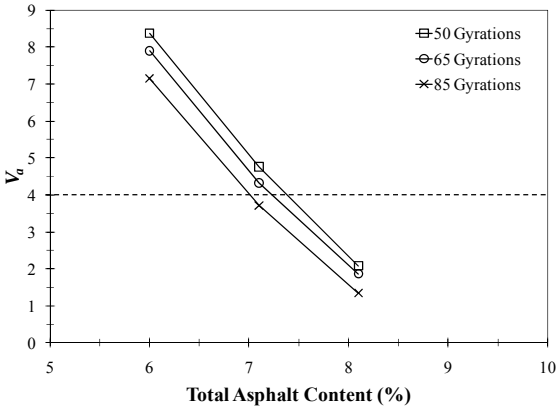
b) 138 C Compaction, No Additive



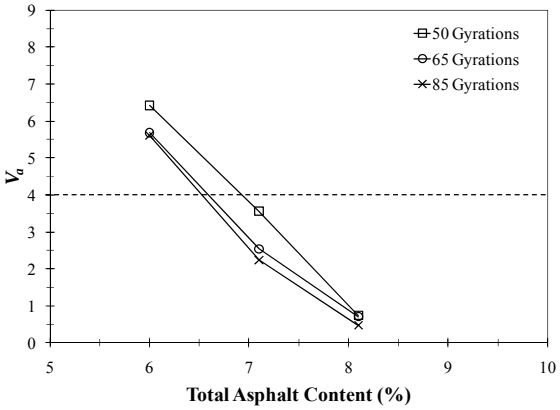
c) 116 C Compaction, Sasobit®



d) 138 C Compaction, Sasobit®

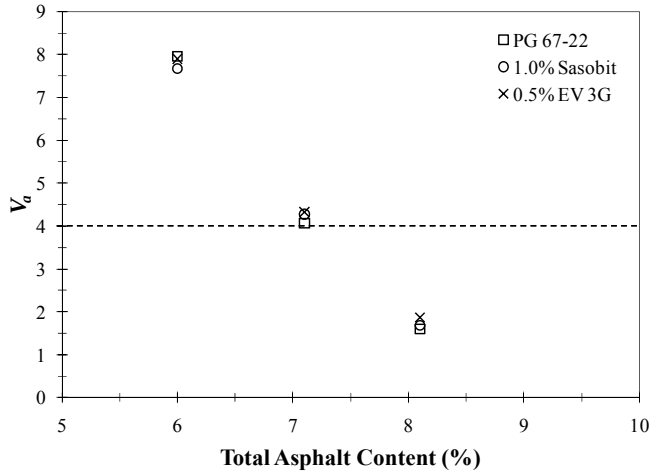


e) 116 C Compaction, Evotherm 3G™

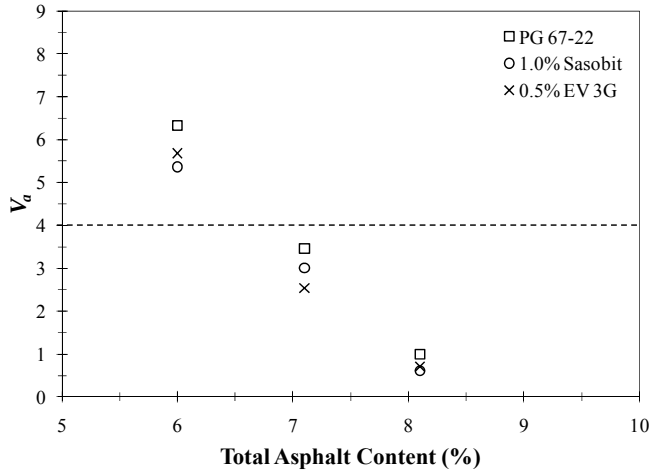


f) 138 C Compaction, Evotherm 3G™

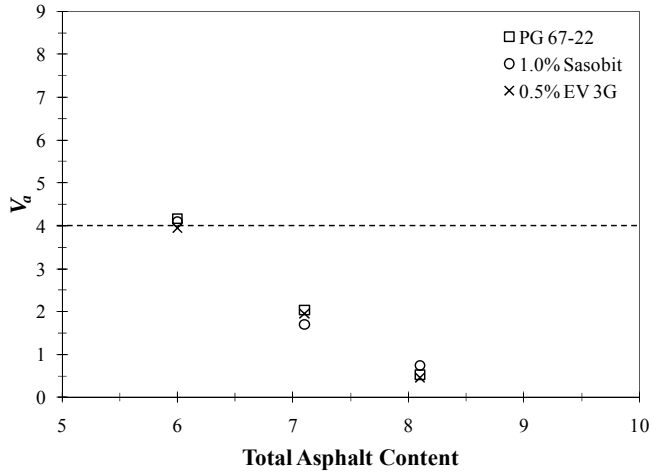
Figure 4.13 Effect of Compaction on *R-1* RAP



a) Compacted at 116 C

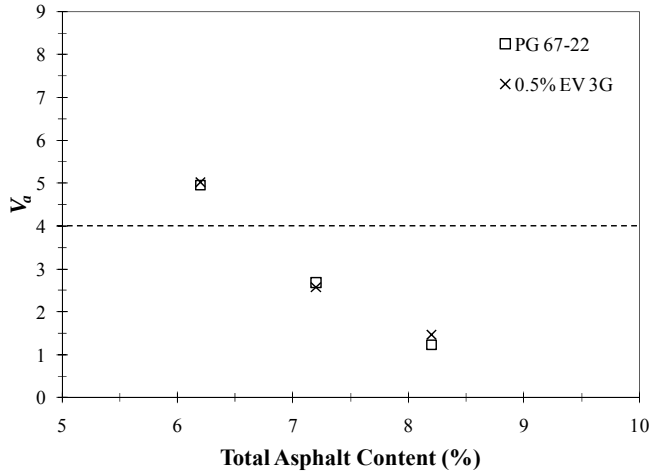


b) Compacted at 138 C

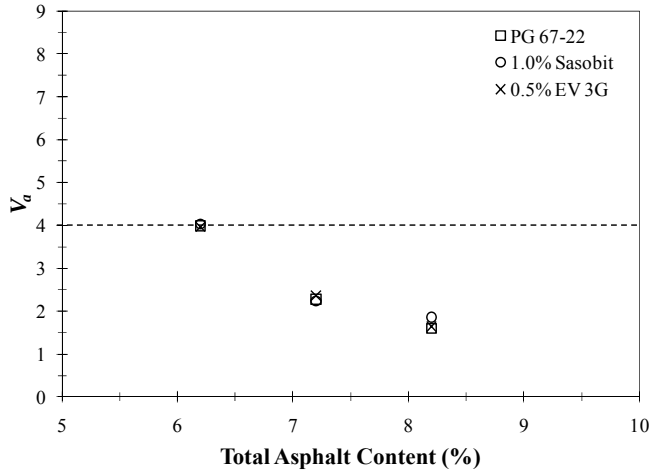


c) Compacted at 154 C

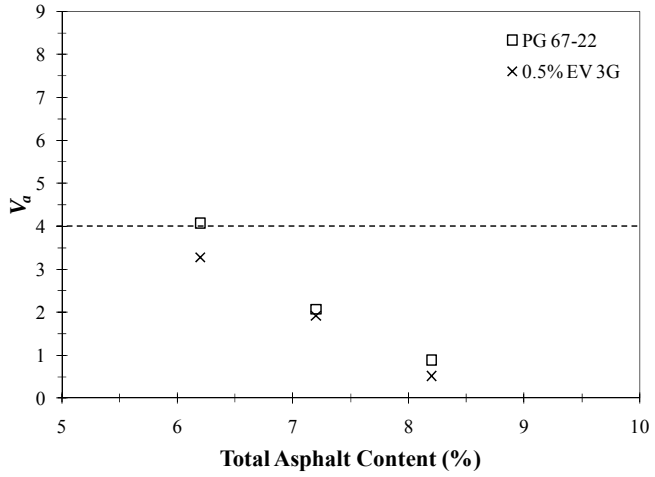
Figure 4.14 Results of *R-1* RAP Compacted to 65 Gyrations



a) Compacted at 116 C

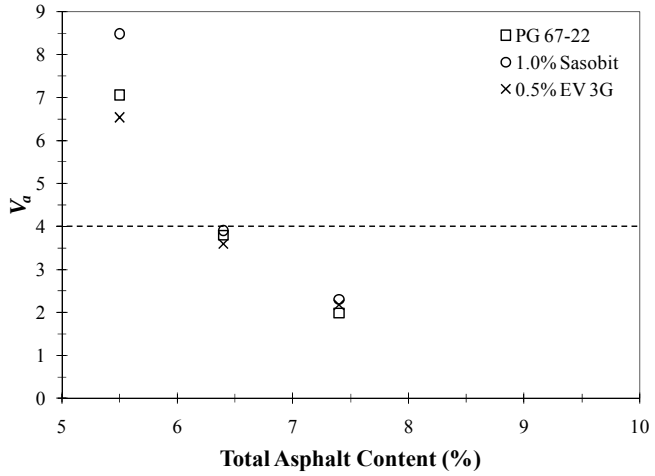


b) Compacted at 138 C

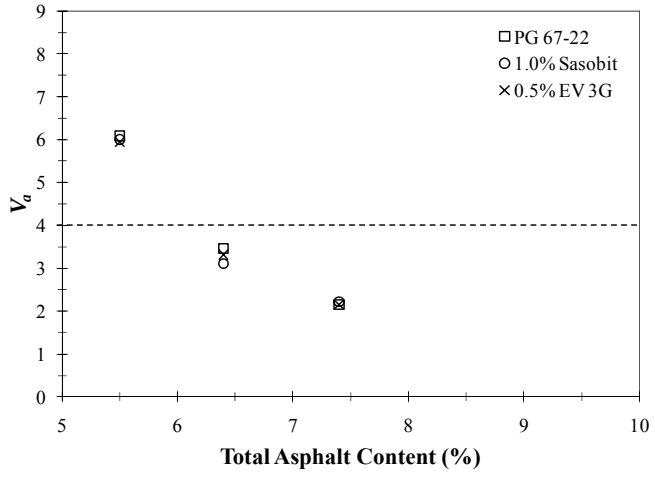


c) Compacted at 154 C

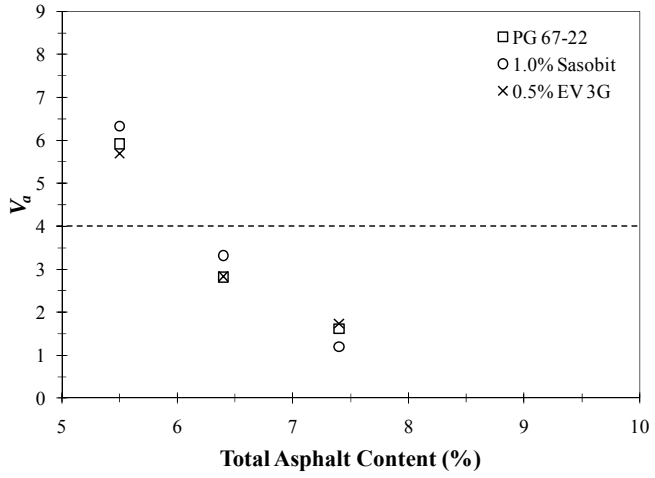
Figure 4.15 Results of *R-2* RAP Compacted to 65 Gyrations



a) Compacted at 116 C

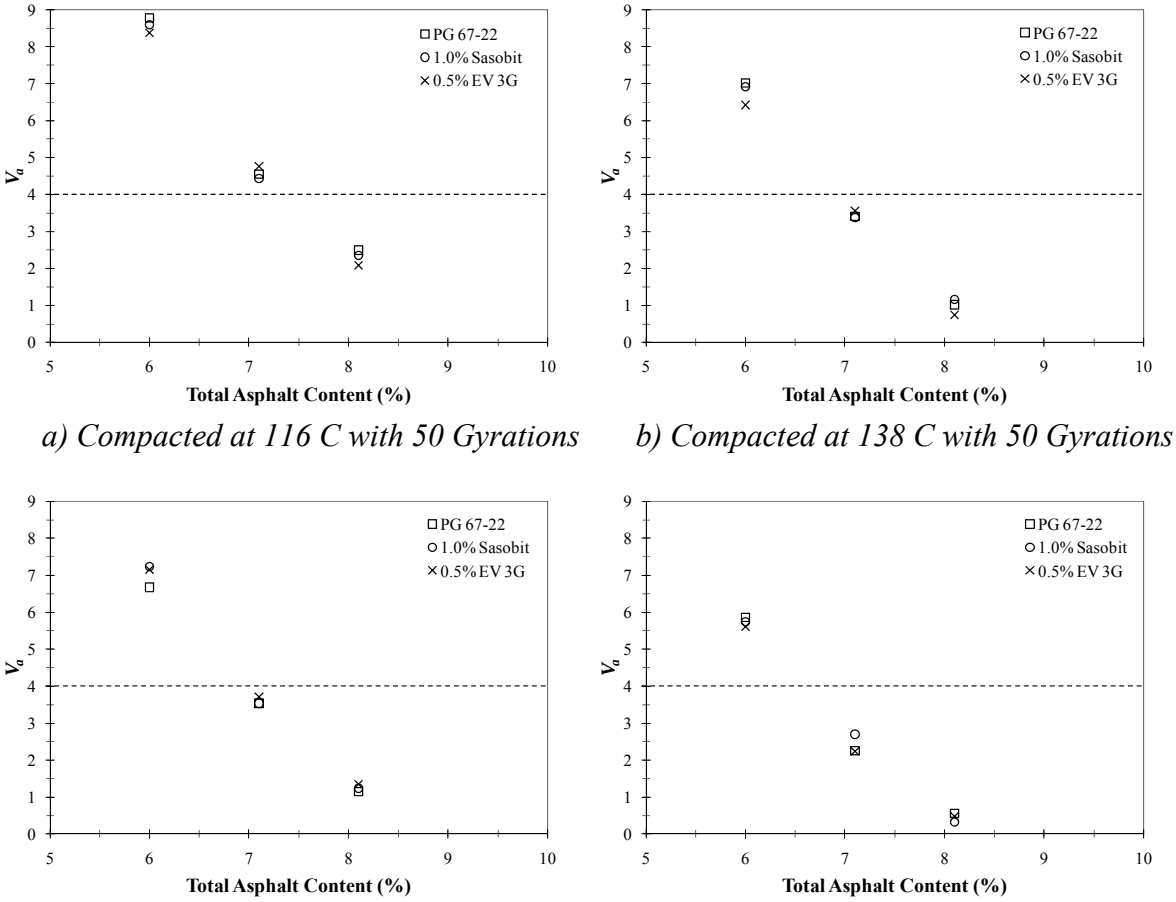


b) Compacted at 138 C



c) Compacted at 154 C

Figure 4.16 Results of *R-3* RAP Compacted to 65 Gyrations



a) Compacted at 116 C with 50 Gyrations *b) Compacted at 138 C with 50 Gyrations*

c) Compacted at 116 C with 85 Gyrations *d) Compacted at 116 C with 85 Gyrations*

Figure 4.17 Results of *R-1* RAP Compacted to 50 and 85 Gyrations

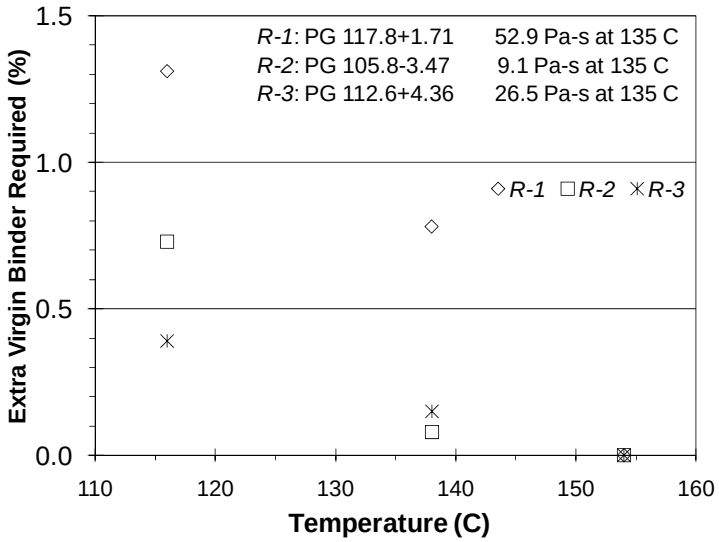


Figure 4.18 Extra Virgin Binder for RAP as a Function of Temperature

Table 4.9 Regression Results From 100% RAP Compacted Testing

RAP ID	Comp Temp (C)	N_{des}	Additive	n	Linear Regression[1] Slope	Intercept	R^2	P_{AC}	Avg. P_{AC}
R-1	116	50	None	18	-3.01	26.5	0.97	7.48	
			Sasobit®	15	-2.99	26.2	0.97	7.42	**7.44**
			Evotherm 3G™	16	-3.00	26.3	0.99	7.43	
		65	None	15	-3.04	26.0	0.99	7.24	
			Sasobit®	16	-2.86	24.7	0.99	7.24	**7.26**
			Evotherm 3G™	15	-2.88	25.0	0.99	7.29	
		85	None	15	-2.63	22.4	0.99	7.00	
			Sasobit®	15	-2.86	24.2	0.99	7.06	**7.04**
			Evotherm 3G™	16	-2.77	23.6	0.99	7.08	
	138	50	None	15	-2.86	24.0	0.99	6.99	
			Sasobit®	17	-2.75	23.2	0.99	6.98	**6.97**
			Evotherm 3G™	16	-2.70	22.7	0.99	6.93	
		65	None	18	-2.54	21.6	0.99	6.93	
			Sasobit®	18	-2.27	19.0	0.99	6.61	**6.73**
			Evotherm 3G™	15	-2.38	19.8	0.99	6.64	
		85	None	16	-2.54	20.8	0.97	6.61	
			Sasobit®	17	-2.59	21.2	0.99	6.64	**6.60**
			Evotherm 3G™	18	-2.46	20.1	0.98	6.54	
	154	65	None	6	-1.74	14.5	0.99	6.03	
			Sasobit®	6	-1.61	13.5	0.95	5.90	**5.95**
			Evotherm 3G™	6	-1.67	13.9	0.99	5.93	
R-2	116	65	None	6	-1.86	16.4	0.98	6.67	**6.67**
			Evotherm 3G™	6	-1.77	15.8	0.95	6.67	
	138	65	None	6	-1.19	11.2	0.94	6.05	
			Sasobit®	6	-1.09	10.5	0.88	5.96	**6.02**
			Evotherm 3G™	6	-1.16	11.0	0.95	6.03	
	154	65	None	6	-1.59	13.8	0.98	6.16	**5.94**
			Evotherm 3G™	3	-1.40	12.0	0.99	5.71	
R-3	116	65	None	6	-2.65	21.4	0.96	6.57	
			Sasobit®	3	-3.22	25.6	0.91	6.71	**6.59**
			Evotherm 3G™	6	-2.28	18.8	0.95	6.49	
	138	65	None	6	-2.05	17.1	0.95	6.39	
			Sasobit®	6	-1.97	16.5	0.90	6.35	**6.35**
			Evotherm 3G™	6	-1.98	16.5	0.94	6.31	
	154	65	None	6	-2.24	17.9	0.92	6.21	
			Sasobit®	3	-2.69	20.8	0.97	6.25	**6.20**
			Evotherm 3G™	6	-2.07	16.7	0.92	6.14	

1: $V_a = m(P_{AC}) + b$

4.9 Prediction of RAP Effective Asphalt

Effective asphalt content is even more problematic than absorbed asphalt content because it is not a constant for a given aggregate blend. Mix design establishes the effective

asphalt content, which for a RAP source is more appropriately referred to as surface asphalt since it may not all be effective in a new mixture. The first step in establishing the amount of effective asphalt contributed by the RAP is to be able to decouple surface and absorbed asphalt, which was demonstrated in Sections 4.6 and 4.7.

Ideally, the second step would be to develop a method that could predict the amount of effective asphalt a new mixture would require knowing the aggregate blend and design compactive effort. The MDOT database was used to develop regression equations to estimate the effective asphalt content for a given aggregate blend and design compactive effort. Near perfect correlations were produced when all predictive factors were included, though this is not of practical usefulness since not all predictive factors are known for RAP. Accurate regression equations could not be developed that utilized only known RAP aggregate and asphalt properties. Coefficients of determination (R^2) for the regression equations developed for effective asphalt with only known predictive factors were on the order of 0.30 to 0.35, which isn't useful.

As an alternative to regression equations for effective asphalt prediction, analysis of RAP surface asphalt was conducted in terms of confidence intervals for effective asphalt at each NMAS and level of compactive effort. Population parameters for effective asphalt were determined from the mixture dataset that are provided in Table 4.10. A normal population distribution provided a good fit of the data in most cases. In two cases a few data points were removed to improve the quality of the fit; these cases are described in the Table 4.10 notes. The normal distribution provided a very poor fit for the ST 19.0 mm NMAS data subset. The poor fit was caused by the existence of two groups of data in the distribution and not by a few extreme values. The mean and standard deviation of the ST 19.0 mm NMAS data subset are included in Table 4.10 but should be used with caution.

Table 4.10 Effective Asphalt Population Distributions from Database

	Traffic			Range		Normal Distribution		
NMAS	Level	N_{des}	n	Max	Min	Fit	μ	σ
9.5 mm	HT	85	80	5.57	4.69	Good	5.110	0.1639
	MT	65	75	5.74	4.69	Good	5.238	0.2241
	ST	50	73	6.07	4.83	Good	5.323	0.2751
12.5 mm	HT	85	73	5.11	4.27	Good	4.644	0.1533
	MT	65	45	5.13	4.28	Good[1]	4.696	0.1736
	ST	50	45	5.34	4.36	Excellent	4.844	0.2482
19.0 mm	HT	85	63	4.36	3.80	Good[2]	4.092	0.1285
	MT	65	54	4.81	3.80	Good	4.223	0.2532
	ST	50	51	5.07	3.97	Very Poor	4.313	0.2885

1) Four data points were removed from the MT 12.5 mm NMAS data subset to provide a better fit of the normal probability distribution. The mean value for the data subset was reduced from 4.725 to 4.696 and the standard deviation was reduced from 0.2512 to 0.1736 by this action.

2) Five data points were removed from the HT 19.0 mm NMAS data subset to provide a better fit of the normal probability distribution. The mean value for the data subset was reduced from 4.132 to 4.092 and the standard deviation was reduced from 0.2013 to 0.1285 by this action.

A statistical approach was developed with Table 4.10 as the basis to estimate the amount of RAP surface asphalt that is effective under particular conditions. This approach does not provide a precise estimate of RAP effective asphalt content but it does bound the upper and lower limits of the solution; Figure 4.19 illustrates the approach. For particular

combinations of NMAS and level of design compactive effort, the populations of effective asphalt for new mixtures from the MDOT database were assigned normal probability distributions. With the normal population distribution parameters of mean and standard deviation, a 95% confidence interval (C.I.) was constructed for the distribution of effective asphalt contents (Figure 4.19). The upper and lower limits of the confidence interval represent the expected maximum and minimum effective asphalt content possible for a new mixture of a particular type.

The total amount of surface asphalt in the RAP is defined by Eq. 4.3, where all terms are defined in Figure 4.2. For a given aggregate structure and design compactive effort the amount of effective asphalt can be bounded using Eq. 4.4 using inputs from Table 4.10. The assumption is made that the grade of virgin binder does not appreciably affect compaction characteristics of the aggregate blend; this assumption may not be without consequence but it is routinely made in current practice (e.g. substituting PG 76-22 for PG 67-22 for the same aggregate blend and compactive effort without changing the asphalt content). This assumption allows one to take the distribution of effective asphalt in the database and use the information to make qualitative assessments of RAP surface binder characteristics.

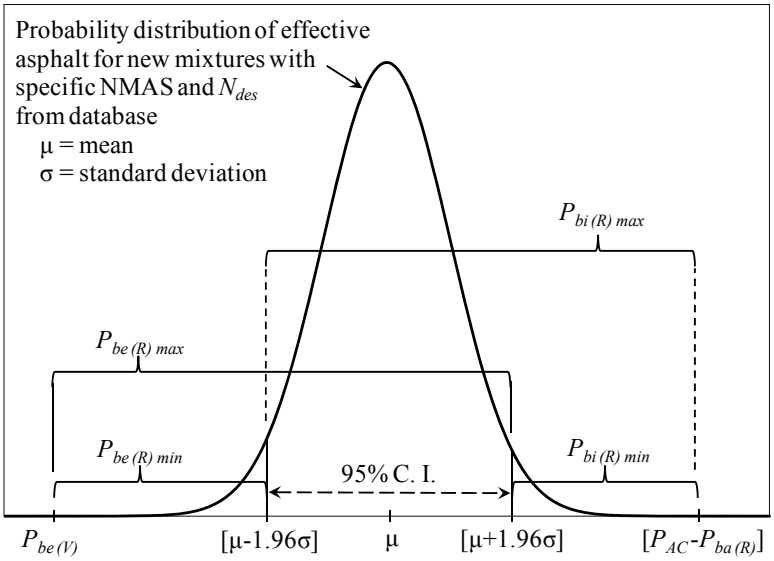


Figure 4.19 Estimation of $P_{be(R)}$ Range

$$P_{bs(R)} = P_{AC} - P_{ba(R)} - P_{be(V)} \tag{4.3}$$

$$P_{be\min,\max} = \mu \pm 1.96(\sigma) \tag{4.4}$$

The amount of effective asphalt in the RAP can be bounded by utilizing Eq. 4.4 and knowing the amount of effective virgin binder added to the RAP source to achieve adequate compaction; the result is Eq. 4.5. By having an estimate of the total RAP surface asphalt from Eq. 4.3 and the boundaries of the effective RAP surface asphalt from Eq. 4.5, the amount of ineffective RAP surface asphalt can also be bounded as shown in Eq. 4.6.

$$P_{be(R)\min,\max} = \left[\mu \pm 1.96(\sigma)\right] - P_{be(V)} \quad (4.5)$$

$$P_{bi(R)\min,\max} = P_{bs(R)} - P_{be(R)\min,\max} \quad (4.6)$$

Prior to using these equations it should be understood that minimum values can be calculated to be negative and those cases should be interpreted as zero. Negative values can occur because distributions are part of the calculations. An example of a condition that would lead to a negative value is a RAP source with a relatively high total asphalt content where nearly all of the surface asphalt is effective.

4.10 Evaluation of RAP Effective Asphalt Prediction

Estimates of $P_{ba(R)}$ determined in Table 4.8 with average G_{se} values and $z_{\alpha/2}$ of zero, effective asphalt population parameters from Table 4.10, and average estimated P_{AC} values determined in Table 4.9 were used to calculate ranges of $P_{be(R)}$ and $P_{bi(R)}$. Results are given in Table 4.11 for each combination of RAP source, compaction temperature, and compactive effort. The $P_{bs(R)}$ values given in Table 4.11 for each RAP source increase slightly as $P_{be(V)}$ decreases because all terms are defined on a mixture mass basis; the mass of RAP surface asphalt does not change. The Table 4.11 data shows that some of the RAP surface asphalt is very likely ineffective in some conditions and that the behavior is condition dependent.

Table 4.11 Summary of RAP Effective Asphalt Calculations

RAP	Compaction					Range of $P_{be\ (R)}$		Range of $P_{bi\ (R)}$	
ID	Temp (C)	N_{des}	P_{AC}	$P_{be(V)}$	$P_{bs(R)}$	Min	Max	Min	Max
R-1	116	50	7.44	2.05	4.76	2.73	3.81	0.95	2.03
		65	7.26	1.86	4.77	2.94	3.82	0.95	1.83
		85	7.04	1.63	4.78	3.16	3.80	0.98	1.62
	138	50	6.97	1.56	4.78	3.22	4.30	0.48	1.56
		65	6.73	1.30	4.80	3.50	4.38	0.42	1.30
		85	6.60	1.16	4.81	3.63	4.27	0.54	1.18
	154	65	5.95	0.48	4.83	4.32	5.20	0.00	0.51
R-2	116	65	6.67	1.13	4.97	3.67	4.55	0.42	1.30
	138	65	6.02	0.44	5.00	4.36	5.24	0.00	0.64
	154	65	5.94	0.36	5.00	4.44	5.32	0.00	0.56
R-3	116	65	6.59	1.67	4.36	2.69	3.37	0.99	1.67
	138	65	6.35	1.42	4.37	2.94	3.62	0.75	1.43
	154	65	6.20	1.26	4.38	3.10	3.78	0.60	1.28

It should be understood that the maximum and minimum values of $P_{be(R)}$ and $P_{bi(R)}$ given in Table 4.11 estimate the range of possible values with a 95% level of confidence but that there is a fairly high probability that the actual value is near the middle of the range. For example, *R-1* at 116 C and 50 gyrations has a range of 2.73 to 3.81% for $P_{be(R)}$ but the actual value is fairly likely to be between 3.0 and 3.5%. Likewise the range of $P_{be(R)}$ is 0.95 to 2.03 but the actual value is fairly likely to be between 1.2 and 1.8%. For a particular level of compactive effort both the minimum and maximum estimates of $P_{be(R)}$ increase as the

compaction temperature is increased indicating that a greater proportion of RAP asphalt is contributing to compaction as the temperature increases.

R-1 had a considerable amount of ineffective surface asphalt at 116 C, though no ineffective asphalt could be detected at 154 C. *R-2* had a moderate amount of ineffective asphalt at 116 C, though no ineffective asphalt could be detected at 138 or 154 C. *R-3* showed ineffective surface asphalt at all temperatures, which was somewhat surprising relative to *R-1* and *R-2*. *R-3* had the lowest RAP asphalt content and its binder properties were intermediate compared to *R-1* and *R-3*. A likely cause of the differing behavior for *R-3* is that it is a multiple source sample so the Table 4.10 12.5 mm NMAS population parameters may not be applicable as the material could be a combination of different mixtures which would affect the effective asphalt content. Additionally, the gradation of a multiple source sample wouldn't necessarily be representative, which is evidenced by the gradation of *R-3* (e.g. sand ratio of 71).

The analysis presented in this section has shown the database approach to evaluating RAP surface asphalt has some appealing characteristics, but that it also has some limitations. Estimates of this nature are valuable for determining the best use of any given RAP source. They also provide estimates of effective RAP asphalt that haven't been available in literature. Limitations are described in the following paragraphs.

The approach appears to work reasonably well for single source RAP samples (i.e. *R-1* and *R-2*) in terms of the ability to estimate the amount of effective and ineffective surface asphalt and to characterize the effect of temperature on the RAP surface asphalt. Based on the data available, the effectiveness of the approach to estimate effective and ineffective surface asphalt for a multiple source RAP sample (i.e. *R-3*) is questionable, though the approach was able to capture the effect of temperature on the multiple source sample. At present, it is not recommended to use the effective asphalt estimation approach in this section unless the RAP sample was obtained from a single source.

Another limitation to the database approach is that gradation changes due to milling are not represented in a direct manner. The fines content of RAP exceeds that of new mixtures (Figure 4.5a and 4.6c). Gradation changes prevent the Table 4.9 distributions from fully representing the distribution of RAP properties.

4.11 Summary of RAP Characterization

Test data was presented in this chapter that provided means to characterize RAP in the context of its temperature dependency. Testing eighteen compacted 100% RAP specimens using the method presented could provide the effect temperature has on virgin binder demand. Test data also showed that RAP does not absorb additional virgin binder and that measurement of G_{se} on RAP coated with virgin binder is an effective approach.

Use of conventionally measured G_{sb} values for extracted RAP aggregate to calculate absorbed RAP asphalt was shown to yield values that were almost certainly incorrect for the RAP sources evaluated. An approach was developed to estimate $P_{ba(R)}$ of Mississippi RAP sources that does not require measurement of G_{sb} on extracted RAP aggregate. The approach cannot pick exact values but does result in estimates of $P_{ba(R)}$ believed to be more reasonable than current practice in certain situations. Use of a large data set encompassing all agency activities for a period of more than five years makes this approach unique. The methodology should be easily implementable by any state DOT or governing entity since the effort to sort

the historical data and use it to develop regression equations is reasonable and this chapter can be used as a guide.

The relative effectiveness of RAP surface asphalt was evaluated for a variety of compaction conditions. The approach coupled distributions of effective asphalt contents in Mississippi determined from the data set of recent historical practice with compaction of RAP with added virgin binder. Effective binder replacement is believed to be a better way to view RAP than total binder replacement and the approach utilized herein allowed for estimation of amounts of effective binder for RAP to be made at varying compaction conditions. The estimates of effective RAP binder are not without flaws but they appear to be a reasonable technique to address a major problem with the use of RAP in high quantities.

CHAPTER 5 – 0 and 15% RAP CONTROL MIXTURE RESULTS

5.1 Overview of 0 and 15% RAP Control Mixture Results

This chapter presents results of testing 0 and 15% RAP control mixtures, as described in Tables 3.4 and 3.5. The chapter is organized by category of mixture performance with subsections for each test method. The data in this chapter is used as a reference for the data in Chapters 6 and 7, and the discussion of all three chapters is provided in Chapter 8.

5.2 Cantabro Durability Data

5.2.1 Testing of Single Aggregate Blend

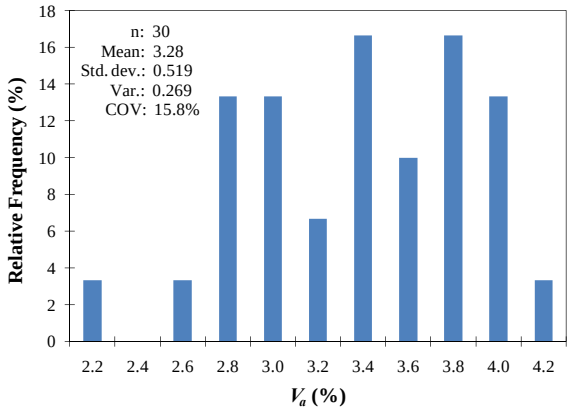
To investigate variability of the Cantabro test method, three sets of thirty plant mixed QC specimens were tested: 1) *9.5-15/CM-6* un-aged; 2) *9.5-15/CM-6* aged according to *R-30*; and 3) *9.5-15/CM-7* un-aged. All specimens were tested for G_{mb} before aging, and the mix design G_{mm} was used to calculate air voids. The mixtures had identical aggregate blends from the same asphalt plant, and the only difference was the design compactive effort (*9.5-15/CM-6* was 50 gyrations and *9.5-15/CM-7* was 65 gyrations) which caused the design asphalt contents to differ by 0.2%. Raw data is located in Tables C.12 to C.14.

Figure 5.1 presents relative frequency histogram results for air voids and mass loss. To evaluate the mass loss effects due to minor variation in design asphalt content an un-equal variance *t*-test was performed on the data for un-aged mixtures *9.5-15/CM-6* and *9.5-15/CM-7* (Table 5.1). The analysis indicated no significant difference in mean mass loss between the two mixtures. To evaluate the effects of aging on mass loss an un-equal variance *t*-test was performed on the data for mixture *9.5-15/CM-6*. The analysis indicated a significant difference in mean mass loss due to *R-30* aging (Table 5.1). *R-30* aging was chosen in favor of *MT-85* aging after testing three replicates of *9.5-15/CM-6* with both protocols and observing a higher mass loss with *R-30* (10.5% loss) than with *MT-85* (9.6% loss).

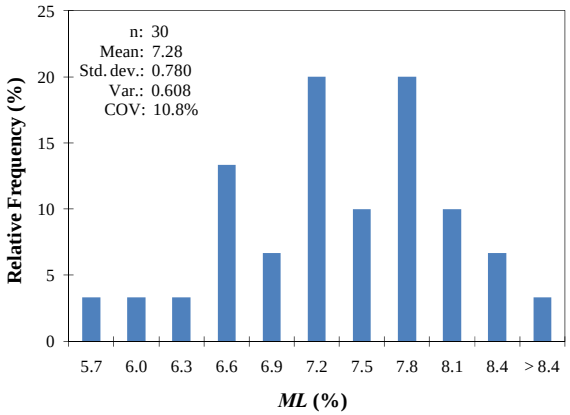
The data collected seems to indicate variation in air voids even within a moderate range affects mass loss. In Figure 5.1, lower variation in air voids corresponded with lower variation in mass loss for all three sets of specimens as evidenced by the COV data presented. Specimens with lower air voids have correspondingly higher VFA for given mixture proportions which would seem to result in a specimen that is more resistant to mass loss. Figure 5.2 plots mass loss and air voids for the three thirty specimen sets. The linear regression equations show at least some correlation of decreased mass loss for decreasing specimen air voids. The slope of the equation for the aged specimen set is higher than for the un-aged specimen sets. This is reasonable since specimens with higher air voids have greater potential exposure to oxygen during the oven aging period resulting in greater binder aging and a more brittle mixture with subsequent higher mass loss.

One source of variation for specimens from the three sets tested could be the normal variation of plant produced mixture throughout the paving season. Differences in gradation and asphalt content could explain some of the variability as they would also change the air voids. Interpretation of Cantabro results presented in this report should be tempered by the observation that air voids and mass loss are collinear to some extent. A test plan that

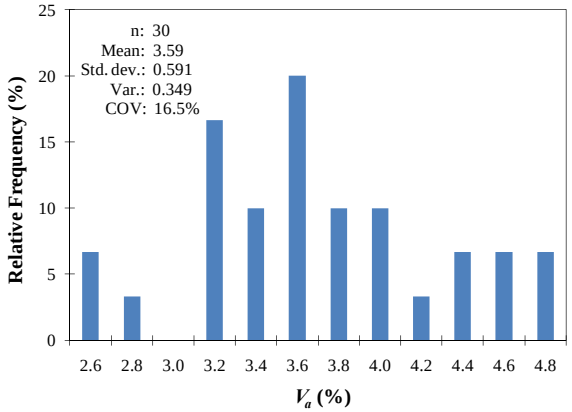
investigates mass loss at a constant level of air voids is needed to make more detailed statements.



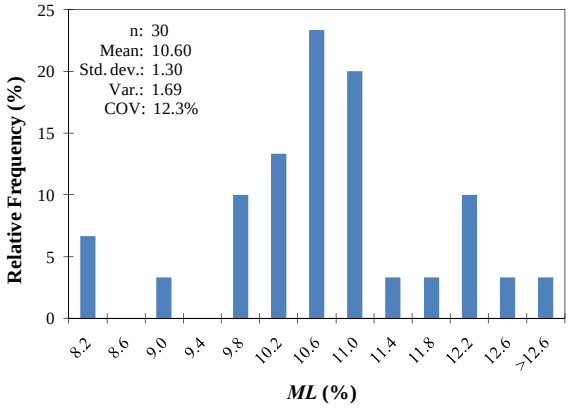
a) 9.5-15/CM-6 Un-aged



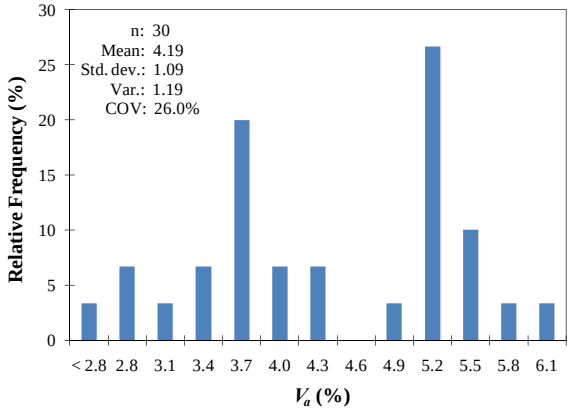
b) 9.5-15/CM-6 Un-aged



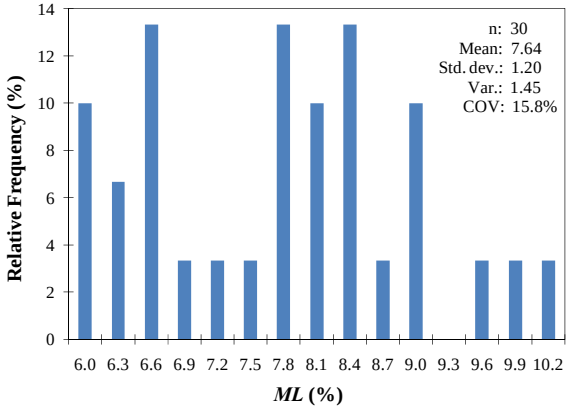
c) 9.5-15/CM-6 R-30 Aged



d) 9.5-15/CM-6 R-30 Aged



e) 9.5-15/CM-7 Un-aged



f) 9.5-15/CM-7 Un-aged

Figure 5.1 Relative Frequency Histograms of Air Voids and Mass Loss

Table 5.1 Un-Equal Variance *t*-test Test Comparisons of Mass Loss Results

Condition	Mixture ID	*n*	Mean	Var.	*t*-stat	*t*-crit	Significantly Different?
Un-aged	*9.5-15/CM-6*	30	7.23	0.608	0.122	±2.01	No
Un-aged	*9.5-15/CM-7*	30	7.64	1.450			
Un-aged	*9.5-15/CM-6*	30	7.23	0.583	-12.3	±2.01	Yes
R-30	*9.5-15/CM-6*	30	10.60	1.680			

Note: Significance testing performed at the 95% confidence level.

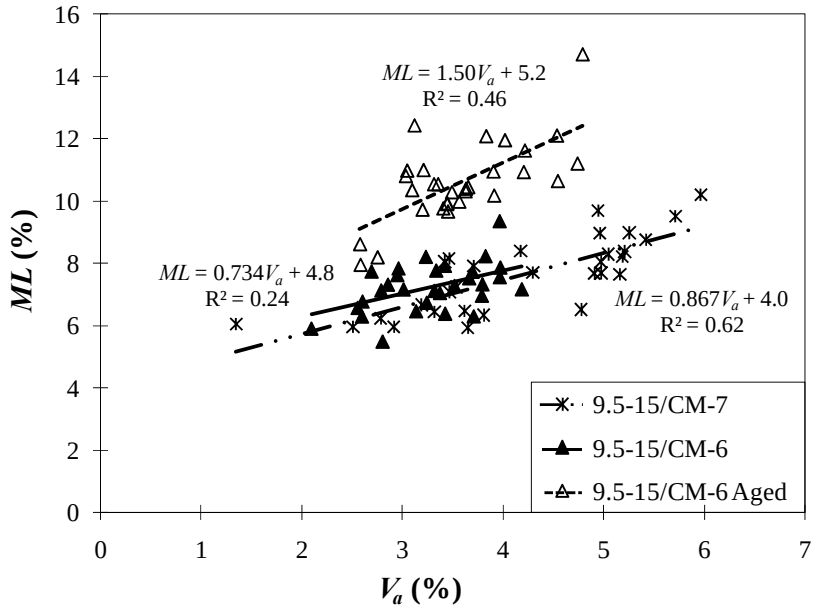


Figure 5.2 Correlation of Air Voids and Mass Loss

5.2.2 Testing of Random QA Specimens

To establish a range of durability results for conventional 9.5 mm dense-graded Mississippi mixtures, plant mixed QA specimens were tested from twenty two mixtures. Basic mixture properties are provided in Table 3.5 with raw data provided in Tables C.15 and C.16. The range of mean mass loss for the dense-graded asphalt mixtures presented in Table 5.2 is 2.8 to 11.7%. The mixture with the highest mass loss (*9.5-0/CM-25*) also had the highest air voids. A linear regression relating air voids to mass loss is provided in the notes of Table 5.2; the correlation is noticeable but is not strong. Figure 5.3 plots the Table 5.2 data sorted by binder grade. In general, specimens with higher air voids have higher mass loss. No specific trends are observed for PG 76-22 binder compared to PG 67-22 binder.

A stepwise multiple linear regression was performed with the data to relate mixture parameters to mass loss. Fifteen parameters were considered during the regression: 1) compactive effort (design gyrations): 2) total asphalt content (P_b); 3) effective asphalt content; 4) absorbed asphalt content; 5) mean air voids; 6) voids in mineral aggregate; 7) voids filled with asphalt; 8) film thickness; 9) dust to effective binder ratio; 10) percentage of gravel aggregate; 11) percentage of limestone aggregate; 12) percentage of sand aggregate; 13) percentage of RAP; 14) sand ratio of the aggregate blend (*SR*) commonly known as "hump" ratio; and 15) surface area of the aggregate blend. The best regression equation is given in the notes of Table 5.2, which is reasonable for the data available.

Table 5.2 Mass Loss Results for Control Mixtures 8 to 29

Mixture ID	P_b (%)	Gravel (%)	*SR*	*n*	Avg. V_a (%)	Avg. *ML* (%)
9.5-15/CM-8	5.4	29	40.7	2	3.3	7.3
9.5-15/CM-9	5.1	29	37.9	2	4.3	2.8
9.5-10/CM-10	5.5	79	43	4	4.6	8.2
9.5-15/CM-11	5.5	50	40.4	2	4.5	7.2
9.5-15/CM-12	6.2	40	42.9	4	4.1	7.6
9.5-15/CM-13	5.4	76	40.6	2	3.4	7.2
9.5-15/CM-14	5.8	45	40.9	2	4.1	6.0
9.5-15/CM-15	5.5	61	38.7	2	4.5	5.3
9.5-15/CM-16	6.0	68	49.8	2	4.4	10.5
9.5-15/CM-17	6.1	37	43.5	2	5.9	10.6
9.5-15/CM-18	5.6	52	39.3	2	4.6	8.5
9.5-15/CM-19	5.3	50	37.4	2	4.2	5.2
9.5-15/CM-20	5.5	31	38.4	2	3.5	5.4
9.5-15/CM-21	6.4	40	42.9	2	2.3	3.9
9.5-10/CM-22	5.7	34	53.0	2	4.8	6.8
9.5-15/CM-23	5.8	74	46.5	2	4.4	10.7
9.5-0/CM-24	5.8	40	46.3	2	7.1	11.7
9.5-10/CM-25	5.6	64	41.4	2	4.1	9.4
9.5-10/CM-26	5.4	29	42.6	2	3.1	4.8
9.5-6/CM-27	5.3	28	42.2	8	4.6	7.6
9.5-10/CM-28	6.4	37	43.5	4	6.2	10.7
9.5-10/CM-29	5.2	49	43.1	2	5.8	6.6

Note: $ML = 1.44V_a + 1.06$ with $R^2 = 0.46$ and n = 22

$ML = -15.2+1.10V_a+1.63P_b+0.0408$ (Gravel %)$+0.157SR$ with $R^2 = 0.64$ and n = 22

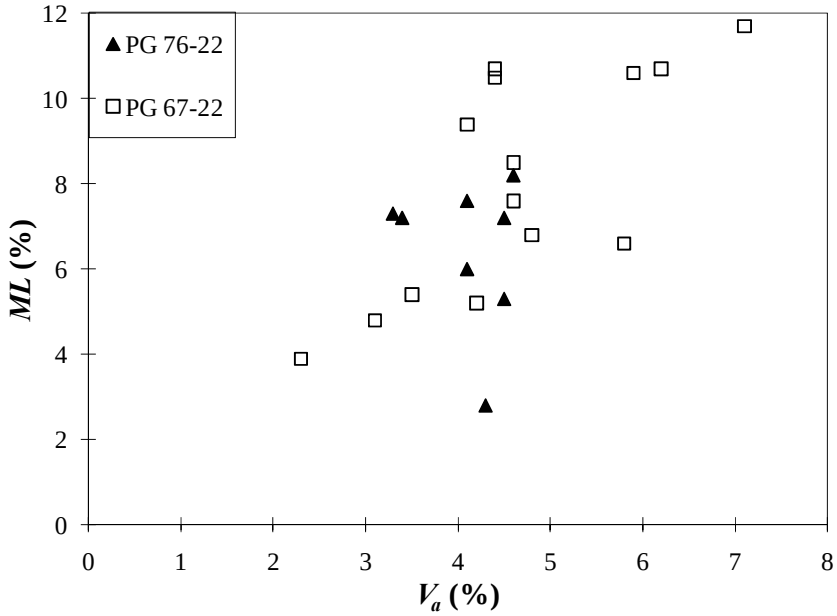


Figure 5.3 Correlation of Mass Loss and Air Voids for Mississippi Mixtures

5.2.3 Testing of Specific Control Mixtures

The control mixtures used as a comparison for several other properties throughout the report were tested and results are provided in this section. Testing was performed as described in Section 3.5.4. Raw data is located in Tables C.8 to C.11.

Table 5.3 provides un-aged mass loss results, which ranged from 4.7 to 11.8%. Large replicate testing shown in Section 5.2.1 resulted in mass loss values within this range for un-aged testing of 7.3 and 7.6%. The 0% RAP mixture had higher mass loss than most of the 15% RAP mixtures; conventional wisdom would predict a mixture without RAP would have lower mass loss than mixtures with 15% RAP. A variety of factors including mixture composition could explain the behavior. The 0% RAP control mixture had a dust to effective binder ratio of 1.7 (above recommended tolerances) whereas the other control mixtures are 1.0 to 1.2. The 0% RAP mixture results could be due to the high dust content. The lowest mass loss was observed for the plant-warm-mixed PG 76-22 mixture (*9.5-15/CM-3*).

Table 5.3 Cantabro Data for Un-Aged Control Mixtures

Mixture ID	*n*	Avg. Air Voids (%)	Avg. *ML* (%)
9.5-0/CM-1	5	5.0	11.5
9.5-15/CM-2	5	5.9	8.0
9.5-15/CM-3	5	3.0	4.7
9.5-15/CM-4a	5	7.5	11.8
9.5-15/CM-4b	5	6.0	11.0
9.5-15/CM-4c	3	5.4	9.9

Table 5.4 provides aged mass loss results, which ranged from 7.6 to 10.6%. Large replicate testing shown in Section 5.2.1 resulted in mass loss values within this range for aged testing of 10.6%. Aging with *R-30* produced greater mass loss for *9.5-15/CM-2* and the same mass loss for *9.5-15/CM-3* when compared to *MT-85*. *R-30* aging produced greater mass loss in Section 5.2.1 when compared to *MT-85*.

Table 5.4 Cantabro Data for Aged Control Mixtures

Mixture ID	Aging Protocol	*n*	Avg. Air Voids (%)	Avg. *ML* (%)
9.5-15/CM-2	*R-30*	3	5.7	10.6
	MT-85	3	6.1	9.5
9.5-15/CM-3	*R-30*	3	2.8	7.6
	MT-85	3	3.0	7.6

Table 5.5 presents un-equal variance *t*-tests of mass loss differences between aging protocols and between aged and un-aged testing. The *R-30* aging protocol resulted in higher mass loss than the *MT-85* aging protocol but the difference was only statistically significant with *9.5-15/CM-2*. Results indicate aged specimens from either aging protocol exhibited significantly higher mass loss than the un-aged specimens for a comparable level of air voids. In general, aged specimens exhibited mass loss on the order of 2 to 4% higher than un-aged specimens of the same mixture.

Table 5.5 Un-Equal Variance *t*-test Test Comparisons of Mass Loss Results

Mixture ID	Condition	*n*	Mean	Var.	*t*-stat	*t*-crit	Significantly Different?
9.5-15/CM-2	*MT-85*	3	9.47	0.013	6.88	±3.18	Yes
	R-30	3	10.60	0.063			
	Un-aged	5	8.02	0.752	-3.68	±2.78	Yes
	MT-85	3	9.47	0.013			
	Un-aged	5	8.02	0.752	-6.15	±2.57	Yes
	R-30	3	10.06	0.063			
9.5-15/CM-3	*MT-85*	3	7.57	0.243	0.07	±2.78	No
	R-30	3	7.60	0.430			
	Un-aged	5	4.66	0.488	-6.88	±2.45	Yes
	MT-85	3	7.57	0.243			
	Un-aged	5	4.66	0.488	-5.99	±2.57	Yes
	R-30	3	7.60	0.430			

Note: Significance testing performed at the 95% confidence level.

5.3 *BBR* Data

Prior to full analysis, data from the *BBR* mixture testing was evaluated for reasonableness and outliers. Reasonableness was evaluated by two checks: 1) deflection of the mixture beam increased (and the corresponding calculated stiffness decreased) over the entire duration of the test: and 2) the slope of the stiffness curve increased over the entire duration of the test (concept identified in literature review). Any data points that failed the two checks was omitted from analysis (very small percentage of the data).

Occasional outliers were observed in the *BBR* data that passed the reasonableness checks where the stiffness was less than half that of other replicates of the same mixture and were not representative of the mixture. Information found during literature review revealed that when mixture beams are sawn from a compacted asphalt specimen, the orientation of aggregate particles is essentially random and in most cases a representative cross section of the asphalt mixture is obtained in a sawn mixture beam. However in some cases the mastic film between aggregates may be oriented in such as way that it in a localized area a large portion of the beam cross-section is composed of the mastic film. This results in a reduction in the measured stiffness of the beam compared to a beam of representative cross-section.

A consistent method to identify these occurrences of mixture stiffness data well below other replicate measurements for the mixture was used. For cases where five replicates were tested, if the standard deviation of stiffness measured at 60 seconds was higher than 4.0 then the data point which was farthest from the mean value for the mix (i.e. very low stiffness) was removed. For cases where three replicates were tested, a cutoff value for standard deviation of 5.0 was used to perform the same data evaluation. All remaining replicates were averaged and used for analysis.

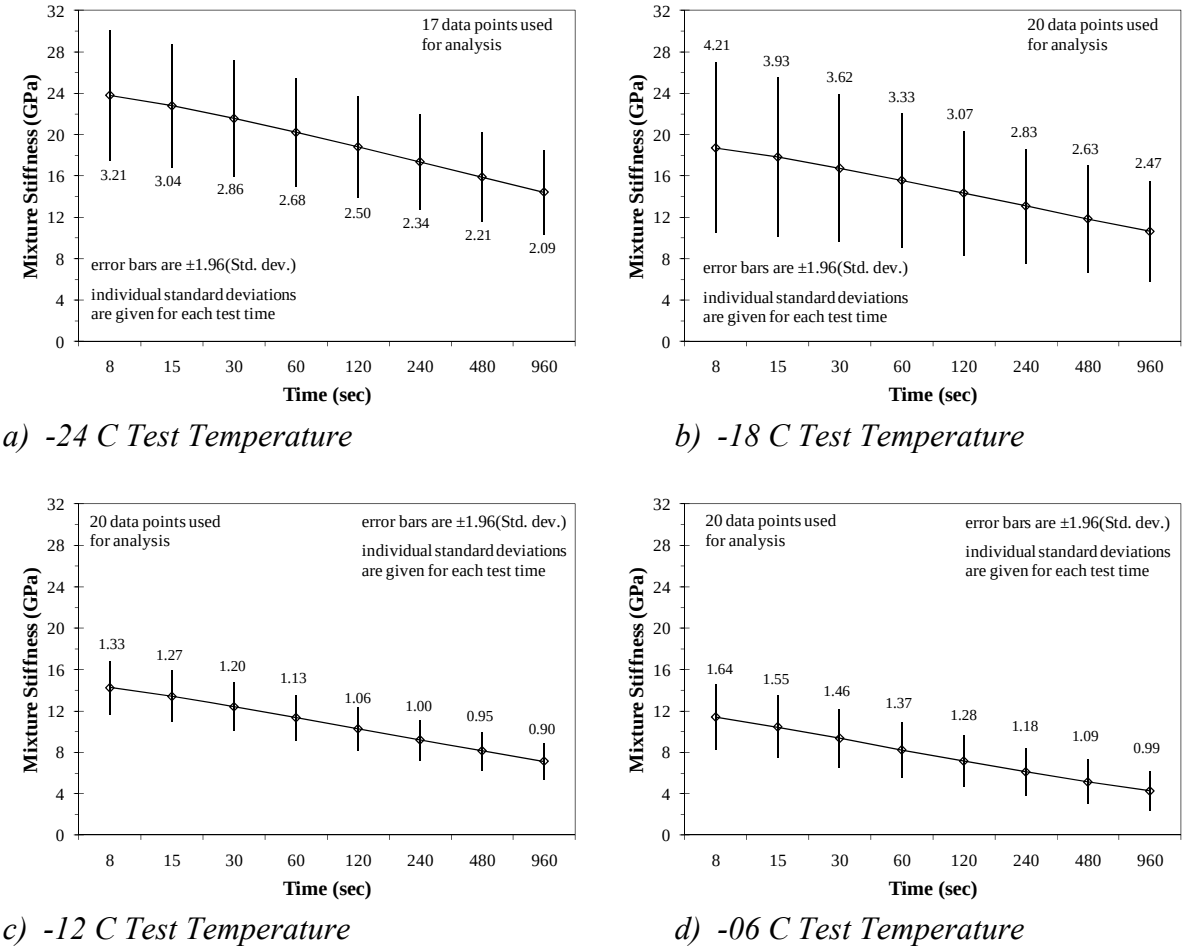
5.3.1 Test Method Variability

To evaluate variability of the *BBR* mixture test method, multiple gyratory compacted specimens of *9.5-15/CM-4a, 9.5-15/CM-4b*, and *9.5-15/CM-1* were tested. Four gyratory specimens were prepared of mixture *9.5-15/CM-4a* and three gyratory specimens each were

prepared of mixtures *9.5-15/CM-4b*, and *9.5-15/CM-1*. Five mixture beam specimens were tested at each of four test temperatures from each gyratory specimen.

Mixture *9.5-15/CM-4a* the test data is located in Tables B.16 to B.19. The data was evaluated for reasonableness and outliers; three outliers at -24 C were omitted from analysis. For control mixture *9.5-15/CM-4b* the data is found in Tables B.20 to B.23. The data was evaluated for reasonableness and outliers; no outliers found. For control mixture *9.5-15/CM-1*, the data is found in Tables B.4 to B.7. The data was evaluated for reasonableness and outliers; two outliers at -24 C and one at -06 C were omitted from analysis.

Figure 5.4 presents *BBR* stiffness test data for mixture *9.5-15/CM-4a* organized by test temperature. Error bars at a 95% confidence interval (± 1.96 standard deviations) are shown for the test data at each test time; the actual standard deviations of test data at a particular test time are shown next to the respective error bars. For *BBR* stiffness measurements at all four temperatures the standard deviations decrease as the test time increases. The same trend is seen in the data for mixtures *9.5-15/CM-4b* and *9.5-15/CM-1*; figures are omitted in the interest of brevity. This result indicates that the stiffness values of replicate beam specimens of a mixture tend to converge at longer test times. Therefore better statistical comparisons of stiffness between different mixtures can be made by using data at longer test times.



a) -24 C Test Temperature

b) -18 C Test Temperature

c) -12 C Test Temperature

d) -06 C Test Temperature

Figure 5.4 *BBR* Stiffness Test Data Variability for Mixture *9.5-15/CM-4a*

At -24 C test temperature the standard deviations range from 3.2 at 8 second test time to 2.09 at 960 second test time. Standard deviations of the test data at -18 C test temperature are higher and range from 4.21 at 8 second test time to 2.47 at 960 second test time. Standard deviations of test data at both -12 C and -06 C test temperatures are much smaller and are all less than 2. Data for mixtures *9.5-15/CM-4b* and *9.5-15/CM-1* have the highest standard deviations at the -24 C test temperature and the lowest standard deviations at either the -12 C or the -06 C test temperature. These results indicate that variability of the *BBR* mixture test method tends to be higher at lower test temperatures.

Variability of the *BBR* mixture stiffness test method is within a reasonable range provided the data is first examined and any outlying data omitted from analysis. For the control mixture data used to evaluate variability only six outliers were identified among the 200 data points (3% of the data). Repeatable results can be obtained with the test method.

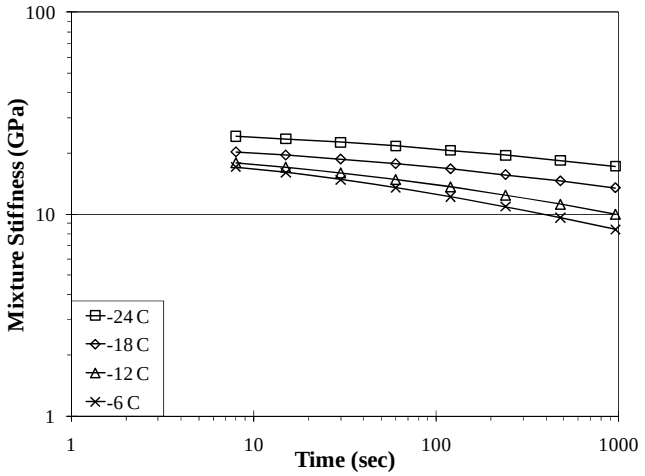
5.3.2 Control Mixture Data

BBR control mixture test data is located in Tables B.4 to B.27. Figures 5.5 and 5.6 present isotherms of mixture stiffness from averaged test data for control mixtures 1, 2, and 3 and 4a, 4b, and 4c, respectively. The data shows the same general trends of behavior that are observed in typical *BBR* binder testing. Isotherms at the lowest test temperature yield the highest stiffness and generally have the flattest slope. Isotherms at increasing temperatures have lower stiffness and generally have a steeper and gradually increasing slope.

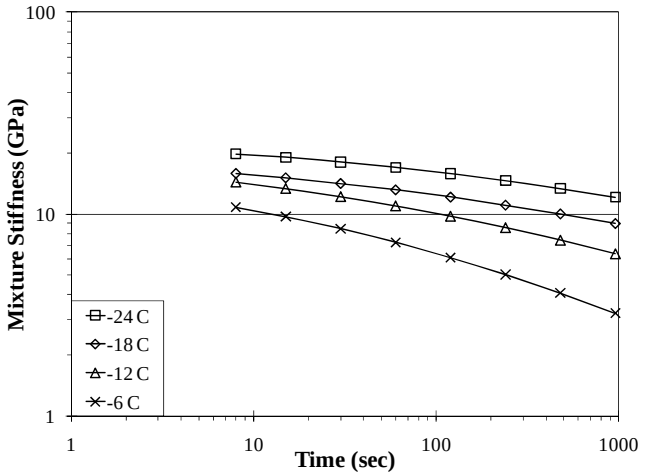
In general the stiffness isotherms for control mixture 1 are as high as or higher than all the other control mixtures and also tend to have flatter curves at all test temperatures. Also the -06 C isotherm is quite close the -12 C isotherm whereas for most of the other control mixtures the -06 C isotherm tends to be noticeably less stiff than the data at colder temperatures. These results for control mixture 1 are hypothesized to be due to the high dust to effective binder ratio of this mixture (value of 1.7 was out of MDOT specification) which will likely result in stiffening of the mixture.

Figure 5.7 presents results for the three versions of control mixture 4 (plant mixed PG 67, lab mixed PG 67, lab mixed PG 76) organized by test temperature to allow for assessment of the effects of different binder grades and mixing preparation methods. Stiffness isotherms of the plant mixed version of control mixture 4 (*9.5-15/CM-4a*) and the laboratory mixed version with PG 67-22 (*9.5-15/CM-4b*) are nearly identical at the -18 and -06 C test temperatures. In contrast the stiffness of the laboratory mixed version is lower than that of the plant mixed version at the -24 and -12 C test temperatures but the difference is relatively small. There is no conclusive evidence that preparation method (plant compared to laboratory) produces any meaningful differences in mixture stiffness at low temperatures as measured by this test method.

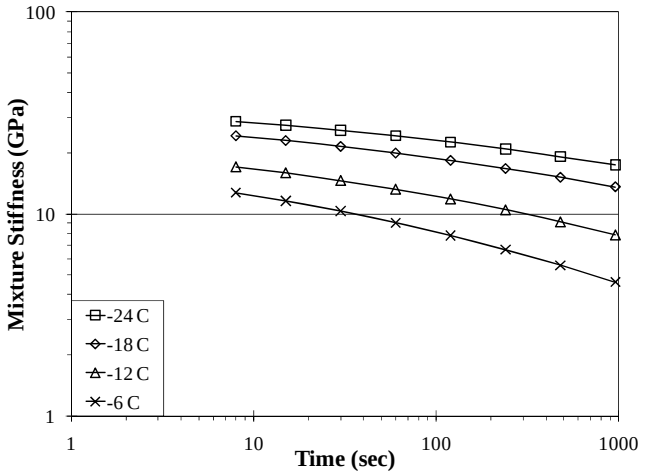
The stiffness isotherm of the mixture with polymer modified binder (PG 76-22) at -24 C lies between the isotherms for mixtures with neat binder (PG 67-22) and at -18 C all three isotherms are indistinguishable. This result is reasonable since these test temperatures bracket the low temperature performance grade of the binders. Interestingly, at -12 C and -06 C the PG 76-22 mixture stiffness isotherms are slightly higher than the isotherms for neat binder mixtures although not dramatically so.



a) Mixture 9.5-0/CM-1

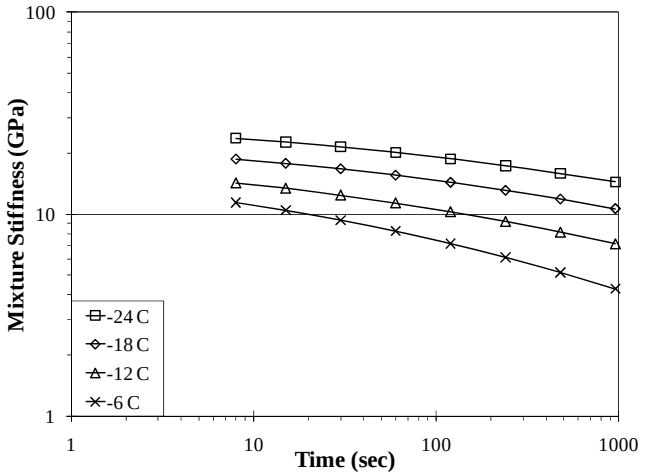


b) Mixture 9.5-15/CM-2

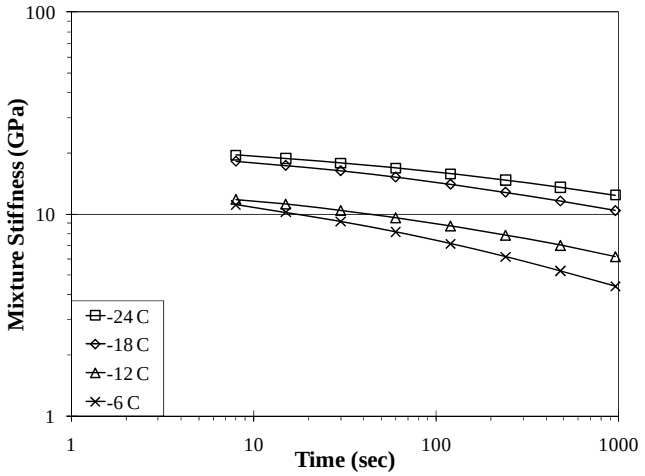


c) Mixture 9.5-15/CM-3

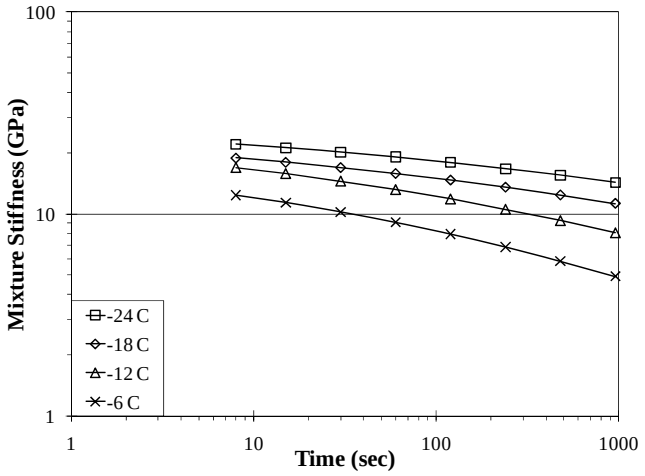
Figure 5.5 *BBR* Stiffness Data for Control Mixtures 1 to 3



a) Mixture 9.5-15/CM-4a



b) Mixture 9.5-15/CM-4b



c) Mixture 9.5-15/CM-4c

Figure 5.6 *BBR* Stiffness Data for Control Mixture 4

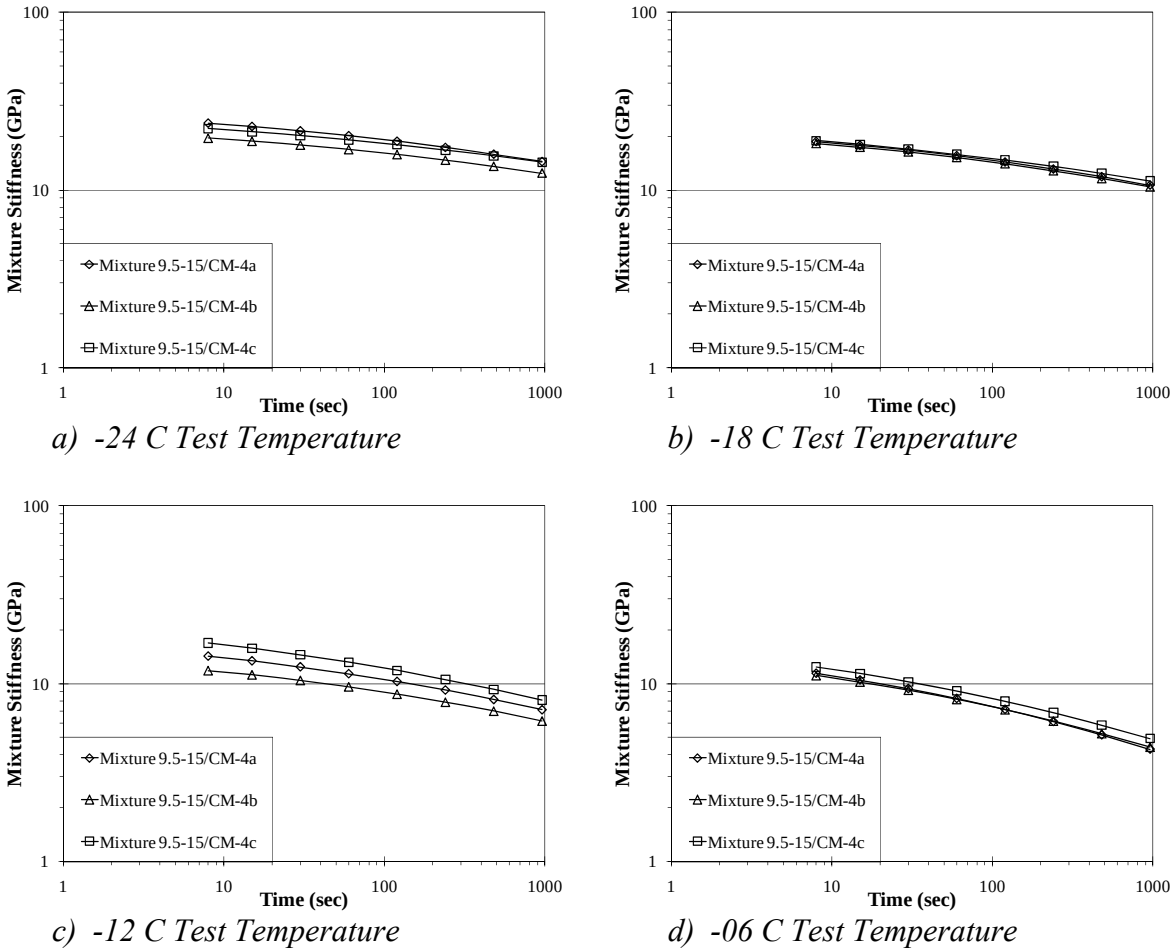
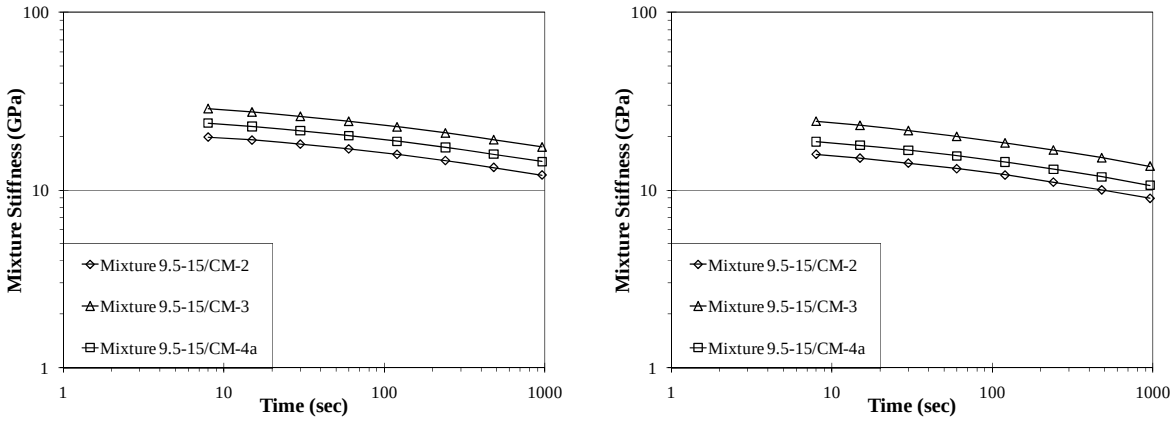


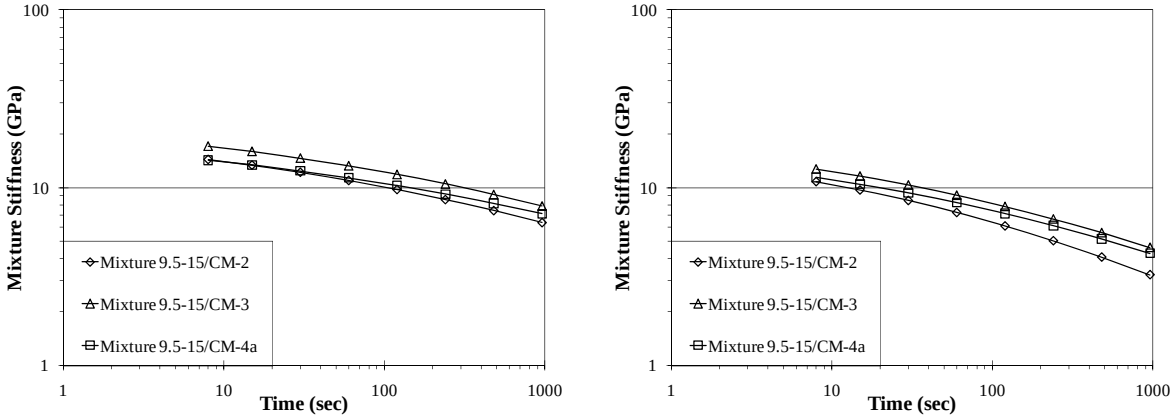
Figure 5.7 *BBR* Stiffness Data for Control Mixture 4 by Test Temperature

Figure 5.8 presents the test data from plant produced control mixtures 2, 3, and 4a organized by test temperature for comparison between plant produced mixtures. Control mixture 2 has the lowest stiffness for each test temperature. This is desirable from the standpoint of susceptibility to thermal cracking (i.e. a less stiff mixture results in lower thermal stress and reduced potential for thermal cracks provided strengths are equivalent to stiffer mixes). This is also reasonable since it is a low traffic (50 design gyration) mixture which results in a greater effective binder content relative to mixtures with higher compactive efforts (MT or HT mixtures).

Stiffness of both the high traffic mixtures is higher than the low traffic mixture. Control mixture 3 has the highest stiffness for each test temperature. Control mixture 4a has an intermediate level of stiffness at each test temperature. Control mixture 3 being stiffer is not thought to be due to the polymer modified binder but rather to some other mixture parameter (e.g. aggregate properties, effective binder content, etc.) based on testing control mixture 4 with different binder grades. The range of mixture stiffness in Figure 5.8 was taken to represent a reasonable expected range of low temperature mixture stiffness for Mississippi mixtures.



a) -24 C Test Temperature *b) -18 C Test Temperature*



c) -12 C Test Temperature *d) -06 C Test Temperature*

Figure 5.8 *BBR* Stiffness Data for Control Mixtures 2, 3, and 4 by Test Temperature

5.4 Rutting Data

Three test methods were utilized to evaluate rutting in a hot-dry condition: 1) *APA* rut testing; 2) PURWheel dry protocol testing; and 3) *MRTCR* testing. *APA* and PURWheel testing were performed at 64 C for control mixtures 2, 3, and 4. *MRTCR* testing was performed at 64 C for control mixture 1.

5.4.1 *APA*

For 15% RAP control mixtures (*9.5-15/CM-2, 9.5-15/CM-3,* and *9.5-15/CM-4*) *APA* rut testing was performed on *SGC* compacted specimens as described in Section 3.5.6; the data is located in Tables D.6 to D.10. Table 5.6 summarizes the data. Average air voids are provided as well as total rut depths at 2,000 and 8,000 cycles.

Two types of regression equations were fitted to the data to provide quantitative parameters for comparison: 1) linear regression between 2,000 and 8,000 cycles; and 2) power law regression of data between 0 and 8,000 cycles. Linear regression of data between 2,000 and 8,000 cycles was chosen to represent the rutting data in the secondary flow region after initial densification. Power law regression was chosen to provide a fit of all the rutting

data including initial densification and secondary flow. Fitted regression constants and corresponding coefficients of determination are provided in Table 5.6; the regression equations generally provided a very good fit as evidenced by the R^2 values of 0.90 or greater.

Table 5.6 *APA* Results for Control Mixtures 2, 3, and 4

Mixture	Avg.	Rut Depth (mm)		Linear Rutting Rate[1]			Power Law[2]		
ID	V_a (%)	2000	8000	Slope (10^{-6})	Intercept	R^2	*a*	*b*	R^2
9.5-15/CM-2	5.8	9.0	12.2	496	8.56	0.94	0.574	0.350	0.93
	9.6	9.0	11.6	381	8.86	0.91	0.654	0.332	0.90
9.5-15/CM-3	6.8	2.0	3.5	243	1.64	0.97	0.059	0.458	0.99
	9.5	4.4	6.3	299	4.04	0.97	0.181	0.405	0.92
9.5-15/CM-4a	6.8	3.6	5.0	228	3.32	0.96	0.102	0.448	0.91
	9.4	2.5	3.7	182	2.27	0.98	0.112	0.396	0.94
9.5-15/CM-4b	7.1	3.1	4.7	238	2.91	0.95	0.072	0.474	0.92
9.5-15/CM-4c	6.9	1.4	2.1	113	1.23	0.99	0.113	0.327	0.95

1: Linear rutting rate regression analysis is based on averaged data between 2,000 and 8,000 cycles.
2: Power law regression analysis is based on averaged data and Eq. 2.3.

Control mixture 2 performed rather poorly with respect to *APA* rutting; total rut depths were over 11 mm regardless of air void level. Control mixture three performed well with total rut depths of 3.5 mm for nominal 7% air voids and 6.3 mm at nominal 10% air voids. With nominal 7% air voids, control mixture 4 with neat binder rutted on the order of 5 mm for both plant and laboratory mixed versions; control mixture 4 with polymer modified binder rutted 2.1 mm.

5.4.2 PURWheel Dry Protocol

For 15% RAP control mixtures (*9.5-15/CM-2, 9.5-15/CM-3,* and *9.5-15/CM-4*) PURWheel dry rut testing was performed on *LAC* compacted specimens as described in Section 3.5.7.1; the data is located in Tables E.7, E.9, E.11, E.13, and E.15. Table 5.7 summarizes the data. Two types of regression equations were fitted to the data to provide quantitative parameters for comparison: 1) linear regression of the data between 2,000 and 20,000 passes; and 2) power law regression of data between 0 and 20,000 passes. The regression equations generally provided a very good fit of the data for control mixtures 3 and 4 as evidenced by the R^2 values of 0.88 or greater. Linear regression equations could not be fitted to data from control mixture 2 since all specimens of that mixture failed before 2,000 passes. Power law regression equations were fitted to the control mixture 2 rutting data and resulted in reasonable R^2 values; however the R^2 values should be interpreted in light of the limited amount of data that was used to perform the regression.

Similar to *APA* results, control mixture 2 performed poorly in the PURWheel dry protocol rutting test; all specimens exhibited an excessive level of rutting prior to 2,000 passes which resulted in early termination of the test to prevent equipment damage. Post-test visual observations of the specimens revealed failure of the mix in shear as evidenced by the sharp vertical edges of the wheel path (seen in Figure E.7). The PURWheel tires were coated with a film of binder once testing was complete.

Table 5.7 PURWheel Dry Test Results for Control Mixtures 2, 3, and 4

			Rut Depth		Linear Rutting Rate[2]			Power Law[3]		
Mixture ID	V_a **(%)**[1]	**Rep**	**Pass**	**mm**	**Slope (10^{-6})**	**Intercept**	**R^2**	***a***	***b***	**R^2**
9.5-15/CM-2	9.2	1-L	1134	24.5	---	---	---	0.001	1.50	0.86
		1-R	800	29.0	---	---	---	1.0 E-4	1.88	0.87
	9.1	2-L	1230	27.5	---	---	---	0.001	1.45	0.86
		2-R	272	12.5	---	---	---	4.0 E-6	2.83	0.95
Average	**9.2**	**---**	**859**	**23.4**	**---**	**---**	**---**	**0.001**	**1.92**	**---**
9.5-15/CM-3	6.9	1-L	20 k	7.0	200	2.92	0.96	0.095	0.438	0.94
		1-R	20 k	4.0	100	2.16	0.98	0.143	0.343	0.89
	8.8	2-L	20 k	5.6	200	2.21	0.95	0.027	0.547	0.94
		2-R	20 k	7.1	200	2.79	0.98	0.078	0.457	0.94
Average	**7.9**	**---**	**20 k**	**5.9**	**175**	**2.52**	**---**	**0.086**	**0.446**	**---**
9.5-15/CM-4a	8.0	1-L	20 k	4.2	100	2.23	0.97	0.191	0.312	0.91
		1-R	20 k	6.0	200	3.07	0.96	0.148	0.378	0.90
	11.5	2-L	20 k	7.3	200	3.07	0.95	0.120	0.416	0.92
		2-R	20 k	11.0	400	3.85	0.96	0.068	0.518	0.96
Average	**10.3**	**---**	**20 k**	**7.1**	**225**	**3.06**	**---**	**0.132**	**0.406**	**---**
9.5-15/CM-4b	10.8	1-L	20 k	11.7	400	4.02	0.99	0.099	0.480	0.95
		1-R	20 k	17.8	700	4.78	0.99	0.216	0.555	0.96
Average	**10.8**	**---**	**20 k**	**14.8**	**550**	**3.06**	**---**	**0.158**	**0.518**	**---**
9.5-15/CM-4c	11.2	1-L	20 k	4.8	100	2.63	0.95	0.185	0.332	0.88
		1-R	20 k	5.5	100	3.07	0.94	0.216	0.331	0.88
Average	**11.2**	**---**	**20 k**	**5.2**	**100**	**2.85**	**---**	**0.201**	**0.332**	**---**

1: Specimen air voids correlated to *AASHTO T 331*.
2: Linear rutting rate regression analysis is based on averaged data between 2000 and 20,000 passes.
3: Power law regression analysis is based on averaged data and Eq. 2.3.

Control mixture 3 performed very well in PURWheel dry rut testing; average rut depths at 20,000 passes were about 6 mm. The other control mixture with polymer-modified binder (*9.5-15/CM-4c*) also performed very well with an average total rut depth of about 5 mm. These two mixtures had the lowest values of slope and intercept parameters for the linear rutting rate regression performed of data between 2,000 and 20,000 passes.

Control mixture 4*a* (plant mixed with PG 67-22 binder) performed well; average rut depths were about 7 mm, not greatly higher than those for polymer-modified binder mixtures. Control mixture 4*b* (also with PG 67-22 binder) did not perform as well as its plant mixed counterpart; average total rut depths were about 15 mm. This result is unexpected. Variations in mean air voids of the specimens do not fully explain the difference in results since mean specimen air voids for the laboratory mixed specimens are within the range of air voids of plant mixed specimens.

In general, the PURWheel dry protocol test results provided the same relative ranking of rutting performance of control mixtures as did the *APA* test results. Control mixture 2 was observed to have the worst performance, and both control mixtures with polymer-modified binder performed similarly and very well. Notable differences in rutting performance between field and laboratory mixed versions of control mixture 4 with neat PG 67-22 binder were observed in PURWheel test results that were not seen in *APA* test results.

5.4.3 *MRTCR*

MRTCR testing was performed on three *SGC* compacted replicate specimens of control mixture *9.5-0/CM-1* at two stress levels; the data is provided in Table G.1. One outlier was identified and omitted from analysis. Figure 5.10 provides all the test data with the outlier removed. Specimens tested at the higher stress level (136 kPa) failed in fewer cycles than those tested at the lower stress level (68 kPa); this result is reasonable. The horizontal bands denote the range of failure strains for specimens tested at each stress level. The higher stress level resulted in a wider range of failure strains.

An ANOVA was performed on the test data for each of the four response variables; for brevity all the results are summarized in Table 5.8. The interaction term between replicate and stress level is not significant for any response variable. Different *SGC* compacted specimen replicates were not a significant factor except for the $(\Delta\varepsilon/\Delta T)^{-1}$ term. This result tends to indicate that the slope term is not an ideal variable for mixture comparison purposes. The stress level was a significant factor for each response variable (expected behavior) besides failure strain (F_ε) which is an interesting result. Examination of Figure 5.19 reveals that that the range of failure strains for specimens tested at the 136 kPa stress level was 6.0 to 11.5% and the range for 68 kPa stress level was 8.9 to 11.0%. The range of failure strains for the lower stress level was narrower and completely contained within the range of results for the higher stress level which explains the statistical results. This result might indicate that specimen failure strain is somewhat insensitive to applied stress level in the *MRTCR* test but with data from only one mixture no conclusive statements can be made. The failure strain response parameter was also observed to be less variable than the other response terms (Table G.1). Based on these results the failure strain parameter is likely the best response variable for comparison of mixtures with the *MRTCR* test.

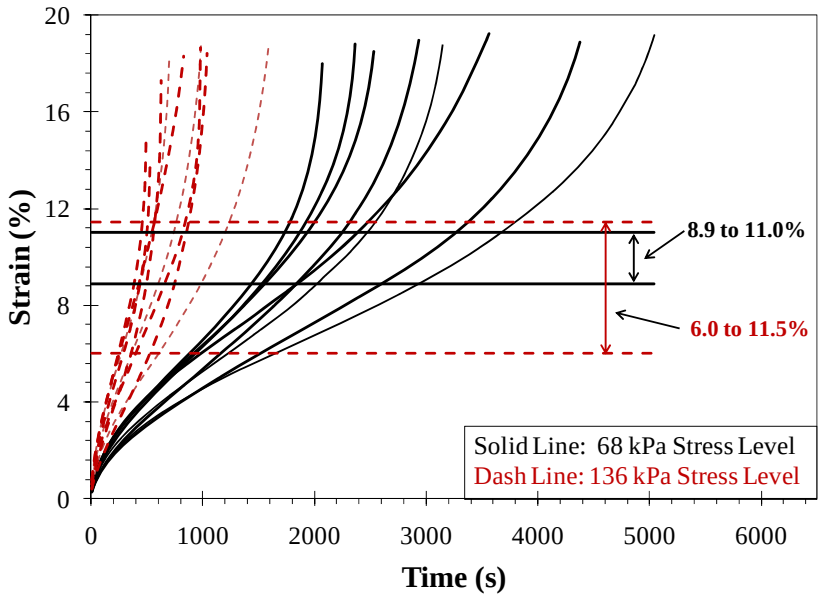


Figure 5.9 *MRTCR* Test Data for Mixture *9.5-0/CM-1*

Table 5.8 Summary of ANOVA for Mixture *9.5-0/CM-1* for each Response Variable

Response Variable	Factor	P_{Value}	Significance
$\varepsilon(5\%)_T$	Replicate	0.105	No
	Stress Level	0.000	Yes
	Replicate * Stress Level	0.165	No
$(\Delta\varepsilon/\Delta T)^{-1}$	Replicate	0.027	Yes
	Stress Level	0.000	Yes
	Replicate * Stress Level	0.101	No
FN	Replicate	0.238	No
	Stress Level	0.000	Yes
	Replicate * Stress Level	0.451	No
F_ε	Replicate	0.112	No
	Stress Level	0.464	No
	Replicate * Stress Level	0.248	No

Note: Significance testing performed at the 95% confidence level.

5.5 Moisture Damage Data

Two test methods were utilized to evaluate susceptibility of the mixtures to moisture damage: 1) *TSR*; and 2) PURWheel wet protocol. The *TSR* test is a standard moisture susceptibility test currently utilized as a screening tool by many agencies including MDOT. The PURWheel is a research grade loaded wheel tracking test that is similar in some respects to the Hamburg wheel tracking test which is used by a few agencies (e.g. Texas DOT).

5.5.1 *TSR*

TSR moisture susceptibility testing was performed on *SGC* compacted specimens as described in Section 3.5.5 for control mixture *9.5-0/CM-1*; the data is located in Table F.1. For control mixtures *9.5-15/CM-2, 9.5-15/CM-3,* and *9.5-15/CM-4* the *TSR* values reported on the MDOT mix design sheet were utilized. Control mixture *TSR* results are summarized in Table 5.9. All mixtures have acceptable *TSR* results (i.e. greater than 80%).

Table 5.9 *TSR* Results for Control Mixtures

Mixture	Conditioned Set			Un-Conditioned Set		
ID	Avg. V_a (%)	Sat (%)	S_t (kPa)	Avg. V_a (%)	S_t (kPa)	*TSR* (%)
9.5-0/CM-1	7.5	62.0	1111	7.6	1208	92.0
9.5-15/CM-2	---	---	---	---	---	93.6
9.5-15/CM-3	---	---	---	---	---	94.5
9.5-15/CM-4a	---	---	---	---	---	94.5

Note: Data for mixtures 2, 3, and 4*a* was taken from MDOT mix design sheets.

5.5.2 PURWheel Wet Protocol

PURWheel wet protocol testing was performed on *LAC* compacted specimens of all control mixtures except *9.5-0/CM-1* as described in section 3.5.7.2 of the experimental program. Control mixture PURWheel wet test data is found in Tables E.8, E.10, E.12, E.14,

and E.16. Analysis of the wet test data was performed as described in the following paragraph.

The data was first plotted and examined for evidence of moisture induced damage. Figure 5.10 provides two example sets of PURWheel wet test data from two different mixtures. Test Data 1 does not provide any evidence of moisture induced damage; the curve resembles a curve from the PURWheel dry test and continues smoothly all the way to 20,000 passes. Test Data 2 has the same general shape as dry test data up to about 5,000 passes. Beginning at approximately 5,000 passes the slope of the curve gradually starts to steepen. Eventually the slope of the curve becomes close to vertical in the vicinity of 7,000 passes. This is evidence of moisture induced damage. Visual observations of specimens at this stage typically reveal bare aggregate surfaces, cracks in the wheel path, and sometimes dislodged and uncoated aggregate. Photographs of test specimens are provided in Appendix E that show these behaviors for moisture damaged specimens.

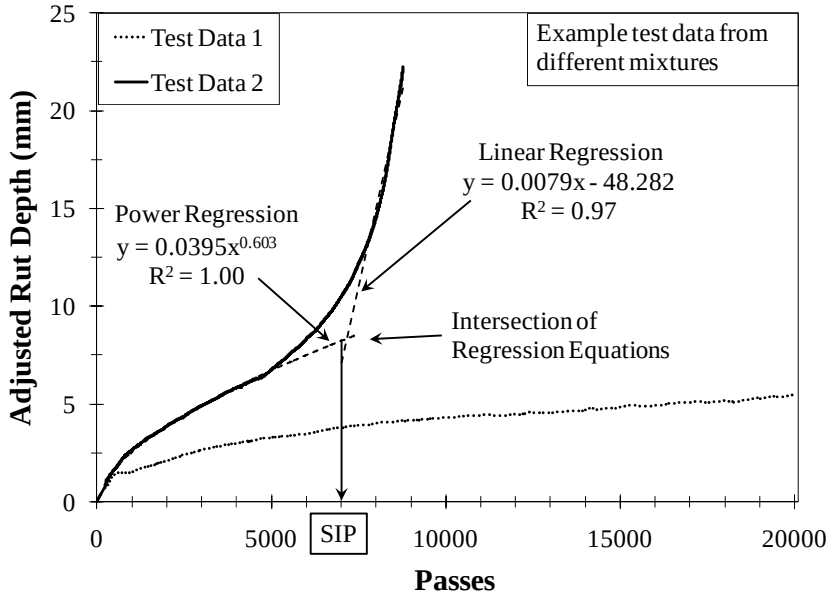


Figure 5.10 Example of PURWheel Moisture Damage Data Analysis Technique

For test data that shows evidence of moisture damage a power law regression equation was fitted to the data from the beginning of the test up to the point where the slope of the data begins to steepen. In the example test data given in Figure 5.11 the power law equation was fitted to the test data between 0 and 5000 passes. Assessment of where the curve began to steepen and what portion of the data provided the best fit of the power law regression equation was accomplished by incrementally increasing the amount of data used for the regression until the R^2 value began to decrease. Next a linear regression equation was fitted to the portion of the data with the steepest slope beginning at the end of the test and progressing backward. The amount of data used for the regression was determined by incrementally increasing the amount of data included until the R^2 value was maximized.

Coefficients of the two regression equations were utilized to determine the intersection point of the equations. The number of passes where the fitted regression equations intersected was considered to be the stripping inflection point (SIP) as shown in Figure 5.10. Calculation of the SIP was rounded to the nearest 500 passes. The power

regression equation was extended forward and the linear regression equation was extended backward in Figure 5.10 to demonstrate where the two curves intersect. For the example data in Figure 5.10 the SIP was 7,000 passes.

Summary plots of PURWheel test results for control mixtures are presented in Figures 5.11 to 5.15; data from both wet and dry PURWheel test protocols are presented in the figures to facilitate discussion of mixture relative performance. As seen in Figure 5.11, all of the *9.5-15/CM-2* test specimens failed in less than 1,500 passes. A slight amount of binder was observed to be removed from the aggregate surface in wet test specimens. As discussed in Section 5.5.2, control mixture 2 performed very poorly in PURWheel dry testing; this is also observed in the wet test data. No differences are observed between wet or dry test data but this result is not informative since the specimens all failed so quickly.

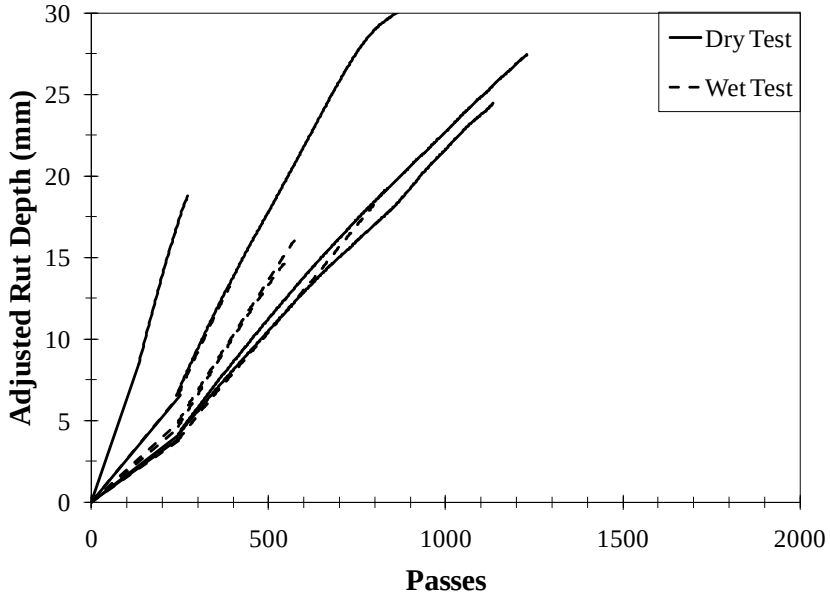


Figure 5.11 PURWheel Test Results for Mixture *9.5-15/CM-2*

For control mixture *9.5-15/CM-3*, two of the four wet specimens exhibited moisture damage as shown in Figure 5.12. Some binder was observed to be removed from the aggregate surface in moisture damaged specimens but no wheel path cracking or loose aggregate was seen. The two specimens without moisture damage exhibited deformation behavior similar to the dry test results although for one of them it appeared that moisture damage may have initiated near the end of the test but it did not lead to failure before the test was over.

For control mixture *9.5-15/CM-4a* only one of the four wet test specimens exhibited moisture damage as shown in Figure 5.13; a small amount of binder was removed from the aggregate surface but no loose aggregate or wheel path cracking was observed. The wet test specimens without moisture damage behaved much the same as dry test specimens.

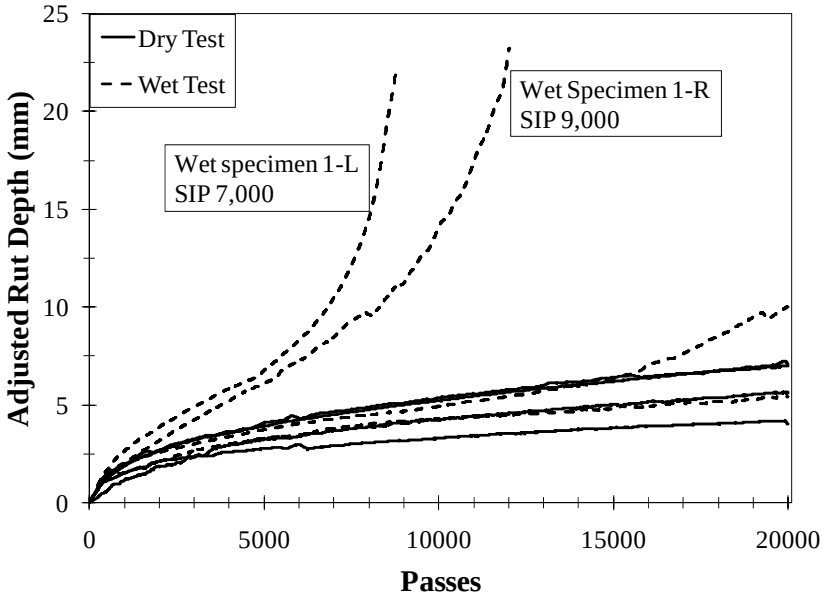


Figure 5.12 PURWheel Test Results for Mixture *9.5-15/CM-3*

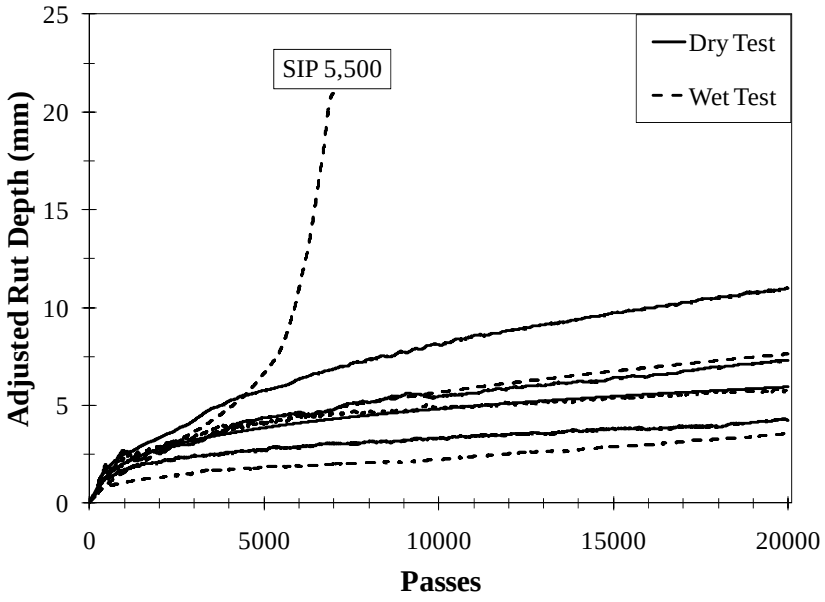


Figure 5.13 PURWheel Test Results for Mixture *9.5-15/CM-4a*

Both wet specimens of the laboratory mixed version of control mixture four (*9.5-15/CM-4b*) exhibited evidence of moisture damage as shown in Figure 5.14; noticeable cracking both within and beside the wheel path and minimal loose aggregate was observed for the specimens. One of the two wet specimens of laboratory mixed *9.5-15/CM-4c* with polymer modified binder shown in Figure 5.15 exhibited moisture damage and the other did not.

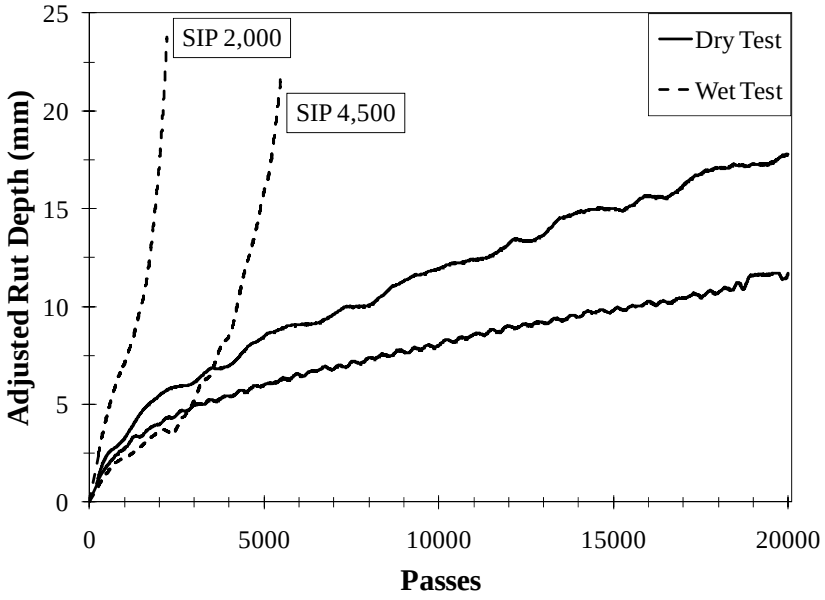


Figure 5.14 PURWheel Test Results for Mixture *9.5-15/CM-4b*

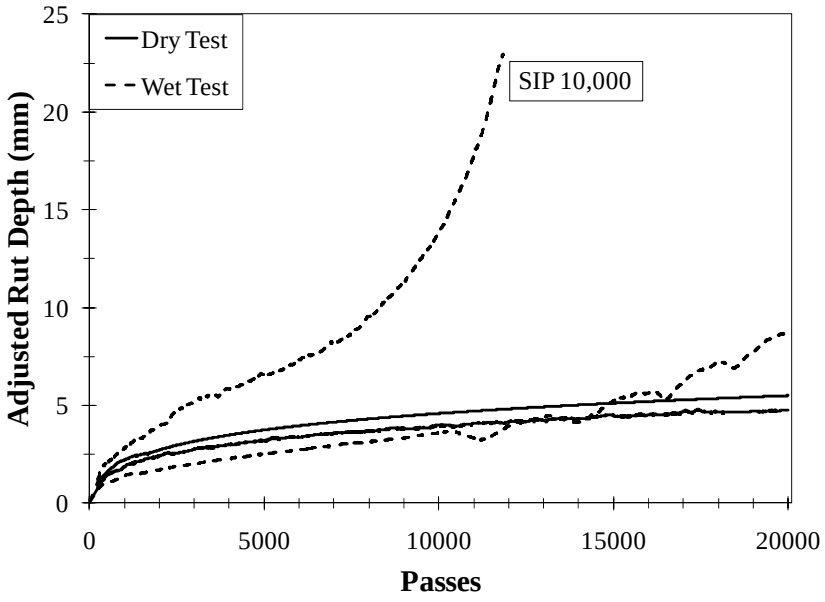


Figure 5.15 PURWheel Test Results for Mixture *9.5-15/CM-4c*

Table 5.10 summarizes PURWheel wet protocol test results for control mixtures. An average SIP value was calculated for each mixture; when no SIP was observed for a specimen a value of 20,000 passes was used to calculate the average SIP. The number of passes at failure and the terminal rut depth of each specimen are given as well as the results of the visual assessment.

Based on performance of the control mixtures, the wet protocol test data is used to suggest a mixture performance classification for this report which is given in Table 5.11. The classification system is based on the average SIP for a mixture. According to the

classification system, control mixtures *9.5-15/CM-3*, *9.5-15/CM-4a* and *9.5-15/CM-4c* would all be considered performance classification 4.

Control mixture *9.5-15/CM-4b* would be considered performance classification 1 but in general it performed poorly in PURWheel testing by either the wet or dry test protocols compared to the plant mixed version. Control mixture *9.5-15/CM-2* would also be considered performance classification 1 but since in general the PURWheel overwhelmed the mixture in both wet and dry tests this does not necessarily provide meaningful information about the mixture's performance related to moisture damage.

Table 5.10 Summary of PURWheel Wet Test Results for Control Mixtures

				Failure		Visual Assessment		
Mixture ID	**V_a (%)[1]**	**Rep**	**SIP**	**Pass**	**(mm)**	**Bare Agg.**	**Loose Agg.**	**Crack**
9.5-15/CM-2	9.1	1-L	None	828	19.1	Yes	No	No
		1-R	None	572	16.1	Yes	No	No
	9.2	2-L	None	550	14.8	Yes	No	No
		2-R	None	390	13.2	Yes	No	No
Average	**9.2**	---	---	**585**	**15.8**	---	---	---
9.5-15/CM-3	7.0	1-L	7,000	8782	22.2	Yes	No	No
		1-R	9,000	12,020	23.2	Yes	No	No
	7.3	2-L	None	20 k	9.7	No	No	No
		2-R	None	20 k	10.0	No	No	No
Average	**7.2**	---	**14,000**	**15,200**	**16.3**	---	---	---
9.5-15/CM-4a	7.4	1-L	None	20 k	5.8	No	No	No
		1-R	None	20 k	3.6	No	No	No
	4.8	2-L	None	20 k	7.9	No	No	No
		2-R	5,500	6978	21.0	Yes	No	No
Average	**6.1**	---	**16,375**	**16745**	**9.6**	---	---	---
9.5-15/CM-4b	10.7	1-L	2,000	2,214	23.8	Yes	No	Yes
		1-R	4,500	5,490	22.0	Yes	Yes	Yes
	10.7	---	**3,250**	**3,852**	**22.9**	---	---	---
9.5-15/CM-4c	10.7	1-L	10,000	11,842	23.0	Yes	No	Yes
		1-R	None	20 k	8.7	Yes	No	No
Average	**10.7**	---	**15,000**	**15,921**	**15.9**	---	---	---

Note: When no SIP was observed, a value of 20,000 passes was used to calculate the average SIP.
1: Specimen air voids correlated to *AASHTO T 331*.

Table 5.11 Proposed PURWheel Wet Protocol Mixture Classification System

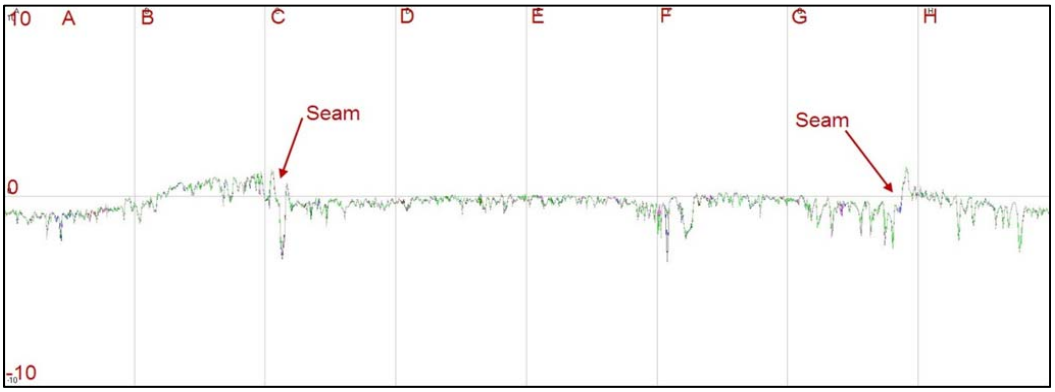
Performance Classification	Average SIP
1	<5,000 passes
2	5,000 to 9,999 passes
3	10,000 to 14,999 passes
4	15,000 to 20,000 passes

5.6 Skid Resistance Data

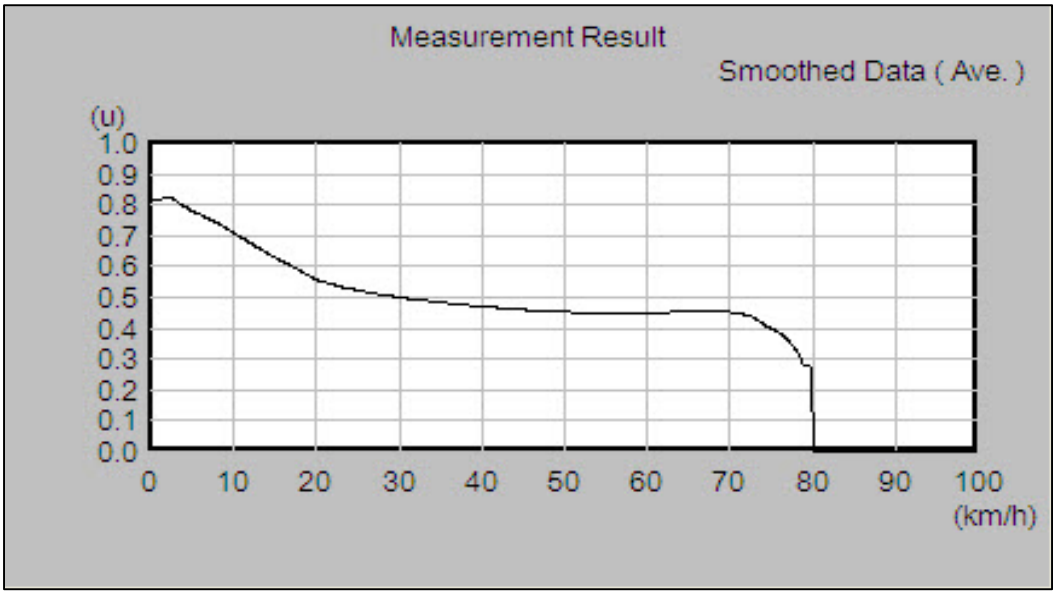
Skid resistance panels of control mixture *9.5-0/CM-5* were tested as described in Section 3.5.8. An estimate of air voids of each panel was made from mixture batch quantities and measured slab dimensions with a correlation equation developed by Doyle and

Howard (2010). The analysis method for skid resistance results is described in the following paragraphs.

Macrotexture results of *CTMeter* testing (*ASTM E 2157*) were evaluated graphically with the software provided by the equipment manufacturer. All eight measurement runs were plotted initially; any unusual or excessively variable runs were eliminated from the analysis. At least five measurements were used for each panel. Figure 5.16*a* is the graphical output for a representative panel using all measurements selected for use. Evidence of the seam between slab pieces can be seen in segments C and G as a sudden change in texture depth. Figure 5.16*a* is representative of results for other panels; however the seam was not always visually evident in texture results. Macrotexture results for all control mixture panels are summarized in Table 5.12.



a) CTMeter Macrotexture Results



b) DFTester Friction Coefficient Results

Figure 5.16 Representative Skid Resistance Test Results

Friction coefficient results of *DFTester* testing were compiled with the software provided by the equipment manufacturer. The raw data was smoothed and results from all

five runs per panel were averaged. Figure 5.16*b* shows the results of smoothed friction coefficient data and is representative of results from all other panels. *DFTester* data is summarized for all panels in Table 5.12. *CTMeter* and *DFTester* results were utilized to calculate IFI values according to *ASTM E 1960* for the friction panels. IFI results for friction panels are summarized in Table 5.13.

Table 5.12 Test Results for Skid Resistance Panels

			Macrotexture *E 2157*			**Friction *E 1911***		
Mixture ID	**Rep**	**Est. V_a (%)**	**N**	**Dropout**	**MPD (mm)**	***DFT*$_{20}$**	***DFT*$_{60}$**	***DFT*$_{64}$**
9.5-0/CM-5	1	9.7	6	2%	0.73	0.635	0.569	0.571
	2	8.5	6	1%	0.43	0.582	0.500	0.498
	3	8.3	8	2%	0.63	0.631	0.570	0.570
	4	9.2	5	2%	0.69	0.697	0.551	0.547
	5	10.6	5	1%	0.42	0.626	0.529	0.528
	Avg.	**9.3**	**6**	**2%**	**0.58**	**0.634**	**0.544**	**0.543**
	Std. Dev.	**0.9**	**1**	**1%**	**0.15**	**0.041**	**0.030**	**0.031**

Note: The superscript for friction coefficient results denote the test speed in *km/hr*.

Table 5.13 *IFI* Calculation Results for Panels by *ASTM E 1960*

Mixture	**Rep**	**Speed Constant (S_p)**	**Friction Value at 60 km/hr (*F60*)**
9.5-0/CM-5	1	79.68	0.36
	2	52.77	0.28
	3	70.71	0.34
	4	76.09	0.38
	5	51.87	0.29
	Avg.	**66.23**	**0.33**
	Std. Dev.	**13.09**	**0.04**

CHAPTER 6 – 100% RAP MIXTURE RESULTS

6.1 Overview of 100% RAP Mixtures Results

This chapter presents 100% RAP performance test results, both designed mixes (Table 3.6) and the expanded 100% RAP compaction experiment (Table 3.9). The chapter is organized by category of mixture performance with subsections for each test method. The data in this chapter is used to provide a perspective of RAP only mix properties relative to 25 and 50% RAP mixes (Chapter 7), not for considering 100% RAP use in service.

6.2 Cantabro Durability Data

6.2.1 Designed 100% RAP Mixtures

Cantabro testing was performed on *SGC* compacted specimens for designed 100% RAP mixes (Table 3.6); the data is located in Table C.2 and the results are summarized in Table 6.1. *R-3* had the highest *ML* followed by *R-1* and then by *R-2*. *ML* for the designed 100% RAP mixtures was noticeably higher than observed for the control mixtures in Chapter 5, which is a reasonable behavior given the stiff and potentially brittle RAP asphalt.

Table 6.1 Cantabro Results for Designed 100% RAP Mixtures

Mixture ID	*n*	Avg. Air Voids (%)	Avg. *ML* (%)
9.5-100/RM-1	3	4.6	31.8
9.5-100/RM-2	3	5.6 [1]	25.7
12.5-100/RM-3	3	4.6	33.7

1: Air voids fell outside design tolerances of 3 to 5%, so the *ML* value is suspect. Lower air voids would likely lead to lower *ML* so the trend of *ML* between RAP sources is believed to be correct.

Relative effects of different heating times were investigated with *9.5-100/RM-1* as discussed in Section 3.6.2.1. The data is available in Table C.1 and is summarized in Figure 6.1. Air voids and mass loss follow the same trend. It is unclear if this is due to changes in air voids, changes in binder properties, or some combination of both (most likely). Further testing with specimens compacted to a target air void level as part of larger test program would be useful to better evaluate this phenomenon.

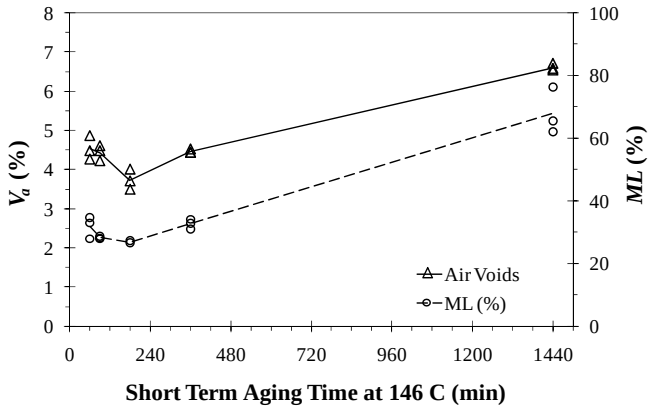


Figure 6.1 Results for *9.5-100/RM-1* Mixture Relative Heating Experiment

6.2.2 Data from Expanded RAP Compaction Experiment

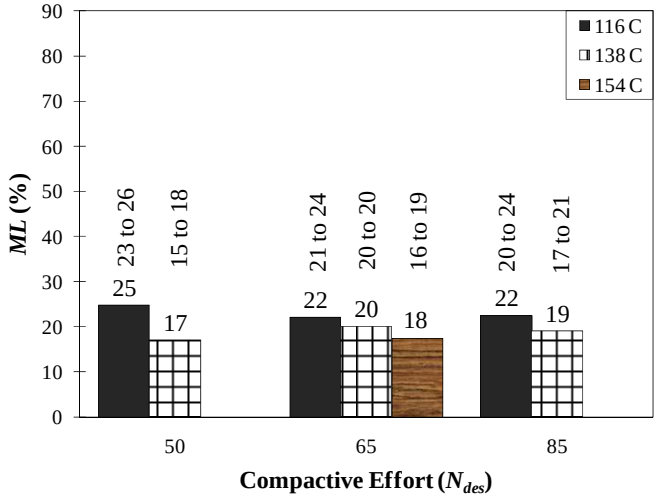
Testing 100% RAP at a variety of compaction efforts and virgin binder contents was performed in the expanded RAP compaction experiment described in Section 3.6.2.2 and Table 3.9. Test results are found in Tables C.3 to C.7. Varying compaction and binder content produced air voids near zero to almost ten percent. No discernable patterns were observed in the 100% RAP durability results with respect to warm mix additives, so data from different warm mix additives was combined to investigate the effects of compactive effort and compaction temperature.

Figure 6.2 presents the durability data for *R-1* RAP organized by total asphalt content and compactive effort, with the mean and range *ML* values provided. Compactive effort differences did not produce any clear trends. The expectation would be that *ML* would decrease as compactive effort increased for a given asphalt content and compaction temperature. This did not occur in all cases, though when *ML* increased with compactive effort increase, the differences could be attributed to variability of testing 100% RAP. Overall, increased gyrations reduced air voids as evidenced by mean air void decreases of all 116 and 138 C *R-1* data of 0.54 and 0.29% with gyration increases from 50 to 65 and 65 to 85, respectively. Many variables coupled with little replication likely masked any durability effects observable from comparing different compactive efforts for 100% RAP.

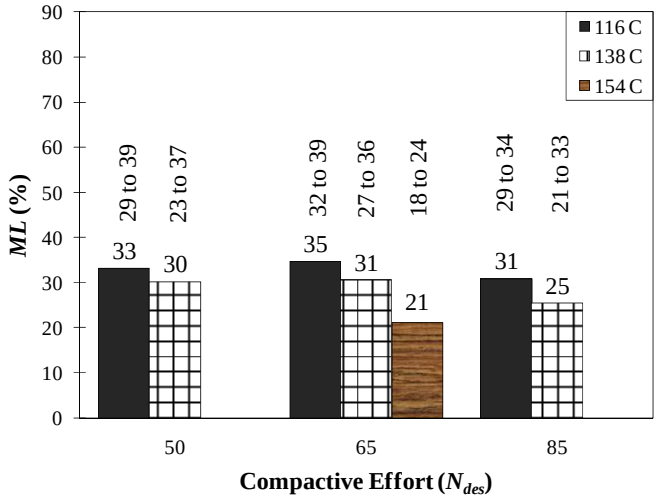
Figure 6.3 plots all durability data compacted to 65 gyrations. A trend of decreasing mean mass loss with increasing total asphalt content is observed with *R-1*, *R-2,* and *R-3*. The largest decrease in mass loss occurred between the low and medium asphalt contents for all three RAP sources and all three compaction temperatures. The reduction in mass loss was less pronounced between the medium and high total asphalt contents indicating that coating of RAP by virgin binder may reduce the effects of RAP in terms of brittleness to some extent. Interestingly, the *R-2* RAP source (softest of the three RAP asphalts) had the lowest mass loss and was the least affected by the addition of virgin binder, while *R-1* and *R-3* (stiffer RAP asphalt) had much higher mass loss and were more affected by virgin binder.

Figure 6.3 does not show a clear trend of mass loss at a given asphalt content with regards to compaction temperature. *R-1* and *R-2* show mass loss decreasing with compaction temperature, but *R-3* does not between 138 and 154 C. The magnitude of decrease related to temperatures of 138 and 154 C for *R-1* and *R-2* is generally within the variability shown in Figure 6.3. Similarly, the magnitude of mass loss increase for *R-3* related to temperatures of 138 and 154 C is generally within the variability shown in Figure 6.3. Overall, it appears that mass loss decreases with compaction temperature between 116 and 138 C, but not necessarily between 138 and 154 C. Data variability coupled with the number of replicates may or may not be preventing a clearer picture as temperature increases above 138 C.

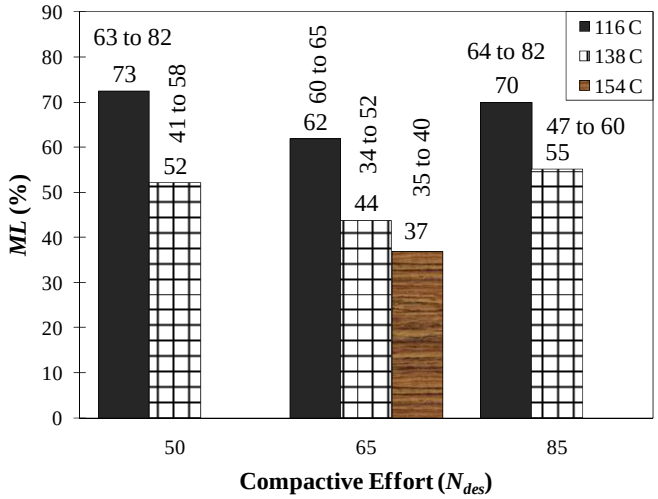
Figure 6.4 plots *ML* as a function of air voids for *R-1*, *R-2*, and *R-3* alongside trendline fits of the data. Air voids have a substantial effect on mass loss and were chosen as the input variable since they indirectly consider asphalt content, compaction temperature, compactive effort, and warm mix additives. The data has scatter but the trendlines show *ML* to align with the properties of the extracted RAP bitumen. *R-1* has the stiffest asphalt and the highest mass loss, *R-3* is somewhat less stiff than *R-1* and has less mass loss, and *R-2* is the softest of the three and has the least mass loss. *R-2* also has a noticeably different slope (i.e. it is less affected by air voids) than *R-1* and *R-3* which have similar slopes. The trendlines predicted the *ML* values of Table 6.1 to within 20, 5, and 1% for *R-1* to *R-3*, respectively.



a) High Total Asphalt Content

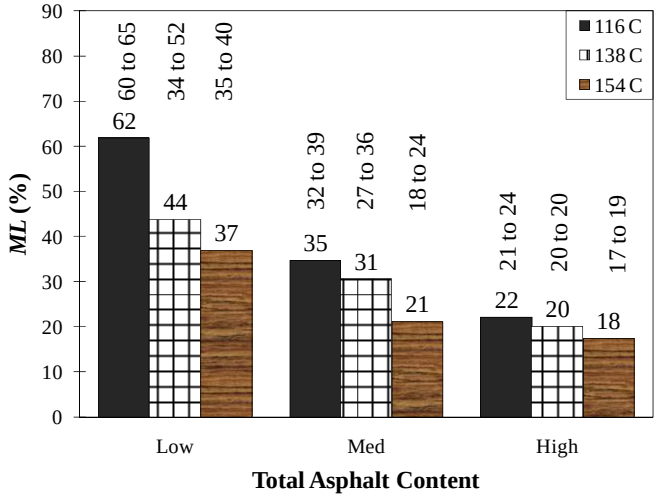


b) Medium Total Asphalt Content

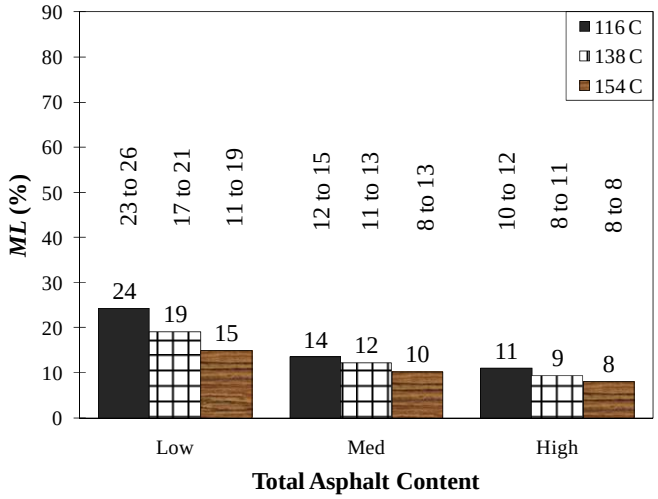


c) Low Total Asphalt Content

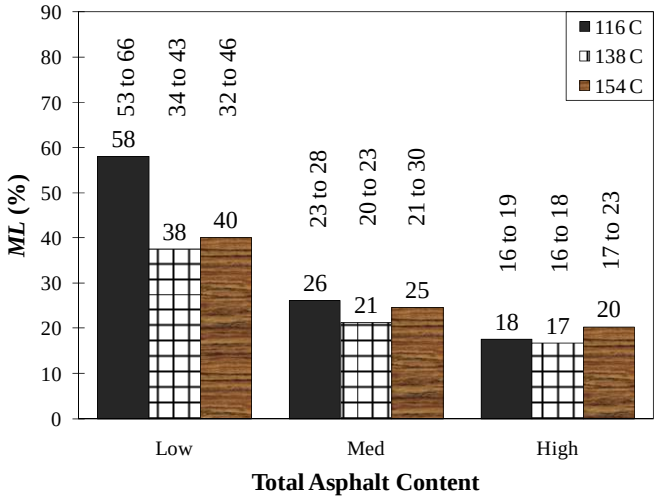
Figure 6.2 Mass Loss Results of *R-1* RAP for Varying Compactive Effort



a) R-1 Durability Data



b) R-2 Durability Data



c) R-3 Durability Data

Figure 6.3 Mass Loss Results for all RAP Sources at 65 Gyrations

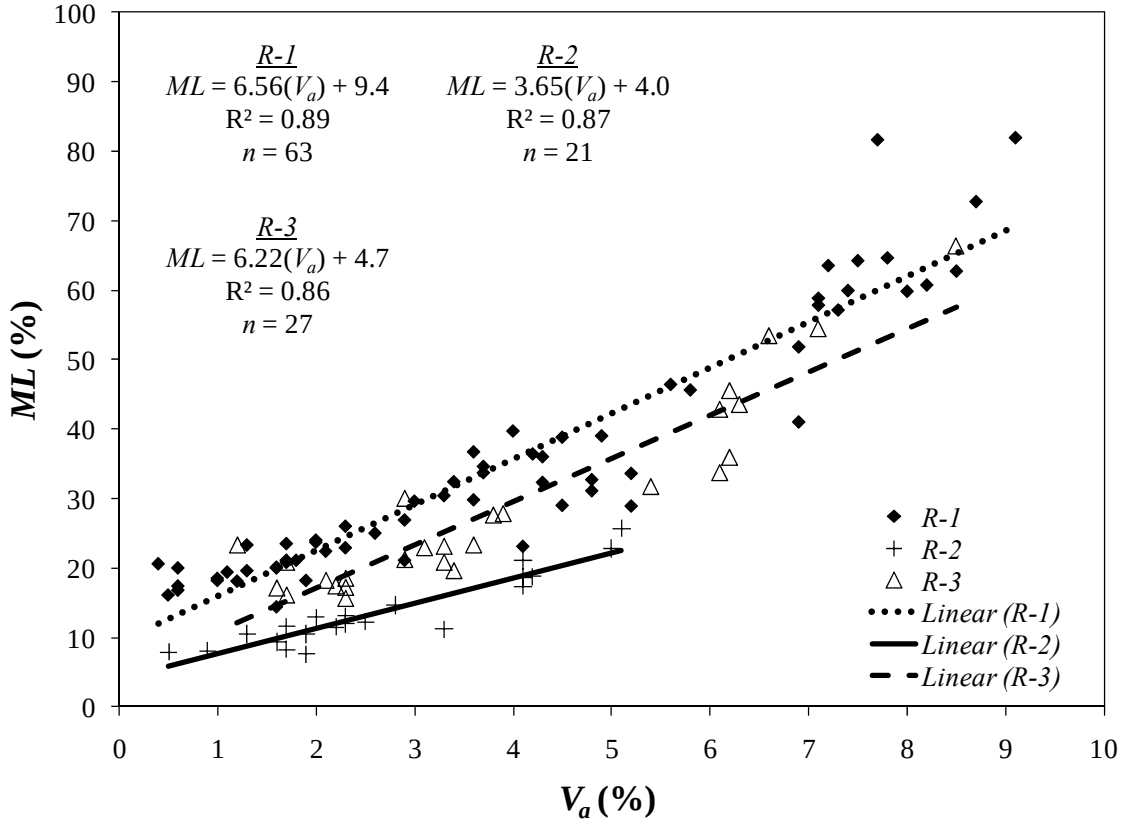


Figure 6.4 Correlation of *ML* and Air Voids for 100% RAP at Varying Conditions

To better interpret the durability data an ANOVA was performed on specimens compacted to 65 gyrations. RAP source, compaction temperature, and total asphalt content were considered. All three factors were determined to be statistically significant in an overall sense. A main effects plot of the three experimental factors is presented in Figure 6.5.

For further insight, the Tukey multiple comparison procedure was used on data from specimens compacted to 65 gyrations to compare levels of each experimental factor; the results are summarized in Table 6.2. Each experimental factor was considered independently of the others in the Tukey multiple comparison procedure. For a specific experimental factor, levels of the factor with the same Tukey letter grouping are not statistically different.

Examination of Figure 6.5 and Table 6.2 reveals that the *R-1* RAP source had the highest mass loss and the *R-2* RAP source had the lowest. Mass loss for the *R-3* RAP source was not significantly different than mass loss for the *R-1* RAP source but was significantly higher than mass loss for the *R-2* RAP source. An increase in compaction temperature from 116 to 138 C resulted in a significant decrease in mass loss but a further increase in compaction temperature from 138 to 154 C resulted in an insignificant reduction in mass loss. Mass loss for all three levels of total asphalt content were significantly different and as expected mass loss increased as the total asphalt content (and corresponding air voids) decreased.

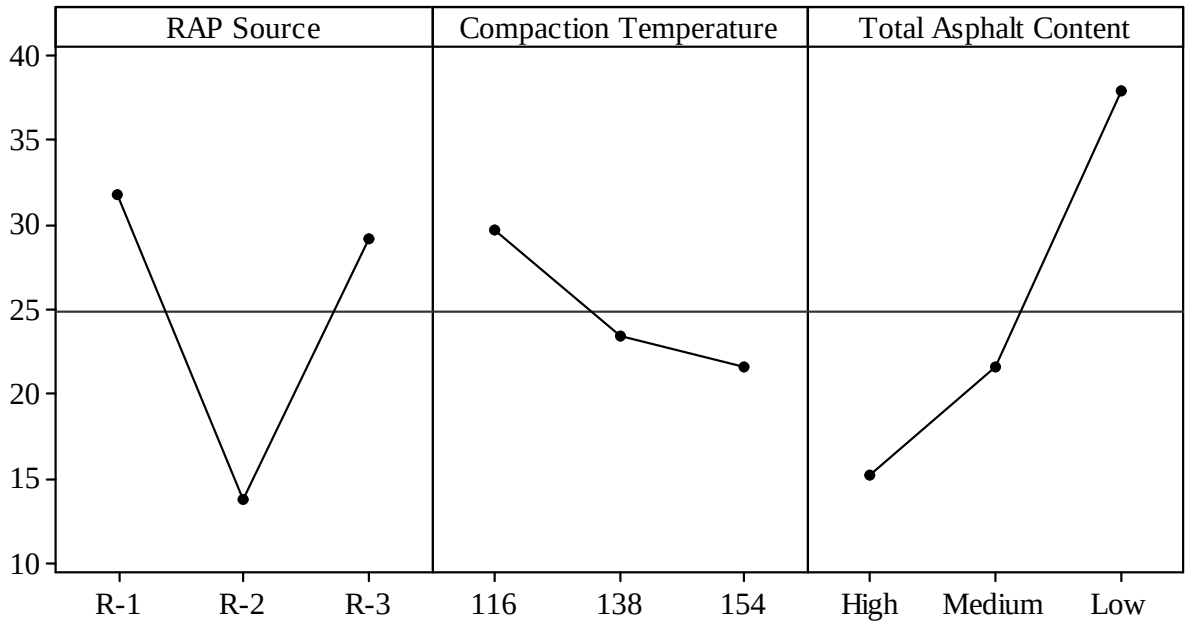


Figure 6.5 Main Effects Plots for Mass Loss with Fitted Means

Table 6.2 Tukey Multiple Comparison Tests of Mass Loss

Experimental Factor and Level	Mean 65 Gyr. *ML* (%)	Tukey Grouping		
RAP Source				
R-1	31.7	**A**		
R-2	13.6		**B**	
R-3	29.2	**A**		
Compaction Temperature				
116 C	31.2	**C**		
138 C	23.4		**D**	
154 C	22.9		**D**	
Total Asphalt Contents				
High	16.5	**E**		
Med	22.4		**F**	
Low	38.8			**G**

Note: For a specific experimental factor the experimental treatments with the same letter grouping are not statistically significantly different at the 5% significance level.

Overall, the data indicates that characterization of 100% RAP using the Cantabaro test would benefit from compacting specimens to a target level of air voids rather than at a fixed compactive effort. This behavior was also observed in Chapter 5. One compaction temperature (mix design temperature) should be sufficient for the evaluation of durability. Testing the effect of virgin asphalt content at a constant air void level in conjunction with one mixing temperature appears to be a promising approach to discovering meaningful behaviors about a given RAP source.

6.3 *BBR* Data

6.3.1 Designed 100% RAP Mixtures

BBR testing of the three designed 100% RAP mixes was performed at four test temperatures, and the data is located in Tables B.1 to B.3. The data was evaluated for the existence of outliers according to the procedure given in Section 5.3 and any outlying data was omitted from analysis. Test results are presented in Figure 6.6. In general the stiffness of the RAP mixes is higher than the control mixes in Chapter 5 but the increase in stiffness is not as dramatic as might be expected. The isotherms are generally rather flat which indicates potentially poor relaxation properties compared to mixes with softer binder. Somewhat surprisingly, stiffness of the different RAP sources at these temperatures is not as different as might be expected given their variation in total asphalt content and observed differences in compaction behavior. At -24 C and -18 C temperatures the mixture with *R-1* RAP is slightly stiffer than the mixture with *R-2* RAP; stiffness of the mixture with the *R-3* RAP source was variable at these test temperatures. At -12 C and -06 C test temperatures the opposite trend is observed with the *R-1* and *R-2* RAP sources (i.e. *R-2* was stiffer than *R-1*); the *R-3* RAP mixture had similar stiffness to the *R-1* mixture at these test temperatures.

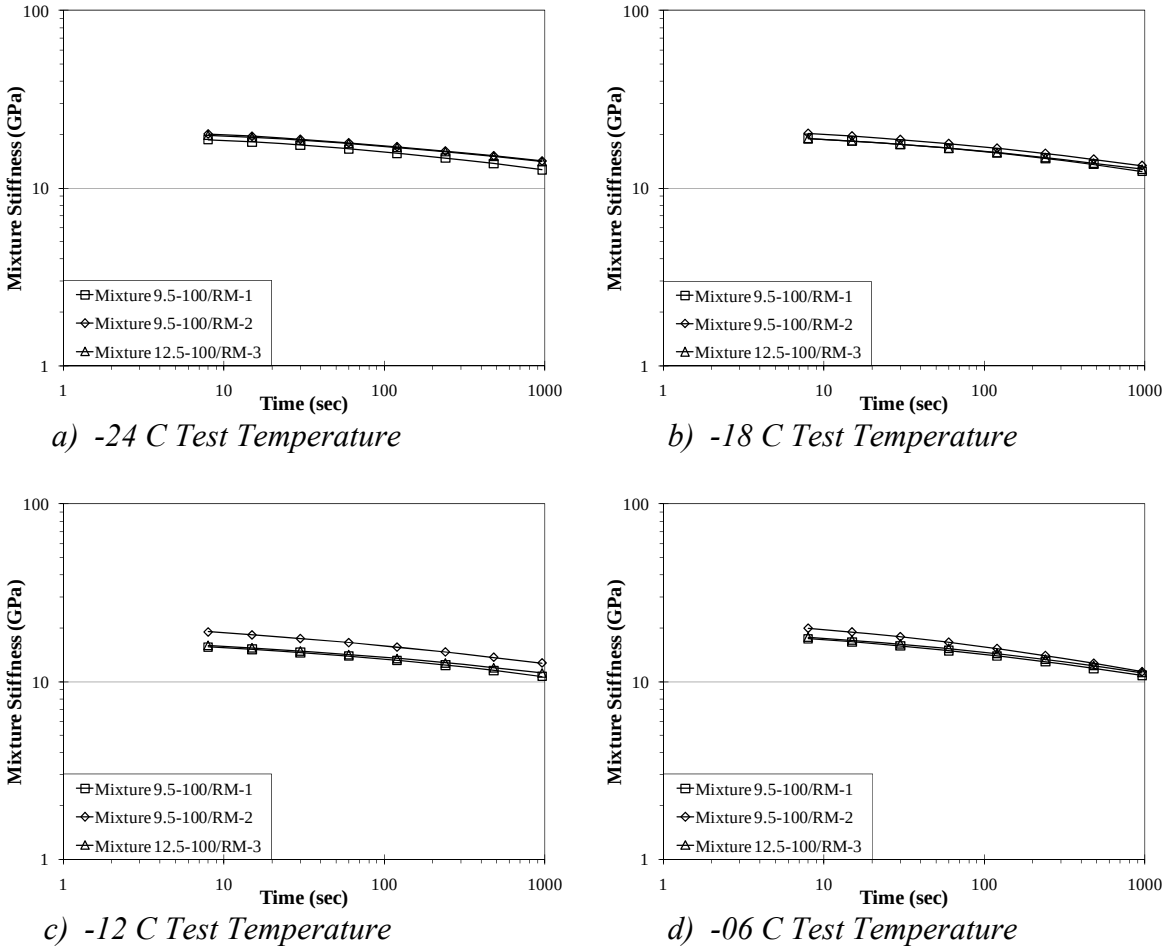


Figure 6.6 *BBR* Data for Designed 100% RAP Mixtures

6.3.2 Data from Expanded RAP Compaction Experiment

Compacted specimens from the expanded RAP compaction experiment described in Section 3.6.2.2 and Table 3.9 were sawn into bars and tested. Raw data is in Tables B.44 to B.88. Of the one-hundred-ninety-eight factor-level combinations attempted in Table 3.9, forty-two (21%) were too brittle to be sawn into specimens and were not tested. Thirty-six were *R-1*, mostly at low asphalt content. The one-hundred-fifty-six remaining factor-level combinations were tested; ninety *R-1*, twenty-eight *R-2*, and thirty-eight *R-3*. *R-1* specimens that were too brittle were not identified on plots since they were isolated to specific areas of the test program; *R-2* and *R-3* specimens too brittle to cut were identified on plots.

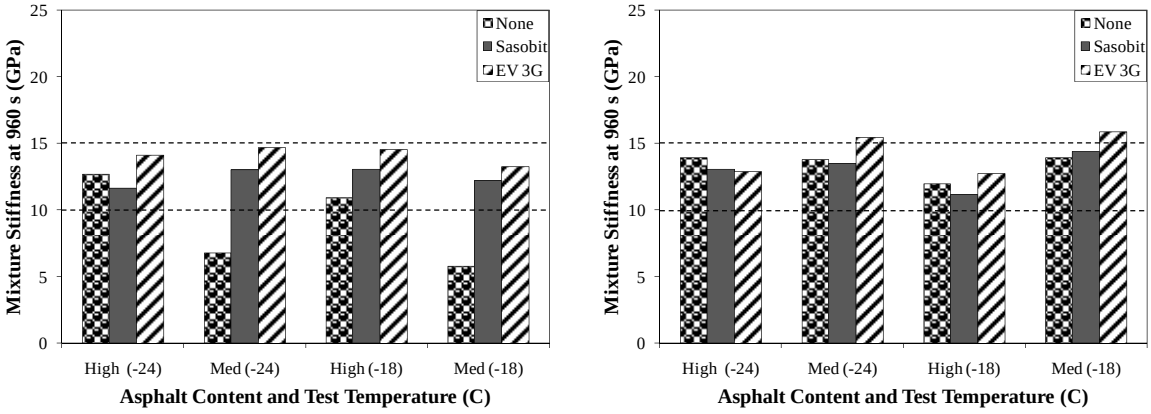
The data was evaluated for the existence of outliers according to the procedure given in Section 5.3 and any outlying data was omitted from analysis. Analysis of the *BBR* mixture test method performed with control mixture data in Chapter 5 revealed that variability of stiffness measurements was lower at longer loading times. As a result, mixture stiffness measured at 960 seconds was selected as the response variable for analysis of the data in this section. Information about the *BBR* mixture test method garnered through literature review indicated that the test was relatively insensitive to variations in air voids. For a given total asphalt content and RAP source, air voids were within a reasonable range. As a result, total asphalt content and test temperature were used to partition the test data for analysis.

Figures 6.7 and 6.8 present *R-1* RAP test results at warm and hot mix temperatures, respectively. In general, different levels of compaction temperature and compactive effort were not observed to have considerable effects on mixture stiffness. Likewise, warm mix additives did not exhibit any identifiable trends. In some cases Evotherm 3G™ had the highest stiffness and in other cases it has the lowest, for example. Of the ninety *R-1* RAP factor-level combinations tested, approximately 90% had mixture stiffness between 10 and 15 GPa. The highest stiffness observed in the *R-1* data was 16.9 GPa and the lowest observed stiffness was 5.8 GPa.

Figures 6.9 and 6.10 present *R-2* RAP test results. Total asphalt content changes are observable to some extent, with low total asphalt content generally being stiffer. No test data fell below 10 GPa, as the lowest observed stiffness was 11.3 GPa. Approximately one-third of the twenty eight factor-level combinations had mixture stiffness values between 10 to 15 GPa, with the remaining two-thirds between 15 to 17.5 GPa. No stiffness was measured higher than 17.5 GPa with *R-2*. In general, stiffness values between 10 to 15 GPa were with high virgin asphalt content and stiffness values between 15 to 17.5 GPa were with medium to low asphalt content. Overall, *R-2* was stiffer than *R-1*, which would not be the case if the only factor affecting mixture stiffness was the RAP bitumen as *R-1* has a higher viscosity and PG grade relative to *R-2*. The contribution of aggregates to mixture stiffness and the amount of effective RAP surface binder (*R-2* appears to have more effective surface binder based on Table 4.11, especially at lower compaction temperatures) are likely affecting the mixture stiffness. The result also indicates that mixture stiffness alone may not be sufficient to characterize the crack potential of asphalt mixtures; more research is needed to explain.

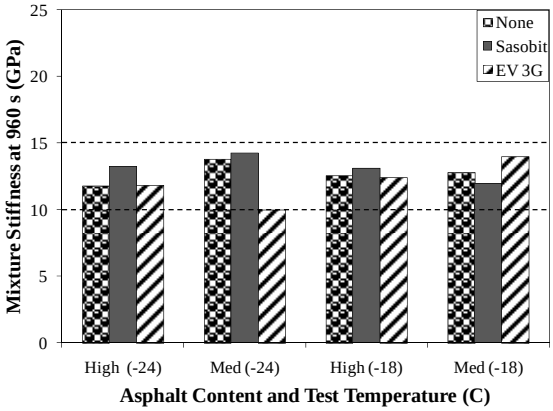
Figures 6.11 and 6.12 present *R-3* RAP test results. Approximately three-fourths of the factor-level combinations tested had mix stiffness between 10 and 15 GPa, with the remaining one-fourth between 15 to 17.5 GPa. The lowest observed stiffness was 11.3 GPa and the highest observed stiffness was 17.5 GPa. This range is very comparable to that observed for the *R-2* RAP source. No other identifiable trends were observed for *R-3*. The

range of measured stiffness for *R-3*, as well as *R-1* and *R-2*, were relatively modest considering the extensive set of factor-level combinations tested. The data provides a good reference from which to evaluate stiffness properties of 25 and 50% RAP mixes using the same sources.

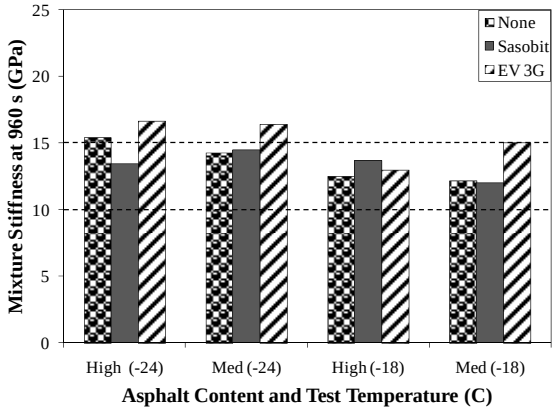


a) 50 Gyrations and 116 C

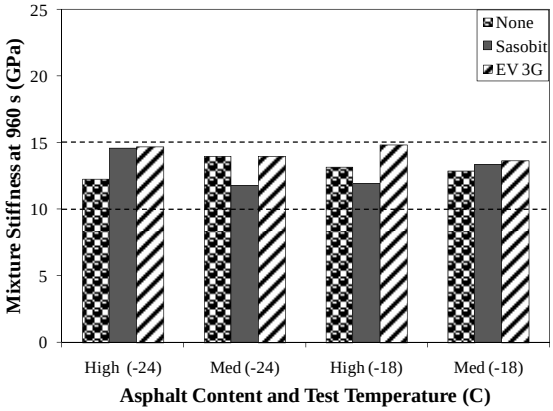
b) 50 Gyrations and 138 C



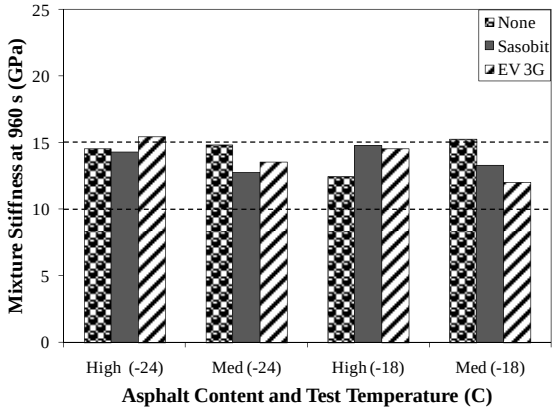
c) 65 Gyrations and 116 C



d) 65 Gyrations and 138 C



e) 85 Gyrations and 116 C



f) 85 Gyrations and 138 C

Figure 6.7 *R-1* Test Results at Warm Mix Temperatures

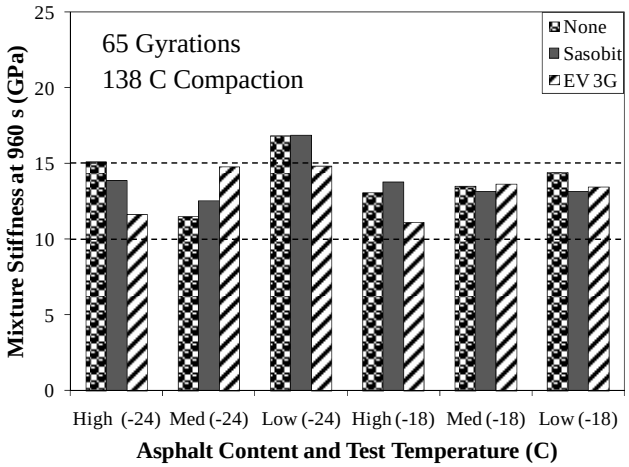


Figure 6.8 *R-1* Test Results at Hot Mix Temperatures

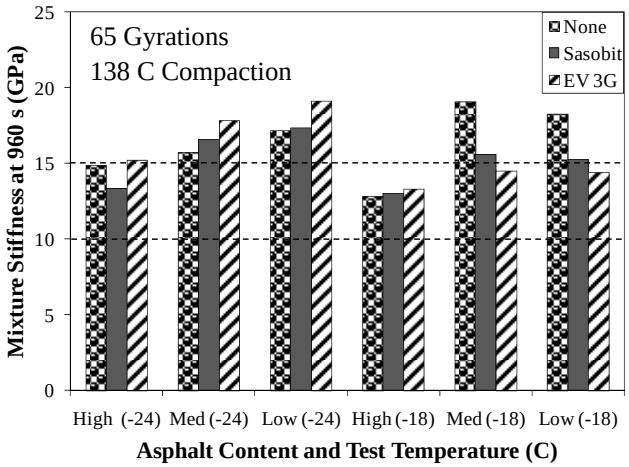


Figure 6.9 *R-2* Test Results by Warm Mix Additive

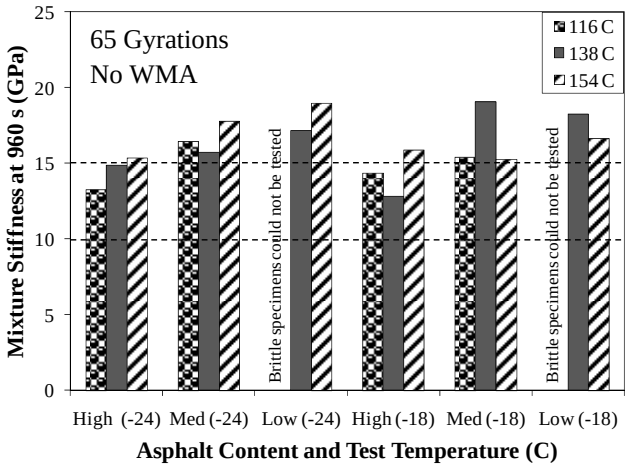


Figure 6.10 *R-2* Test Results by Compaction Temperature

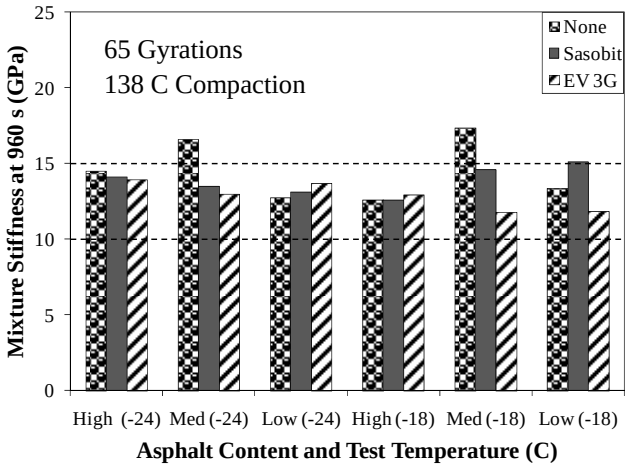
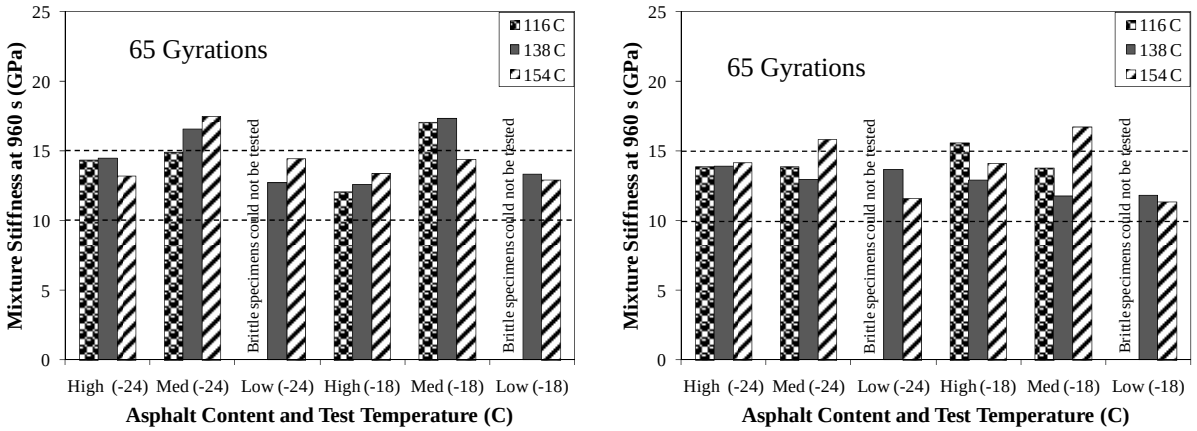


Figure 6.11 *R-3* Test Results by Warm Mix Additive



a) No Warm Mix Additive *b) Evotherm 3G™*

Figure 6.12 *R-3* Test Results by Compaction Temperature

6.4 Rutting Data

Three test methods were utilized to evaluate rutting in a hot-dry condition. They are 1) *APA*; 2) PURWheel dry protocol; and 3) *MRTCR*. All three tests were performed at 64 C.

6.4.1 *APA*

6.4.1.1 Designed 100% RAP Mixtures

APA rut testing was performed on *SGC* compacted specimens as described in Section 3.5.6 at nominal air void levels of 7 and 10%. Raw data is located in Tables D.1, D.2, and D.3, and Table 6.3 summarizes the results. In all cases the regression equations provided a good fit of the data as evidenced by the R^2 values of 0.95 or greater. In all cases total rutting was very low; less than 1.5 mm for 7% air voids and less than 2.5 mm for 10% air voids.

The amount of total rutting was similar to that of control mixtures with polymer modified binder.

Table 6.3 *APA* Results for Designed 100% RAP Mixtures

Mixture ID	Avg. V_a (%)	Rut Depth (mm)		Linear Rutting Rate[1]			Power Law[2]		
		2000	8000	Slope (10^{-6})	Intercept	R^2	*a*	*b*	R^2
9.5-100/RM-1	6.7	0.8	1.1	57	0.69	0.98	0.082	0.293	0.95
	9.6	1.2	2.0	128	0.96	0.99	0.059	0.389	0.98
9.5-100/RM-2	7.1	0.8	1.2	132	0.75	0.98	0.029	0.458	0.99
	10.1	1.2	2.3	184	0.85	0.99	0.025	0.504	0.99
12.5-100/RM-3	7.0	1.0	1.5	89	0.81	0.98	0.065	0.351	0.97
	9.8	0.8	1.5	100	0.68	0.99	0.047	0.381	0.99

1: Linear rutting rate regression analysis is based on averaged data between 2000 and 8000 cycles.

2: Power law regression analysis is based on averaged data and Eq. 2.3.

6.4.1.2 Data from Expanded RAP Compaction Experiment

R-1 RAP with additional virgin binder was compacted at a variety of factor-level combinations as described in Section 3.6.2. A single replicate of each factor-level combination was then tested as described in Table 3.9. The specimens encompassed a range of air voids rather than V_a of 7.0 ± 0.5 % as specified by *AASHTO TP 63*. The purpose of testing was to investigate if 100% RAP specimens with varying amounts of virgin binder were at all susceptible to rutting.

Specimens that were 150 mm diameter and nominal 115 mm tall were trimmed to 75 mm tall then tested as described in Section 3.5.6. The final rut depths are provided in Tables D.4 and D.5. Manual rut depth measurements generally compared well to the automatic measurements from the *APA*. For all specimens, no rut depths exceeded 2 mm. Figure 6.13 plots air voids versus rut depth for the specimens. Slightly higher rut depths are seen in specimens with higher total asphalt content (an expected behavior). Rut depths were less than 1 mm for specimens compacted within *AASHTO TP 63* air void limits. The results indicate that 100% RAP specimens with virgin binder rut on the same order of magnitude as acceptable traditional mixes but the values are smaller (e.g. 7 mm versus 1 mm).

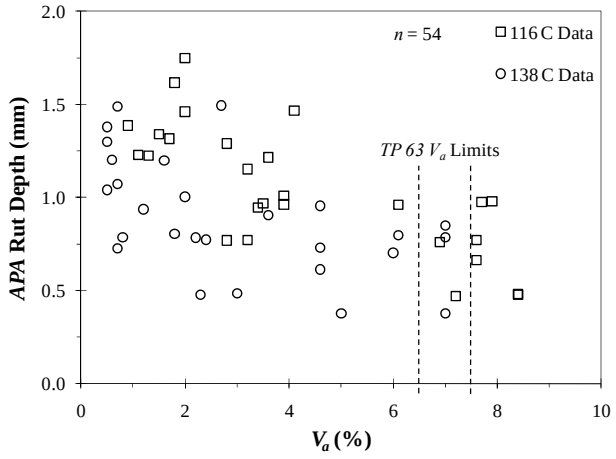


Figure 6.13 *APA* Rut Depth Results for *R-1* at Varying Conditions

6.4.2 PURWheel Dry Protocol for Designed 100% RAP Mixtures

PURWheel dry protocol rut testing was performed on *LAC* compacted specimens of designed 100% RAP mixtures as described in Section 3.5.7. Raw data is located in Tables E.1, E.3, and E.5, and the data is summarized in Table 6.4. Linear regression equations were fitted to the data between 2,000 and 20,000 passes and power law regression equations were fitted to the full range of data. The regression equations generally provided a good fit of the data as evidenced by R^2 values of 0.86 or greater.

PURWheel dry protocol average total rut depths for 100% RAP mixtures were generally low. For mixtures *9.5-100/RM-1* and *12.5-100/RM-3* the average total rut depths were the same, about 4.5 mm, and slightly less than those observed for control mixtures with polymer-modified binder in Chapter 5. Mixture *9.5-100/RM-2* exhibited an average total rut depth of about 6.5 mm, which is slightly higher than results for the other 100% RAP mixtures. Both *APA* and PURWheel test results indicate that 100% RAP mixes with virgin binder are rut resistant but they do rut a measurable amount.

Table 6.4 PURWheel Dry Protocol Test Results for Mixtures

			Rut Depth		Linear Rutting Rate[2]			Power Law[3]		
Mixture ID	**V_a (%)[1]**	**Rep**	**Pass**	**mm**	**Slope (10^{-4})**	**Intercept**	**R^2**	***a***	***b***	**R^2**
9.5-100/RM-1	9.5	1-L	20 k	4.4	100	1.91	0.98	0.102	0.380	0.98
		1-R	20 k	5.0	100	2.31	0.97	0.173	0.334	0.86
	9.8	2-L	20 k	3.3	90	1.55	0.97	0.087	0.367	0.99
		2-R	20 k	5.3	200	2.42	0.98	0.134	0.371	0.99
Average	**9.7**	**---**	**20 k**	**4.5**	**123**	**2.05**	**---**	**0.124**	**0.363**	**---**
9.5-100/RM-2	10.0	1-L	20 k	8.7	300	2.84	0.98	0.073	0.475	0.95
		1-R	20 k	7.1	200	2.84	0.96	0.052	0.494	0.92
	9.6	2-L	20 k	5.2	200	1.79	0.97	0.039	0.500	0.96
		2-R	20 k	5.4	200	1.85	0.97	0.031	0.524	0.96
Average	**9.8**	**---**	**20 k**	**6.6**	**225**	**2.33**	**---**	**0.049**	**0.498**	**---**
12.5-100/RM-3	9.5	1-L	20 k	4.1	100	1.84	0.97	0.099	0.376	0.91
		1-R	20 k	5.7	200	2.78	0.95	0.091	0.423	0.92
	11.2	2-L	20 k	3.4	100	1.40	0.97	0.029	0.490	0.88
		2-R	20 k	5.3	200	1.73	0.97	0.029	0.527	0.96
Average	**10.4**	**---**	**20 k**	**4.6**	**150**	**1.94**	**---**	**0.062**	**0.454**	**---**

1: Specimen air voids correlated to *AASHTO T 331.*
2: Linear rutting rate regression analysis is based on averaged data between 2000 and 20000 passes.
3: Power law regression analysis is based on averaged data and Eq. 2.3.

6.4.3 *MRTCR* Data from Expanded RAP Compaction Experiment

MRTCR testing was performed as described in Section 3.5.9 on the factor-level combinations described in Table 3.9. Raw data is located in Tables G.2 to G.9. Based on analysis of control mixture data described in Section 5.4.3, failure strain (F_ε) was selected as the response variable for analysis of the data in this section. ANOVA statistical testing was performed of the various subsets of data as discussed in the following paragraphs. Details of the statistical analyses are omitted for brevity and only summary conclusions are discussed.

All testing of *R-1* RAP specimens was performed at a 272 kPa stress level. Analysis of *R-1* RAP data at 116 C compaction temperature revealed that level of compactive effort had a significant effect on failure strain but this result is probably due to the increased compaction and lower air voids with increased compaction effort. Warm mix additives were not observed to have a significant effect although a difference was noticeable. Mix without additives had a lower failure strain than mix with additives; both additives had a similar level of failure strain. *R-1* data at 138 C compaction temperature did not reveal any statistical significance. Analysis of all *R-1* data revealed compaction temperature was a significant factor but, similar to compactive effort, the result was likely driven by air void differences.

Specimens of *R-2* RAP with high total asphalt content were tested with a 272 kPa stress level, while *R-2* RAP with medium asphalt content was tested at a 544 kPa stress level. For high total asphalt content, warm mix additives were observed to have a noticeable but not statistically significant effect on failure strain. Specimens with Evotherm 3G™ had the highest failure strains and specimens with no additive had the lowest failure strains. Warm mix additives were not observed to have significant effects on medium asphalt content data.

R-3 specimens with high total asphalt content were tested with a 272 kPa stress level; specimens with medium and low total asphalt content were tested with a 544 kPa stress level. For high total asphalt content *R-3* specimens, warm mix additives had a significant effect with Evotherm 3G™ specimens having the highest failure strains and no additive specimens having the lowest failure strains. Specimens with Sasobit® had an intermediate failure strain that was not statistically different than specimens without additives. For *R-3* tested with the higher stress level, total asphalt content was found to have a significant effect on failure strain but this is not surprising given the differences in compaction and of virgin binder.

When all data with 138 C compaction temperature, 65 gyrations compactive effort, and 272 kPa test stress level was analyzed some interesting trends were observed. Figure 6.14 presents *MRTCR* results for all three RAP sources at the aforementioned combination of factors. For *R-1*, no significant differences are observed between warm mix additives and average failure strain is about 15%. For *R-2,* both warm mix additives have higher failure strains than no additive. Overall the failure strains for *R-2* ranged from 26 to 33% which is nearly double that for *R-1*. For *R-3,* the differences in performance of warm mix additives follow the same ranking as for *R-2* (i.e. Evotherm 3G™ specimens had the highest failure strain, no additive the lowest, and Sasobit® specimens had an intermediate level of failure strain). The relative differences between performance of warm mix additives are greater for *R-3* than for *R-2*. Failure strains for *R-3* specimens ranged from 22 to 31% which overlapped the range of performance for *R-2* but was still much higher than failure strains for *R-1*.

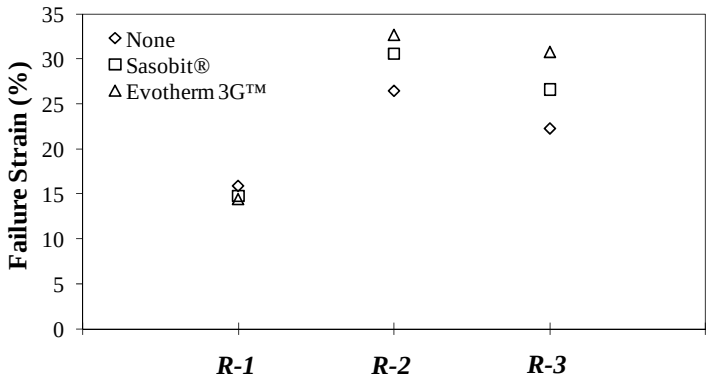


Figure 6.14 *MRTCR* Results

6.5 Moisture Damage Data

6.5.1 *TSR*

For designed 100% RAP mixtures (*9.5-100/RM-1, 9.5-100/RM-2,* and *9.5-100/RM-3*) *TSR* moisture susceptibility testing was performed on *SGC* compacted specimens as described in Section 3.5.5. Raw data is located in Tables F.6 to F.8, and the results are summarized in Table 6.5. The *R-1* RAP source had an acceptable *TSR* value (i.e. >80%), while the *R-2* and *R-3* RAP sources did not. Air voids for mixture *9.5-100/RM-2* were higher than specified by the test method, but the mixture was not re-tested.

Table 6.5 *TSR* Results for Designed 100% RAP Mixtures

Mixture	Conditioned Set			Un-Conditioned Set		
ID	Avg. V_a (%)	Sat (%)	S_t (kPa)	Avg. V_a (%)	S_t (kPa)	*TSR* (%)
9.5-100/RM-1	6.4	68	2008	6.5	2229	90
9.5-100/RM-2	8.4[1]	62	1680	8.4	2603	65
12.5-100/RM-3	7.4	62	1383	7.5	1959	71

1: Air voids slightly high but not re-tested.

6.5.2 PURWheel Wet Protocol

PURWheel wet protocol testing was performed as described in Section 3.5.7 for all designed 100% RAP mixtures. Raw data is located in Tables E.2, E.4, and E.6. Analysis of the data was performed in the manner described in Section 5.5.2. Figure 6.15 presents results of wet and dry protocol PURWheel tests for mixture with *R-1*; three of the four wet test specimens exhibited evidence of moisture damage in the data and early test termination. The wet test specimen that did not terminate early exhibited a higher rate of rutting than dry test specimens.

Figure 6.16 presents results of wet and dry protocol PURWheel testing for mixture with *R-2*; only one of the four wet test specimens exhibited evidence of moisture damage and premature test termination. The other wet test specimens did exhibit somewhat higher rates of rutting than did the dry test specimens.

Figure 6.17 presents wet and dry protocol PURWheel test results of mixture with *R-3*. Overall three of the four wet test specimens exhibited moisture damage and early test termination. The two replicates with the worst performance came from the same *LAC* compacted slab.

Table 6.6 summarizes PURWheel wet protocol results for designed 100% RAP mixes. Mixtures *9.5-100/RM-1, 9.5-100/RM-2*, and *9.5-100/RM-3* have Table 5.11 performance classifications of 3, 4, and 3 (almost classified as 2), respectively. The *LAC* compacted replicate slab specimen seen in Figure 6.17 that performed poorly had higher air voids than its companion slab. Examination of the results for mixture *9.5-100/RM-1* in Table 6.6 and Figure 6.15 reveals that the *LAC* slab in that test set with higher air voids outperformed the companion slab with lower voids. The results bring into question the impact of air voids in evaluating performance of *LAC* slab specimens in the PURWheel wet protocol test. Several tests of one mixture with varying air voids is needed before specific statements could be made. Interestingly, results of *TSR* testing on designed 100% RAP mixtures does not agree with PURWheel wet protocol test results for the same mixture.

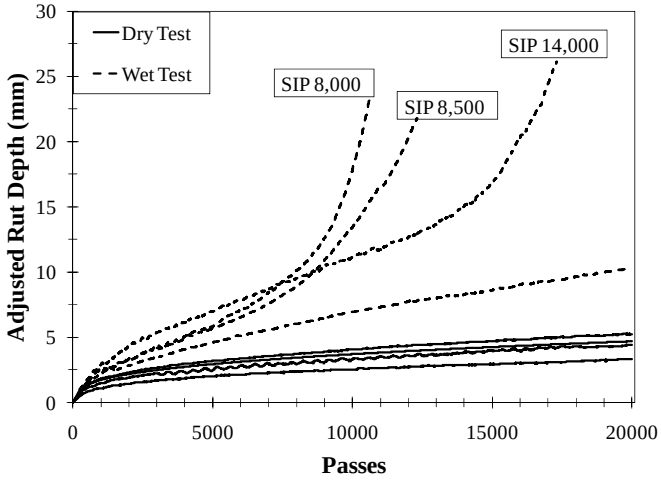


Figure 6.15 PURWheel Test Results for Mixture *9.5-100/RM-1*

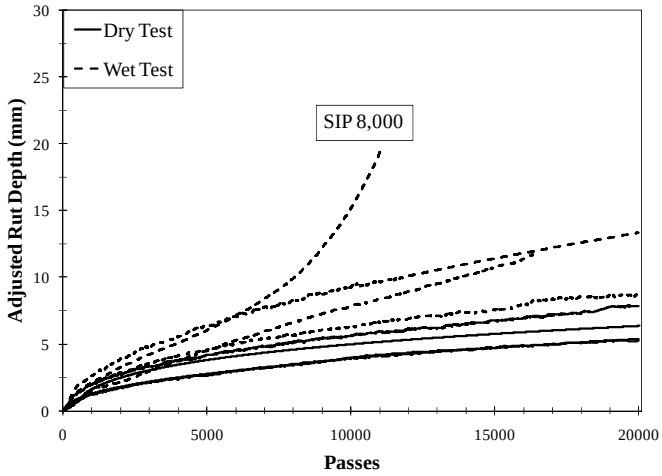


Figure 6.16 PURWheel Test Results for Mixture *9.5-100/RM-2*

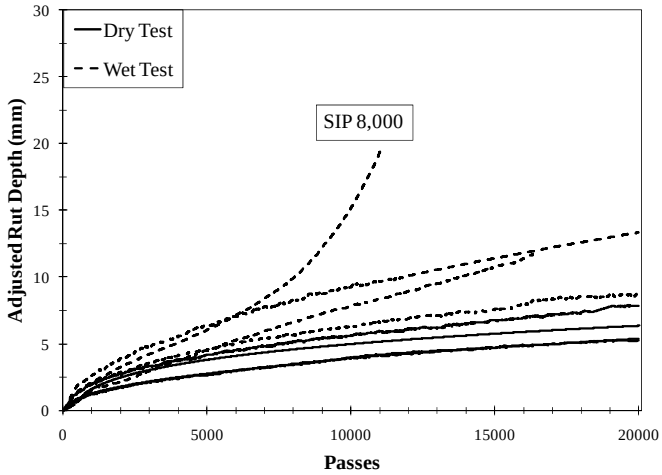


Figure 6.17 PURWheel Test Results for Mixture *12.5-100/RM-3*

Table 6.6 Summary of PURWheel Wet Test Results for Designed 100% RAP Mixtures

				Termination		Visual Assessment		
Mixture ID	**V_a (%)[1]**	**Rep**	**SIP**	**Pass**	**(mm)**	**Bare Agg.**	**Loose Agg.**	**Crack**
9.5-100/RM-1	9.8	1-L	8,500	10,620	23.5	Yes	Yes	Yes
		1-R	8,000	12,314	21.8	Yes	Yes	Yes
	11.3	2-L	14,000	17,312	26.1	Yes	Yes	Yes
		2-R	None	20 k	10.3	Yes	No	Yes
Average	**10.6**	**---**	**12,625**	**15,062**	**20.4**	**---**	**---**	**---**
9.5-100/RM-2	8.8	1-L	None	20 k	8.8	Yes	No	No
		1-R	None	16,412	11.7	Yes	No	No
	10.6	2-L	None	20 k	13.3	Yes	No	No
		2-R	8,000	11,490	19.8	Yes	Yes	Yes
Average	**9.7**	**---**	**17,000**	**16,976**	**13.4**	**---**	**---**	**---**
12.5-100/RM-3	8.7	1-L	16,000	18,130	16.2	Yes	Yes	No
		1-R	None	20,000	6.2	Yes	No	No
	11.5	2-L	3,000	3,800	29.5	Yes	Yes	Yes
		2-R	4,000	4,174	18.1	Yes	Yes	Yes
Average	**10.1**	**---**	**10,750**	**11,526**	**17.5**	**---**	**---**	**---**

Note: When no SIP was observed, a value of 20,000 passes was used to calculate the average SIP.
1: Specimen air voids correlated to *AASHTO T 331*.

6.6 Skid Resistance Data

Analysis was performed with the methods described in Section 5.6. Panel properties, macrotexture results, and friction tester results are found in Table 6.7. *CTMeter* and *DFTester* results were utilized to calculate IFI values according to *ASTM E 1960* (Table 6.8).

Table 6.7 Test Results for Skid Resistance Panels of *9.5-100/RM-1*

		Est. V_a	Macrotexture *E 2157*			Friction *E 1911*		
Mixture ID	**Rep**	**(%)**	**N**	**Dropout**	**MPD (mm)**	***DFT*$_{20}$**	***DFT*$_{60}$**	***DFT*$_{64}$**
9.5-100/RM-1	1	8.5	8	0%	0.42	0.518	0.431	0.432
	2	9.0	7	2%	0.64	0.651	0.452	0.454
	3	9.8	6	2%	0.57	0.585	0.403	0.406
	4	6.7	5	3%	0.62	0.630	0.448	0.449
	5	8.7	6	1%	0.52	0.563	0.443	0.447
	Avg.	**8.5**	**6**	**2%**	**0.55**	**0.589**	**0.435**	**0.438**
	Std. Dev.	**1.1**	**1**	**1%**	**0.09**	**0.053**	**0.020**	**0.019**

Note: The subscript for friction coefficient results denote the test speed in *km/hr*.

Table 6.8 IFI Calculation Results for Panels by *ASTM E 1960*

Mixture	**Rep**	**Speed Constant (S_p)**	**Friction Value at 60 km/hr (*F60*)**
9.5-100/RM-1	1	51.87	0.26
	2	71.61	0.35
	3	65.33	0.31
	4	69.81	0.34
	5	60.84	0.29
	Avg.	**63.89**	**0.31**
	Std. Dev.	**7.91**	**0.04**

6.7 Indirect Tensile Strength Data

Indirect tensile (IDT) strength testing was performed on specimens from the expanded RAP compaction experiment described in Sections 3.5.2 and 3.6.2.2. The data is provided in Tables 6.9 and 6.10. Figure 6.18 plots the relationship between indirect tensile strength and air voids using all the data. Data for both compaction temperatures was intermingled and it was observed that a large portion of the variation in S_t was driven by changes in V_a although the trend is nonlinear. No useful trends were observed in the response variables of time to failure (*T*) or vertical specimen deformation before failure (*V-def*).

Table 6.9 Indirect Tensile Data for 100% *R-1* RAP Compacted at 116 C

N_{des}	Additive	P_{AC} (%)	V_a (%)	S_t (kPa)	*T* (sec)	*V-def* (mm)
50	None	8.1	2.7	2944	3.066	2.18
		7.1	5.4	2464	2.866	2.11
		6.0	8.9	1858	2.266	1.42
	Sasobit®	8.1	2.3	2993	2.633	1.85
		7.1	4.3	2947	2.666	2.01
		6.0	8.5	1765	2.633	1.85
	Evotherm 3G™	8.1	2.1	3198	2.700	1.91
		7.1	5.4	2669	2.700	2.01
		6.0	8.5	1759	1.933	1.40
65	None	8.1	1.5	3261	2.900	1.98
		7.1	3.9	3182	2.566	1.78
		6.0	7.6	2083	1.867	1.37
	Sasobit®	8.1	1.5	3277	2.800	2.01
		7.1	4.5	3049	2.433	1.70
		6.0	8.2	1939	1.867	1.30
	Evotherm 3G™	8.1	1.8	3200	2.733	1.88
		7.1	4.9	2816	2.933	2.11
		6.0	7.9	2178	1.900	1.37
85	None	8.1	1.4	3285	2.766	1.98
		7.1	3.2	3504	2.767	1.91
		6.0	6.0	2300	1.900	1.45
	Sasobit®	8.1	1.4	3266	2.634	1.96
		7.1	3.6	3122	2.866	1.98
		6.0	7.4	2188	3.533	1.37
	Evotherm 3G™	8.1	1.1	3180	2.766	1.96
		7.1	4.2	3599	2.700	1.73
		6.0	6.0	2101	2.000	1.45

Table 6.10 Indirect Tensile Data for 100% *R-1* RAP Compacted at 138 C

N_{des}	Additive	P_{AC} (%)	V_a (%)	S_t (kPa)	T (sec)	*V-def* (mm)
50	None	8.1	1.1	3351	2.933	1.96
		7.1	3.7	3357	2.633	1.83
		6.0	7.2	2425	2.433	1.75
	Sasobit®	8.1	1.1	3327	2.800	1.91
		7.1	3.6	3275	2.600	1.85
		6.0	6.9	2372	2.166	1.55
	Evotherm 3G™	8.1	0.6	3381	2.800	1.91
		7.1	4.1	3225	2.534	1.68
		6.0	7.0	2778	2.000	1.37
65	None	8.1	0.8	3363	3.900	2.39
		7.1	3.3	3491	3.134	1.98
		6.0	6.5	2487	3.067	1.57
	Sasobit®	8.1	0.6	3097	2.967	2.12
		7.1	3.2	3564	2.917	1.92
		6.0	5.2	2880	2.200	1.60
	Evotherm 3G™	8.1	0.7	3033	2.900	2.08
		7.1	2.9	3556	3.534	2.51
		6.0	6.3	2983	2.400	1.60
85	None	8.1	0.6	3498	3.033	1.93
		7.1	2.4	3374	2.833	1.91
		6.0	6.1	2649	2.033	1.40
	Sasobit®	8.1	0.3	3423	3.534	2.57
		7.1	2.9	3479	2.634	1.88
		6.0	4.3	3640	2.334	1.50
	Evotherm 3G™	8.1	0.1	3527	2.967	2.08
		7.1	2.1	3519	2.700	1.83
		6.0	4.9	2718	2.234	1.70

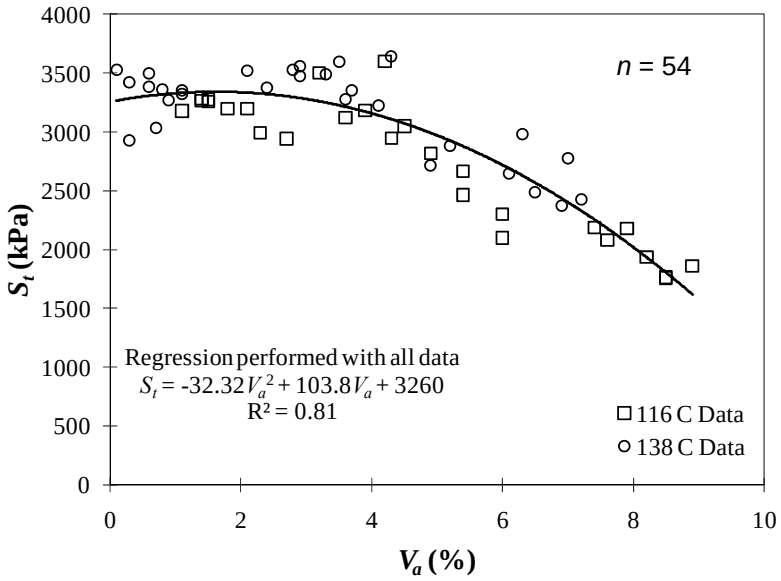


Figure 6.18 Relationship between S_t and V_a for Compacted 100% *R-1* RAP

CHAPTER 7 – 25 and 50% RAP MIXTURE RESULTS

7.1 Overview of 25 and 50% RAP Mixture Results

This chapter presents results of testing of 25 and 50% RAP recycled mixtures, as described in Table 3.11. The chapter is organized by category of mixture performance with subsections for each test method. The mixtures evaluated in this chapter are the primary focus of this report. They are under consideration for use in service and are evaluated with respect to the mixes presented in Chapters 5 and 6 in Chapter 8.

7.2 Cantabro Durability Data

Cantabro testing (aged and un-aged) was performed as described in Section 3.5.4. The data is located in Tables C.17 to C.20, and the results are summarized in Table 7.1. Mass loss was 11.9 to 13.2% for the 25% RAP mixtures. These results were similar to or only slightly higher than the range of mass loss observed for control mixtures of 12% or less. Mass loss was 14.1 to 16.7% for the 50% RAP mixtures. These results were slightly higher than results for the 25% RAP mixtures and somewhat higher than results observed for control mixtures.

Increasing the amount of *R-1* RAP from 25 to 50% resulted in a mass loss increase of about 5% while the same increase in *R-2* RAP only resulted in a mass loss increase of about 1%. Cantabro testing of 100% RAP mixtures indicated *R-1* would be more susceptible to mass loss than *R-2* when incorporated into a recycled mixture. This was observed in the 50% RAP mixtures but not in the 25% RAP mixtures. The difference in average specimen air voids between 25% RAP mixtures might account for the observed difference in mass loss since the difference in mass loss between the 25% RAP mixtures was only 1.3%.

Table 7.1 Cantabro Data for Un-Aged 25 and 50% Recycled Mixtures

Mixture ID	*n*	Avg. Air Voids (%)	Avg. *ML* (%)
9.5-25/RM-1	3	4.6	11.9
9.5-25/RM-2	3	5.2	13.2
9.5-50/RM-1	3	5.2	16.7
9.5-50/RM-2	3	5.2	14.1

Aged Cantabaro test results are summarized in Table 7.2. Mixtures with *R-1* RAP and *R-30* aging were utilized based on previous test results that they produced higher mass loss. With 25% RAP the aged specimens had an increase in mass loss compared to the un-aged specimens of about 6%, which is slightly higher than the 2 to 4% increase observed for control mixtures after aging. For the 50% RAP mixture the mass loss after *R-30* aging was on the order of 9% higher than mass loss for the un-aged mixture.

Table 7.2 Cantabro Data for Aged 25 and 50% Recycled Mixtures with *R-1* RAP

Mixture ID	Aging Protocol	*n*	Avg. Air Voids (%)	Avg. *ML* (%)
9.5-25/RM-1	*R-30*	3	4.7	17.8
9.5-50/RM-1	*R-30*	3	5.7	25.6

7.3 *BBR* Data

BBR testing of recycled mixtures was performed at four test temperatures as described in Section 3.5.3. The data is located in Tables B.28 to B.43. Figure 7.1 presents stiffness isotherms of the *BBR* data at -24 C. Dashed lines in Figure 7.1 are the upper and lower stiffness isotherms for control mixtures tested in Chapter 5 at -24 C. Stiffness isotherms for all four mixtures with 25 or 50% RAP fall within or overlap the band of control mixture (CM) stiffness. Figure 7.2 presents data at -18 C; stiffness isotherms for all four mixtures with 25 or 50% RAP again fall within or overlap the band of control mixture stiffness. In general, the mixes tested at -18 C are less stiff than when tested at -24 C which is a reasonable result. In general, at -24 C and -18 C the mixtures with 50% RAP are slightly stiffer than or of similar stiffness to the mixtures with 25% of the same source of RAP.

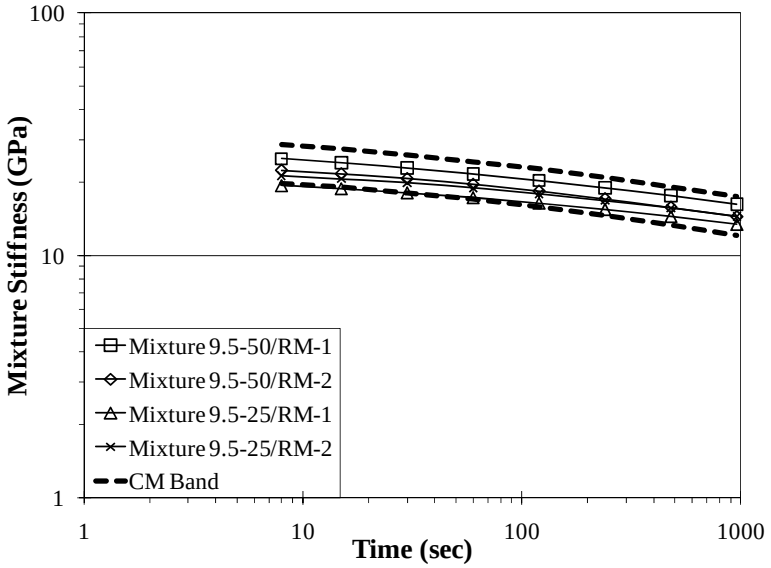


Figure 7.1 *BBR* Stiffness Data for 25 and 50% RAP Mixtures at -24 C

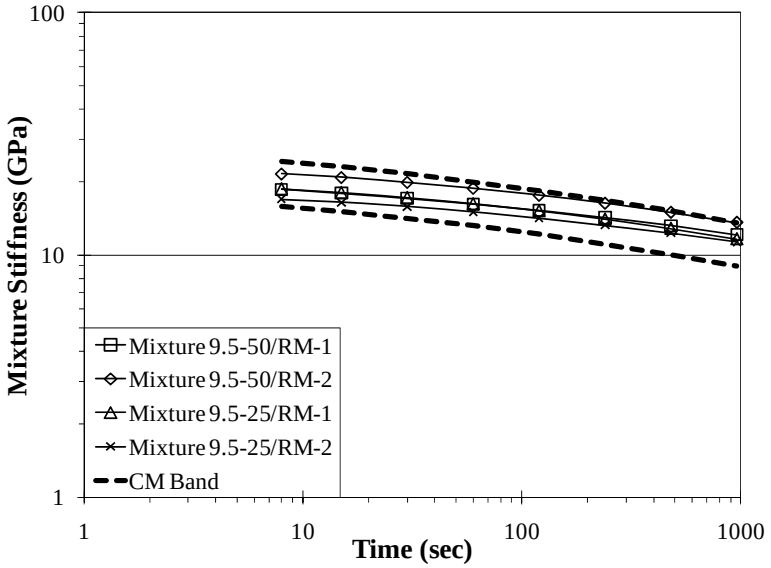


Figure 7.2 *BBR* Stiffness Data for 25 and 50% RAP Mixtures at -18 C

Figures 7.3 and 7.4 present stiffness isotherms of 25 and 50 % RAP mixes alongside control mixture bands collected at -12 C and -06 C, respectively. All 25 and 50% RAP mixes at -12 C and -06 C are of similar or higher stiffness than the upper band of control mixture stiffness. In general, the mixes tested at -06 C are less stiff than when tested at -12 C which is a reasonable result. In general, at -12 C and -06 C the mixes with 50% RAP are slightly stiffer than or of similar stiffness to the mixes with 25% of the same source of RAP.

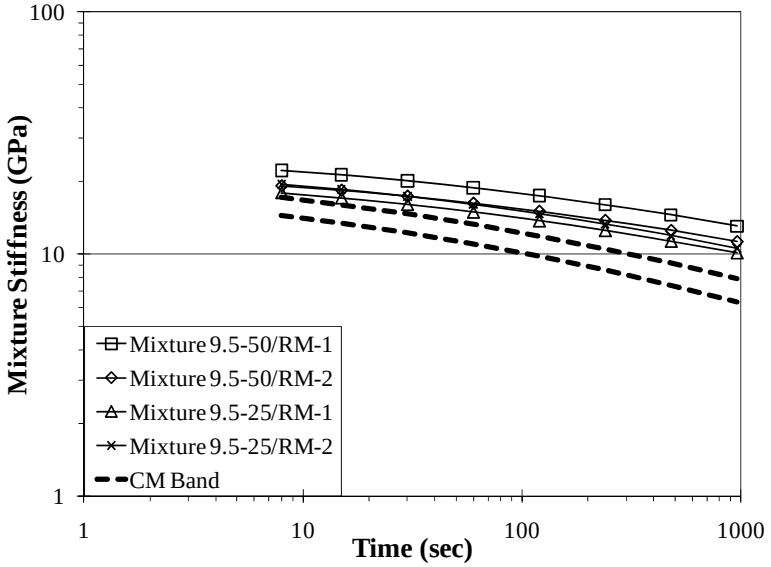


Figure 7.3 *BBR* Stiffness Data for 25 and 50% RAP Mixtures at -12 C

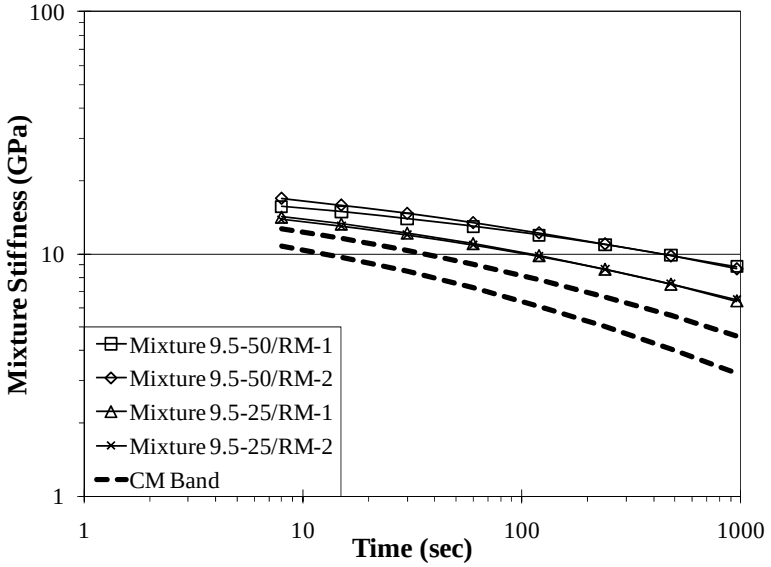


Figure 7.4 *BBR* Stiffness Data for 25 and 50% RAP Mixtures at -06 C

7.4 Rutting Data

Two test methods were utilized to evaluate rutting in a hot-dry condition. They are: 1) *APA*; and 2) PURWheel dry protocol. Both tests were performed at 64 C.

7.4.1 *APA*

For 25 and 50% RAP control mixtures *APA* testing was performed on *SGC* compacted specimens as described in Section 3.5.6. Specimens with 7 and 10% nominal air voids were tested, and the data is located in Tables D.11 to D.14; Table 7.3 summarizes the data. Linear regression equations were fitted to the data between 2,000 and 8,000 passes and power law regression equations were fitted to the full range of test data. The regression equations generally provided a good fit of the data as evidenced by R^2 values of 0.94 or greater. Total rut depths for 25% RAP mixtures were less than 3 mm for nominal 7% air void specimens, and were less than 5 mm for nominal 10% air void specimens. *APA* rutting performance of the 25% RAP mixtures was comparable to that of HT control mixtures, yet they were designed as MT mixtures.

The total rut depth for the 50% *R-1* mixture was 1.9 mm for nominal 7% air voids and 2.9 mm for nominal 10% air voids. For 50% *R-2* the total rut depths were on the order of 4 mm for 7% air void specimens and less than 6 mm for 10% air void specimens. The *R-2* RAP source had slightly higher rutting than the *R-1* RAP source. Overall, *APA* rutting performance of the 25 and 50% RAP mixtures was good and comparable to HT control mixtures, which is the best reference for rut resistance.

Table 7.3 *APA* Results for 25 and 50% RAP Mixtures

Mixture	Avg.	Rut Depth (mm)		Linear Rutting Rate[1]			Power Law[2]		
ID	V_a (%)	2000	8000	Slope (10^{-6})	Intercept	R^2	*a*	*b*	R^2
9.5-25/RM-1	6.9	1.3	2.4	180	1.04	0.99	0.047	0.439	0.99
	9.5	3.3	5.0	266	3.04	0.94	0.071	0.488	0.95
9.5-25/RM-2	6.9	1.5	3.0	251	1.03	1.00	0.045	0.462	0.99
	9.9	3.3	5.0	268	2.96	0.97	0.093	0.454	0.94
9.5-50/RM-1	7.0	1.2	1.9	107	1.08	0.99	0.083	0.352	0.97
	9.9	1.5	2.9	212	1.21	0.98	0.056	0.438	1.00
9.5-50/RM-2	7.0	2.2	4.3	319	1.80	0.98	0.036	0.537	0.99
	10.0	3.3	5.6	369	2.86	0.96	0.054	0.527	0.97

1: Linear rutting rate regression analysis is based on averaged data between 2000 and 8000 cycles.
2: Power law regression analysis is based on averaged data and Eq. 2.3.

7.4.2 PURWheel Dry Protocol

For 25 and 50% RAP mixtures PURWheel dry rut testing was performed on *LAC* compacted specimens as described in Section 3.5.7. Raw data is located in Tables E.17, E.19, E.21, and E.23. Table 7.4 summarizes the data. Linear regression equations were fitted to the data between 2,000 and 20,000 passes and power law regression equations were fitted to the full range of test data. The regression equations generally provided a good fit of the data for the data as evidenced by the R^2 values of 0.85 or greater.

Average total rut depth for mixture *9.5-25/RM-1* was about 10 mm, and average total rut depth for mixture *9.5-25/RM-2* was about 8 mm. Considering variability between specimens, RAP sources *R-1* and *R-2* had similar rut levels when they comprised 25% of the total mixture. For 25% RAP mixtures the average total rut depths were higher than those observed for polymer-modified control mixtures and somewhat higher than those observed

for the field mixed version of control mixture 4 with PG 67-22. Total rut depths for 25% RAP mixes were less than those for control mixture 2 (ST mixture).

For 50% RAP mixtures, rutting was less than was observed for 25% RAP mixtures. Average total rut depth for *9.5-50/RM-1* was 3 mm and average total rut depth for mixture *9.5-50/RM-2* was about 7 mm. This result agrees with the higher viscosity and PG grade of *R-1* RAP asphalt compared to *R-2 RAP* asphalt which would indicate better rutting performance of *R-1*. PURWheel dry protocol test results for 50% RAP mixtures provided the same ranking of rutting performance as *APA* results. Rutting performance of the mixture with 50% *R-1* RAP was comparably or slightly better than that observed for polymer modified control mixtures; rutting performance of the mixture with 50% *R-2* RAP was similar to that observed for the field mixed version of control mixture 4 with PG 67-22. Total rut depths for 50% RAP mixes were less than those for control mixture 2 (ST mixture).

Table 7.4 PURWheel Dry Test Results for 25 and 50% RAP Mixtures

			Rut Depth		Linear Rutting Rate[1]			Power Law[2]		
Mixture ID	**V_a (%)[3]**	**Rep**	**Pass**	**mm**	**Slope (10^{-6})**	**Intercept**	**R^2**	***a***	***b***	**R^2**
9.5-25/RM-1	10.3	1-L	20 k	14.3	600	3.11	1.00	0.035	0.605	0.97
		1-R	20 k	9.1	400	2.34	0.99	0.030	0.576	0.97
	9.0	2-L	20 k	8.5	300	2.88	0.99	0.079	0.473	0.95
		2-R	20 k	6.0	200	2.05	0.99	0.043	0.500	0.96
Average	**9.7**	**---**	**20 k**	**9.5**	**375**	**2.60**	**---**	**0.047**	**0.539**	**---**
9.5-25/RM-2	---[4]	1-L	---	---	---	---	---	---	---	---
		1-R	---	---	---	---	---	---	---	---
	10.4	2-L	20 k	5.4	200	2.45	0.97	0.102	0.403	0.92
		2-R	20 k	11.0	400	4.45	0.98	0.152	0.434	0.93
Average	**10.4**	**---**	**20 k**	**8.2**	**300**	**3.45**	**---**	**0.127**	**0.419**	**---**
9.5-50/RM-1	8.1	1-L	20 k	2.7	60	1.69	0.95	0.135	0.309	0.86
		1-R	20 k	2.4	50	1.47	0.95	0.138	0.294	0.85
	8.7	2-L	20 k	3.9	90	2.36	0.90	0.155	0.334	0.87
		2-R	20 k	2.9	90	1.37	0.92	0.072	0.381	0.92
Average	**8.4**	**---**	**20 k**	**3.0**	**72.5**	**1.72**	**---**	**0.125**	**0.330**	**---**
9.5-50/RM-2	6.4	1-L	20 k	7.6	300	2.78	0.98	0.087	0.452	0.94
		1-R	20 k	5.5	200	2.22	0.98	0.086	0.419	0.94
	8.0	2-L	20 k	6.1	200	2.35	0.98	0.074	0.448	0.94
		2-R	20 k	9.8	300	3.23	0.99	0.086	0.477	0.95
Average	**7.2**	**---**	**20 k**	**7.3**	**250**	**2.65**	**---**	**0.083**	**0.449**	**---**

1: Specimen air voids correlated to *AASHTO T 331*.
2: Linear rutting rate regression analysis is based on averaged data between 2,000 and 20,000 passes.
3: Power law regression analysis is based on averaged data and Eq. 2.3.
4: Replicate one was found to be incorrect due to a laboratory batching error and was not re-made.

7.5 Moisture Damage Data

7.5.1 *TSR*

For 25 and 50% RAP mixtures *TSR* testing was performed on *SGC* compacted specimens as described in Section 3.5.5. Raw data is located in Tables F.2 to F.5, and the

results are summarized in Table 7.5. All mixtures had acceptable *TSR* results (i.e. >80%). In general, the 50% RAP mixtures had slightly higher tensile strengths than the 25% RAP mixtures. *TSR* testing of designed 100% RAP mixtures indicated that *R-2* RAP might be more prone to moisture susceptibility than *R-1* RAP but that trend is not observed in the 25 and 50% RAP mixture *TSR* data.

Table 7.5 *TSR* Results for 25 and 50% RAP Mixtures

Mixture	Conditioned Set			Un-Conditioned Set		
ID	Avg. V_a (%)	Sat (%)	S_t (kPa)	Avg. V_a (%)	S_t (kPa)	*TSR* (%)
9.5-25/RM-1	7.5	59	1407	7.4	1447	97
9.5-25/RM-2	7.9	64	1571	7.8	1614	97
9.5-50/RM-1	7.3	64	2053	7.2	2091	98
9.5-50/RM-2	8.0	62	1798	8.0	1942	93

7.5.2 PURWheel Wet Protocol

PURWheel wet protocol testing was performed as described in Section 3.5.7 for all 25 and 50% RAP mixtures. The data is located in Tables E.18, E.20, E.22, and E.24. Analysis of the data was performed in the manner described in Section 5.5.2. Figure 7.5 presents results of wet and dry protocol PURWheel testing of mixture *9.5-25/RM-1* containing 25% *R-1* RAP. All four PURWheel wet protocol specimens exhibited evidence of moisture damage and early test termination.

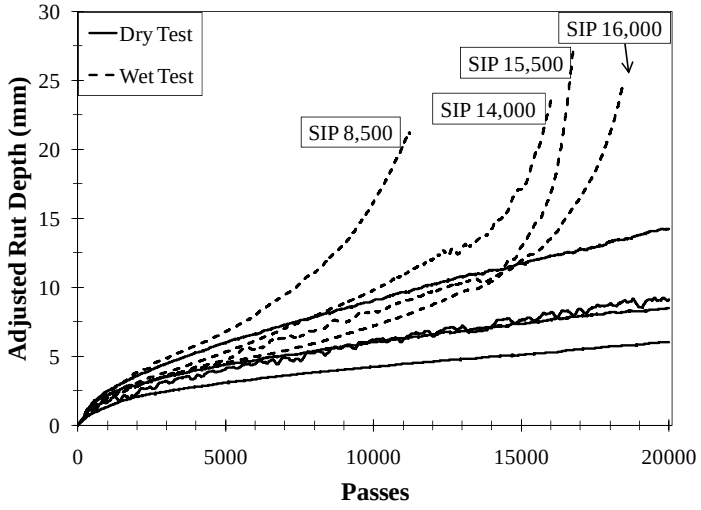


Figure 7.5 PURWheel Test Results for Mixture *9.5-25/RM-1*

Figure 7.6 presents PURWheel wet and dry protocol results for mixture *9.5-25/RM-2* containing 25% *R-2* RAP. Three of the four wet protocol specimens exhibited evidence of moisture damage. The specimen that did not exhibit moisture damage had rutting performance similar to that of dry specimens.

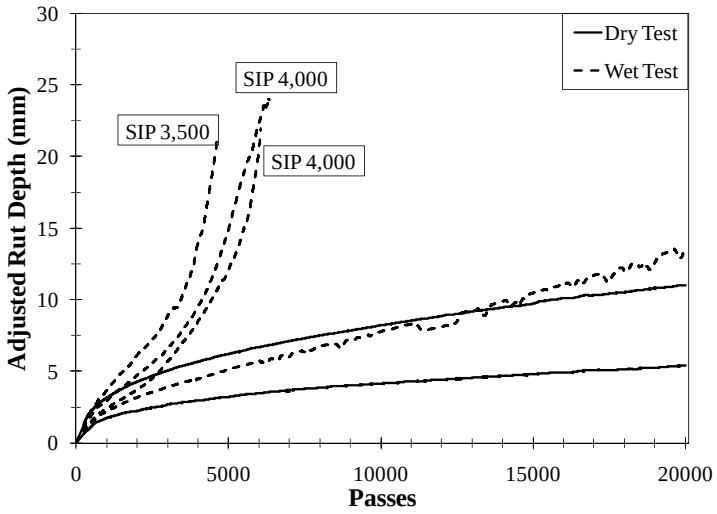


Figure 7.6 PURWheel Test Results for Mixture *9.5-25/RM-2*

Figure 7.7 presents wet and dry protocol PURWheel results for mixture *9.5-50/RM-1* containing 50% *R-1* RAP. Three of the four wet protocol specimens exhibited evidence of moisture damage. The wet protocol specimen that did not exhibit evidence of moisture damage performed similarly to specimens tested according to PURWheel dry protocol.

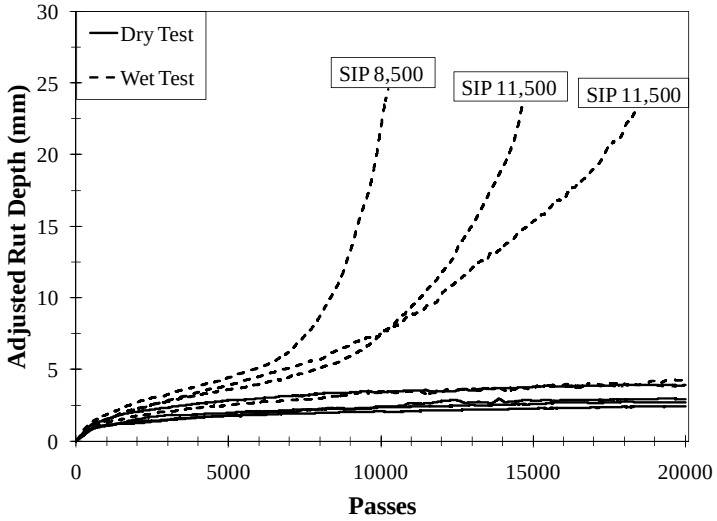


Figure 7.7 PURWheel Test Results for Mixture *9.5-50/RM-1*

Figure 7.8 presents wet and dry PURWheel test results for mixture *9.5-50/RM-2* containing 50% *R-2* RAP. Three of the four wet test specimens exhibited evidence of moisture damage. The wet test specimen that did not exhibit definitive evidence of moisture damage did have an increased rate of rutting compared to dry test specimens in the second half of the test; a mechanical malfunction caused premature termination of the test at 18,000 passes for the wet test specimen without definitive evidence of moisture damage.

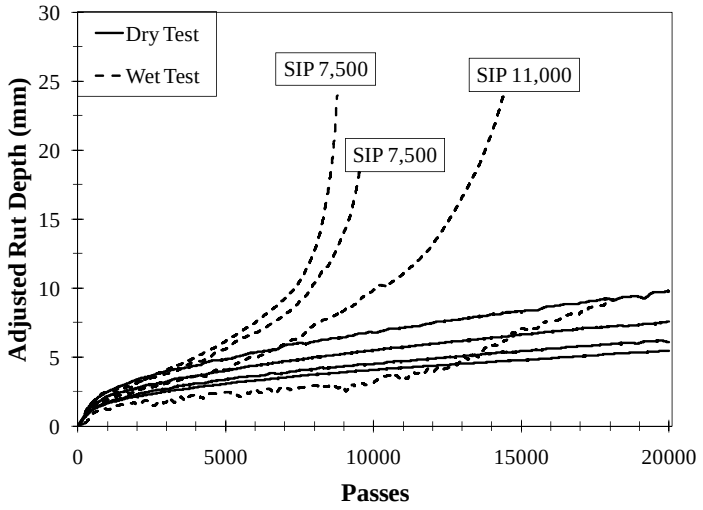


Figure 7.8 PURWheel Test Results for Mixture *9.5-50/RM-2*

Table 7.6 has results of 25 and 50% RAP mixes in the PURWheel wet protocol test. An average SIP was calculated for each mix; when no SIP was observed for a wet test specimen, a value of 20,000 passes was used to calculate an average SIP. Mixtures *9.5-25/RM-1*, *9.5-50/RM-1*, and *9.5-50/RM-2* are performance classification 3 according to Table 5.11. Mixture *9.5-25/RM-2* is a performance classification of 2 in the same proposed system.

Table 7.6 Summary of PURWheel Wet Test Results for 25 and 50% RAP Mixtures

				Termination		Visual Assessment		
Mixture ID	**V_a (%)[1]**	**Rep**	**SIP**	**Pass**	**(mm)**	**Bare Agg.**	**Loose Agg.**	**Crack**
9.5-25/RM-1	9.5	1-L	8,500	11,232	21.2	Yes	No	Yes
		1-R	14,000	16,022	23.7	Yes	No	No
	9.1	2-L	15,500	16,766	27.4	Yes	No	No
		2-R	16,000	18,452	25.0	Yes	No	No
Average	**9.3**	**---**	**13,500**	**15,618**	**24.3**	**---**	**---**	**---**
9.5-25/RM-2	9.1	1-L	3,500	4,660	21.5	Yes	No	Yes
		1-R	4,500	6,066	22.0	Yes	No	No
	8.9	2-L	4,000	6,342	24.0	Yes	No	No
		2-R	None	20 k	13.6	Yes	No	No
Average	**9.0**	**---**	**8,000**	**9,267**	**20.3**	**---**	**---**	**---**
9.5-50/RM-1	8.2	1-L	11,500	14,690	23.7	Yes	No	Yes
		1-R	11,500	18,360	23.0	Yes	No	No
	8.3	2-L	8,500	10,238	24.6	Yes	No	Yes
		2-R	None	20 k	4.3	Yes	No	No
Average	**8.3**	**---**	**12,875**	**15,822**	**18.9**	**---**	**---**	**---**
9.5-50/RM-2	6.4	1-L	11,000	14,406	24.1	Yes	No	No
		1-R	7,500	9,526	18.4	Yes	No	No
	8.0	2-L	7,500	8,774	24.0	Yes	Yes	Yes
		2-R	None	18,012[2]	9.2	Yes	No	No
Average	**7.4**	**---**	**11,500**	**12,680**	**18.9**	**---**	**---**	**---**

Note: When no SIP was observed, a value of 20,000 passes was used to calculate the average SIP.

1: Air voids correlated to *AASHTO T 331* values.

2: Premature termination caused by mechanical malfunction and not by excessive specimen deformation.

Overall, mixtures containing *R-1* RAP as either 25 or 50% of the total mixture performed somewhat better than mixtures containing *R-2* RAP in the same percentage. This result aligns with the results of *TSR* testing of designed 100% RAP mixtures. The result does not agree with results of PURWheel wet protocol testing of designed 100% RAP mixtures in terms of relative ranking.

7.6 Skid Resistance Data

Analysis of skid resistance data for panels of 50% RAP mixture *9.5-50/RM-1b* was performed according to the method described in Section 5.6. Properties of panels, macrotexture results, and friction tester results are presented in Table 7.7. Results of *CTMeter* and *DFTester* testing were utilized to calculate IFI values according to *ASTM E 1960* for the friction panels. IFI results for friction panels are summarized in Table 7.8.

Table 7.7 Test Results for Skid Resistance Panels

		Est. V_a	Macrotexture *E 2157*			Friction *E 1911*		
Mixture ID	**Rep**	**(%)**	**N**	**Dropout**	**MPD (mm)**	DFT_{20}	DFT_{60}	DFT_{64}
9.5-50/RM-1b	1	8.1	5	1%	0.50	0.578	0.442	0.442
	2	7.5	7	2%	0.76	0.623	0.537	0.541
	3	8.5	7	2%	0.60	0.554	0.448	0.449
	4	7.9	8	1%	0.65	0.558	0.451	0.453
	5	7.9	6	2%	0.62	0.668	0.527	0.528
	Avg.	**8.0**	**7**	**2%**	**0.63**	**0.596**	**0.481**	**0.483**
	Std. Dev.	**8.1**	**5**	**1%**	**0.50**	**0.578**	**0.442**	**0.442**

Note: The superscript for friction coefficient results denote the test speed in *km/hr*.

Table 7.8 IFI Calculation Results for Panels by *ASTM E 1960*

Mixture	**Rep**	**Speed Constant (S_p)**	**Friction Value at 60 km/hr (*F60*)**
9.5-50/RM-1b	1	59.05	0.30
	2	82.37	0.36
	3	68.02	0.31
	4	72.51	0.32
	5	69.81	0.36
	Avg.	**70.35**	**0.33**
	Std. Dev.	**8.41**	**0.03**

CHAPTER 8 – DISCUSSION OF RESULTS

8.1 Overview of Results Discussion

This chapter discusses the results presented in chapters 4 through 7 in the context of feasibility of 25 and 50% RAP surface mixes using warm mix technology. The chapter is organized by topic, with performance of 25 and 50% RAP mixtures compared to current practice control mixtures. This chapter also discusses how well test results of 100% RAP translate to performance of 25 and 50% RAP mixes using the same RAP source.

8.2 Durability

The Cantabro test was used to assess durability, and since literature review did not identify previous use of the test for dense graded mixtures, a random selection of QA specimens was tested to establish a baseline of expected performance of conventional practice Mississippi surface mixtures. Test specimens were compacted with a given number of gyrations as this would be most desirable for use as a routine quality control tool. Data in previous chapters showed a considerable effect of air voids, which should be considered when interpreting the data presented in this section.

Figure 8.1 presents test results of un-aged Cantabaro durability specimens. The band of results determined for control mixtures (2.8 to 11.7%) is represented by horizontal dashed lines. Mass loss for 25% RAP recycled mixtures was on the order of 12 to 13% and comparable to the upper end of Cantabro performance observed for control mixtures. Mass loss for 50% RAP mixtures was on the order of 14 to 17% which was slightly higher than the observed range of performance for control mixtures. For the *R-1* RAP source, increasing the amount of RAP from 25 to 50% caused an increase in mass loss of about 5%. For the *R-2* RAP source, increasing the amount of RAP from 25 to 50% caused an increase in mass loss of about 1%. Mass loss of all control, 25 and 50% RAP mixtures was less than the 20% upper limit for mass loss recommended in literature for OGFC and PFC mixtures.

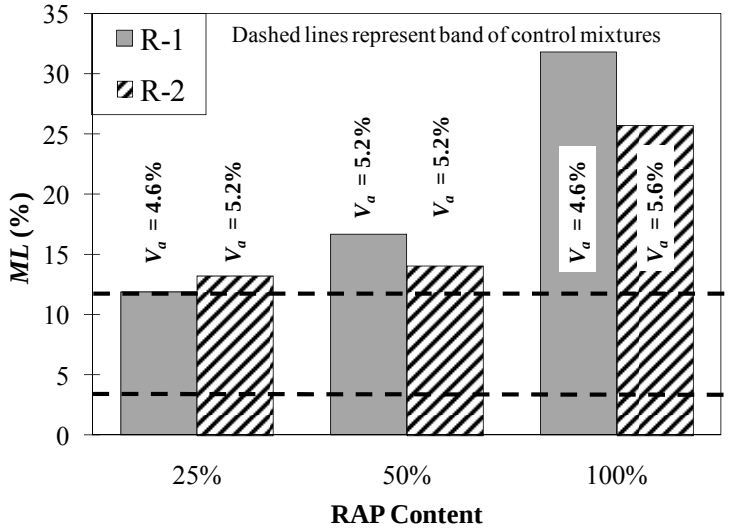


Figure 8.1 Effect of RAP Source on Cantabro Mass Loss for Un-Aged Specimens

Results of testing 100% RAP indicated that mixtures containing *R-1* RAP would likely have higher mass loss than mixtures containing *R-2* RAP. Cantabro testing of 100% RAP mixtures successfully predicted the relative performance of the different RAP sources in 50% RAP mixtures. For 25% RAP mixtures, Cantabro performance was similar regardless of RAP source and the small difference in mass loss in the two mixtures may be partly explained by the difference in specimen air voids of the 25% RAP mixtures.

The effects of *R-30* aging on mass loss are presented in Figure 8.2. Control mixtures designed according to current practice experienced an increase in mass loss of 2 to 4% compared to un-aged specimens. For 25% and 50% RAP, the increase in mass loss with aging was about 6% and 9% above un-aged results, respectively. The data indicates that specimens with more RAP may become more prone to durability problems over time than would conventional mixtures; more investigation is needed for additional explanation.

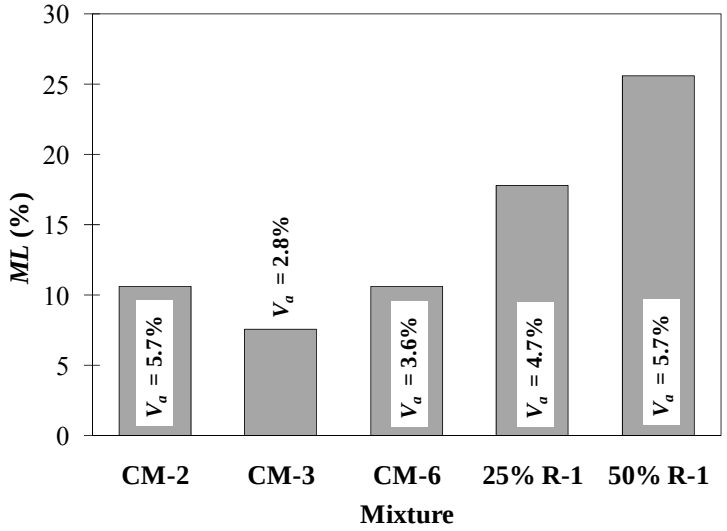


Figure 8.2 Effect of Laboratory Aging on Specimen Mass Loss for Select Mixtures

Overall, results indicated that mixtures with high RAP may be somewhat more prone to durability issues than current practice mixtures, but the data did not indicate that durability problems would prohibit their use. At higher RAP contents not all RAP sources will give the same level of performance at a particular percentage of total mixture. None of the results indicated that use of high RAP in surface mixtures would not be feasible. Further research is needed to quantify the relationship between laboratory performance in the Cantabro test and performance of field mixtures with respect to durability.

8.3 Crack Resistance

BBR mixture testing was performed at -24 C and -18 C to bracket the low temperature performance grade of the virgin binders used in this study. Additional testing was performed at -12 C and -06 C to provide a measurement of mixture stiffness at temperatures that can occur in the field slightly above the low temperature performance grade of the virgin binder. Results of control mixture testing established that control mixtures two and three represented the lowest and highest stiffnesses for plant produced control mixtures at all loading times and test temperatures.

Figures 8.3 and 8.4 present the effects of RAP source on mixture stiffness at 960 seconds for -24 C and -18 C test temperatures. Stiffness of all the 25 and 50% RAP mixtures was within the range of stiffness observed for plant produced control mixtures. Designed 100% RAP mixtures also fell within the range of control mixtures. Figures 8.5 and 8.6 present the effects of RAP source on mixture stiffness at 960 seconds for -12 C and -06 C test temperatures. Stiffness of all the 25 and 50% RAP mixtures was higher than the range of stiffness observed for plant produced control mixtures. Designed 100% RAP mixtures also fell above the range of control mixtures. This increased stiffness may suggest that the mixes are more susceptible to cracking. Further testing is needed to make definitive statements as to why the mixtures perform within the control bands at temperatures bracketing the low temperature grade of virgin binder used in Mississippi, but are above the control bands at higher temperatures.

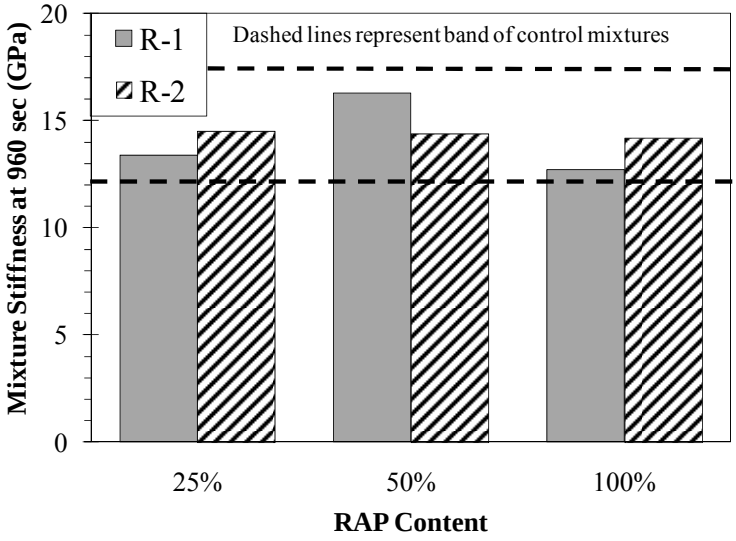


Figure 8.3 Effects of RAP Source on Mixture Stiffness at -24 C

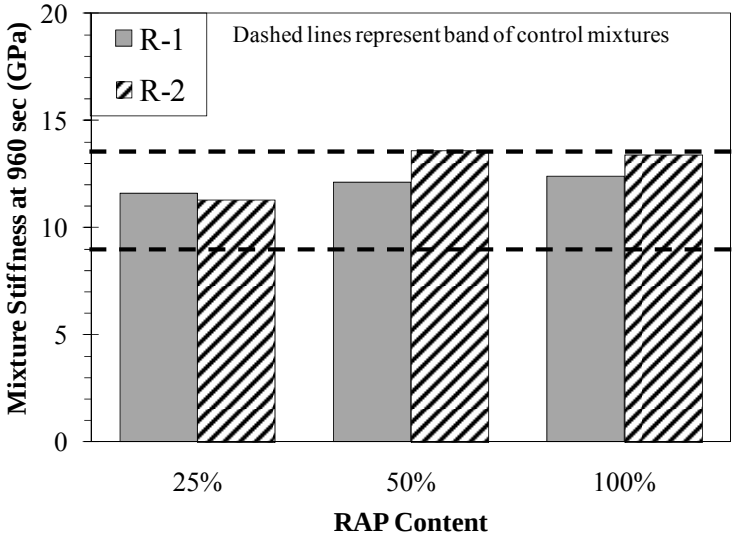


Figure 8.4 Effects of RAP Source on Mixture Stiffness at -18 C

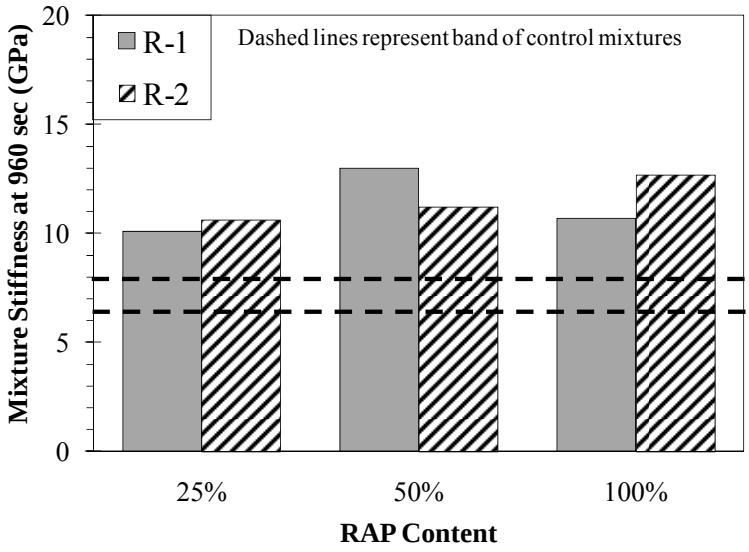


Figure 8.5 Effects of RAP Source on Mixture Stiffness at -12 C

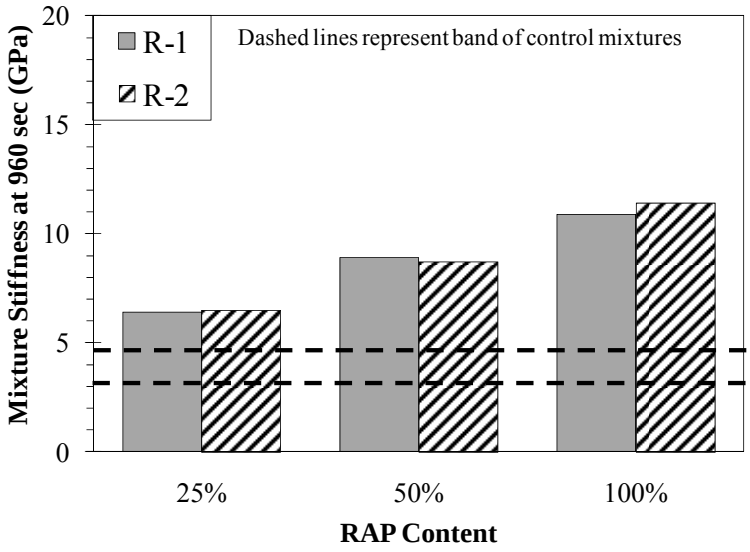


Figure 8.6 Effects of RAP Source on Mixture Stiffness at -06 C

An ST control mixture produced the lowest stiffness, while an HT control mixture produced the highest stiffness. At -24 C and -18 C, the 25 and 50% RAP mixes performed worse than the ST mix (most crack resistant in conventional practice) but better than the HT mix (least crack resistant in conventional practice) in terms of stiffness. This provides some evidence that an MT designed mixture with 25 to 50% RAP can perform in a comparable manner in the context of cracking relative to a control mixture. At -12 C and -06 C, this behavior was not observed.

Results for designed 100% RAP mixtures indicated that *R-2* mixture was of similar or somewhat higher stiffness than *R-1* mixture. Testing of 100% RAP specimens compacted with varying virgin asphalt contents and several compaction parameters at -24 C and -18 C test temperatures indicated some general trends of mixture stiffness at 960 second loading

time. For the *R-1* RAP, stiffness was generally between 10 and 15 GPa with the highest observed stiffness being 16.9 GPa. For the *R-2* RAP, stiffness was frequently higher than 15 GPa; however the highest stiffness of 100% *R-2* RAP was 19.1 GPa.

Testing of 100% RAP indicated that mixtures containing *R-2* RAP source would likely have higher stiffness than mixtures containing *R-1* RAP. This result is counterintuitive given the higher low temperature PG grade for the *R-1* asphalt (+1.7) compared to the *R-2* asphalt (-3.5). Of the eight cases where *R-1* and *R-2* RAP sources were tested for the same conditions (two RAP levels and four test temperatures) only three followed the prediction. In another three of the eight cases the stiffness of *R-1* and *R-2* mixtures was about the same. For the last two cases the observed results were reverse of the prediction. Testing of 100% RAP only correctly predicted the relative ranking of mixture stiffness for the *R-1* and *R-2* RAP sources in 25 and 50% RAP mixture in three of eight cases. Low temperature binder grades of the *R-1* and *R-2* RAP sources only correctly predicted the relative ranking of mixture stiffness in 25 and 50% RAP mixture in two of eight cases.

A limited amount of dynamic modulus testing was performed to investigate the stiffness properties of a selection of mixtures in this experimental program for a variety of temperatures and loading frequencies. Results of the testing were somewhat inconclusive and did not readily lend themselves to detailed analysis. Testing of additional high RAP mixtures as part of a targeted experimental program could be performed to allow more conclusive statements to be made.

Overall, mixtures with 25% RAP did not exhibit characteristics to prohibit recommendation of use on the surface. Mixtures with 50% RAP only exhibited potentially problematic behavior at temperatures somewhat above than the low temperature binder grade in Mississippi. Results indicated that stiffness of mixtures with high RAP at temperatures near the low temperature performance grade of virgin binder (-22 C) is within the range of stiffness results observed for current practice mixtures. Consequently, 25 or 50% RAP mixtures are thought likely feasible in terms of mixture stiffness at these temperatures. Results of testing at temperatures slightly above the low temperature performance grade indicated that high RAP mixtures may be somewhat stiffer than conventional practice mixtures. For 25% RAP, the stiffness did not exceed the control mixture band by a considerable amount, whereas 50% RAP exceeded the control mixture band considerably more.

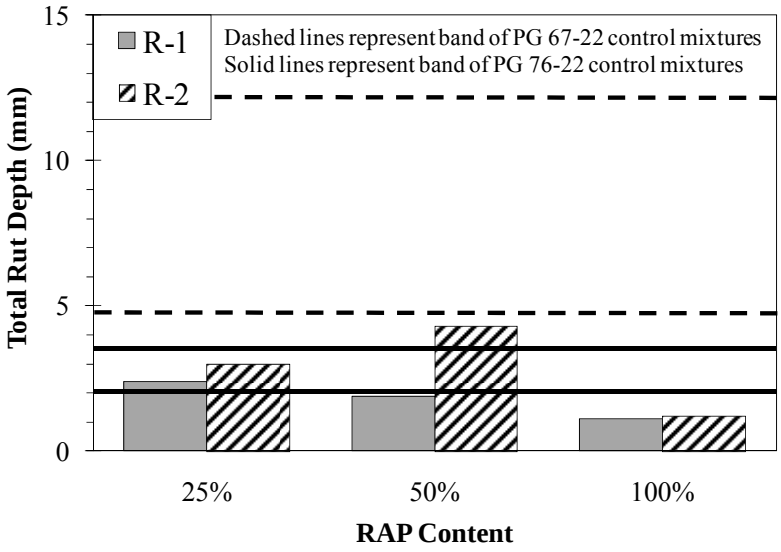
8.4 Rut Resistance

Three test methods were used to evaluate rut resistance: 1) *APA*; 2) PURWheel dry protocol; and 3) *MRTCR*. *APA* testing was selected as a conventional test method; specimens were tested at nominal air void levels of 7 and 10%. PURWheel dry protocol testing was selected as a more simulative wheel tracking test method to evaluate rutting as well as being a complement to PURWheel wet protocol testing. *MRTCR* testing was selected as an un-conventional test method to be evaluated for characterization of mixtures with high RAP.

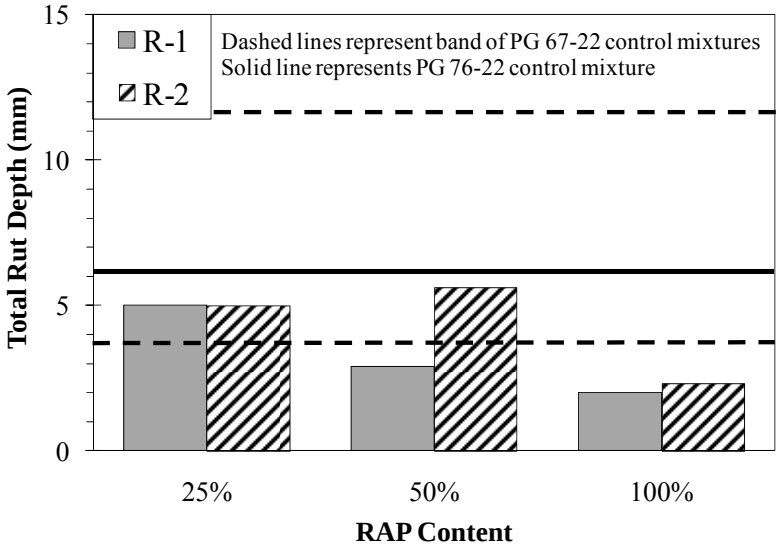
The ST control mixture exhibited the highest *APA* total rut depths (≈12 mm), and the HT mixture exhibited the lowest total rut depths for both nominal air void levels. Control mixtures with polymer-modified binder had total rut depths on the order of 2 to 3.5 mm for nominal 7% air voids and on the order of 6 mm for nominal 10% air voids. PURWheel dry protocol results confirmed that the ST control mixture performed poorly and that mixtures

containing polymer-modified binder performed well. PURWheel testing indicated a difference in rutting between the field and laboratory mixed version of the HT control mixture with PG 67-22 binder that was not observed in *APA* results.

Figure 8.7 presents results of *APA* testing in terms of RAP source. The range of results from testing control mixtures with PG 67-22 and PG 76-22 binder grades are represented with horizontal lines in Figure 8.7. For specimens of 25 and 50% RAP mixtures with 7% nominal air voids (Figure 8.7*a*) the total rut depths are less than the lowest measured for PG 67-22 control mixtures and are comparable to results for polymer modified control mixtures. For specimens of 25 and 50% RAP mixtures with 10% nominal air voids (Figure 8.7*b*) the total rut depths are also comparable with the best performing control mixtures.



a) Nominal 7% V_a Specimens



b) Nominal 10% V_a Specimens

Figure 8.7 Effects of RAP Source on *APA* Rutting

Figure 8.8 presents of PURWheel dry protocol testing in terms of RAP source. Mixtures containing 25% RAP had a level of rutting well within and generally at the lower end of the range observed for control mixtures. Mixtures containing 50% RAP had total rut depths either at the lower end of or less than the range observed for control mixtures.

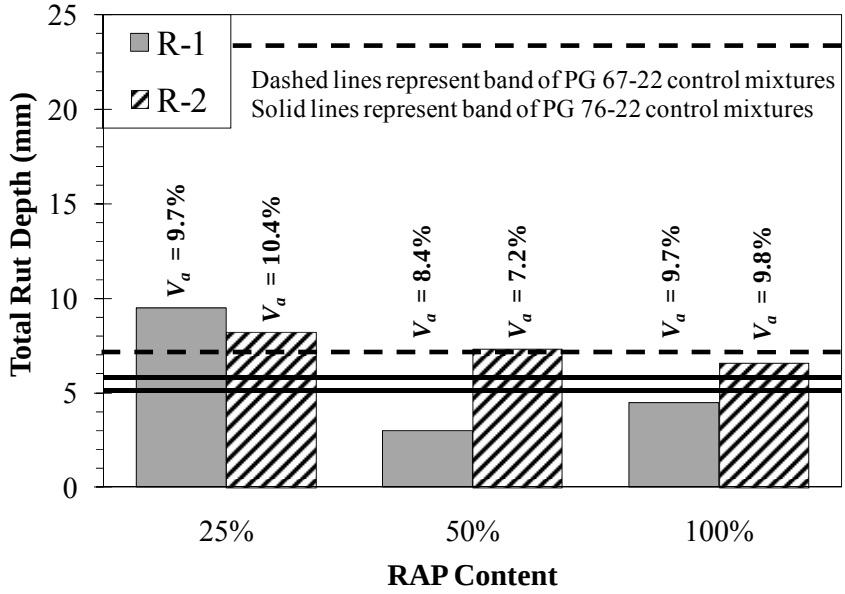


Figure 8.8 Effect of RAP Source on PURWheel Dry Protocol Rutting

Total *APA* rut depths of designed 100% RAP mixtures at nominal 7 and 10% air voids were lower than any of the control mixtures tested at the same air void level. Designed 100% RAP mixtures had total rut depths either at the lower end of or less than the range observed for control mixtures in PURWheel dry protocol testing. Results of 100% RAP testing indicated that mixtures containing *R-2* RAP source would likely have higher total rut depths than mixtures with *R-1* RAP source. This prediction held true for all testing of 50% RAP mixtures by either *APA* or PURWheel dry testing. For mixtures with 25% RAP, the difference in total rut depths between different RAP sources was small. For *APA* testing of 25% RAP mixtures with 7% air voids, the *R-2* RAP had slightly higher total rut depth than the *R-1* RAP. For 10% air voids the total *APA* rut depths were the same for both RAP sources. For PURWheel dry testing of 25% RAP mixtures the *R-1* RAP source mixture had slightly higher total rut depth than the *R-2* RAP source mixture.

MRTCR testing was performed on a 0% RAP control mixture and on 100% RAP with varying virgin asphalt contents compacted for a variety of conditions. The stress levels required to successfully test the 100% RAP specimens to failure were two to eight times higher than that for 0% RAP specimens. The result indicated that 100% RAP was much stiffer than the 0% RAP mixture which indicates increased rut resistance. The method was able to identify effects due to warm mix additives on the compacted 100% RAP in some cases. Variability of the test method was found to be rather high due to the small specimen size relative to the NMAS of the aggregate gradation and the high test temperature. Due to availability of other test methods utilizing more representative specimen sizes requiring less preparation (e.g. *APA*), the *MRTCR* test was deemed to not be ideally suited to the needs of this study.

Overall, results indicated MT designed (i.e. 65 gyration) mixtures with high RAP are likely to be highly rut resistant although at higher RAP contents not all RAP sources will give equivalent performance for a particular percentage of total mixture. At RAP contents on the order of 50% the data in this report shows some sources of RAP can give performance comparable to that of HT mixtures with polymer-modified PG 76-22 binder. However, it must be stressed that not every source of RAP is necessarily capable of that level of performance. In general, properly designed high RAP mixtures should be feasible in terms of rut resistance for high traffic (HT) applications. The ability of a 65 gyration PG 67-22 design to be comparable to a PG 76-22 85 gyration design in terms of rut resistance is significant as it allows a balance of rut and crack resistance.

8.5 Moisture Damage Susceptibility

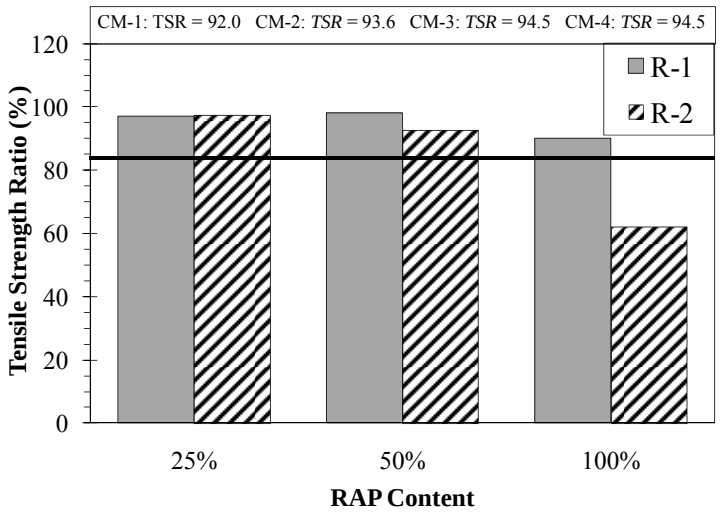
Two test methods were selected to evaluate moisture susceptibility of asphalt mixtures in this study: 1) *TSR*; and 2) PURWheel wet protocol test. Results of *TSR* moisture sensitivity testing shown in Figure 8.9*a* indicated that all control, 25% RAP, and 50% RAP mixtures should provide acceptable performance (i.e. *TSR* greater than 80%) with regards to potential for moisture damage. Results of PURWheel wet protocol testing shown in Figure 8.9*b* indicated that 25 and 50% warm mixed RAP mixtures generally did not perform quite as well as plant mixed HMA controls. For control mixture wet testing, 50% of the specimens exhibited evidence of moisture damage. For 25 and 50% RAP mixture wet testing, on the order of 80% of the specimens exhibited evidence of moisture damage (7 of 8 for 25% RAP and 6 of 8 for 50% RAP). The data provided does not allow definitive statements as to whether high RAP content, warm mix temperatures, or other factors made the mixes in this study perform worse in the PURWheel wet protocol test than the control mixtures.

Data presented in Doyle et al. (2011) indicated that increasing the RAP content in WMA mixtures improved their *TSR* values; this result was not observed in the limited *TSR* testing performed in this study. The data presented in this study indicates that *TSR* testing and PURWheel wet protocol testing did not provide the same relative results for 25 and 50% RAP mixes in terms of potential for moisture damage. Performance of the *R-1* RAP source in PURWheel wet testing did not vary much regardless of its proportion in the mixture being tested. Performance of mixtures containing *R-2* RAP improved as the amount of RAP was increased; this result coincides with the results observed by Doyle et al. (2011) albeit for different test methods.

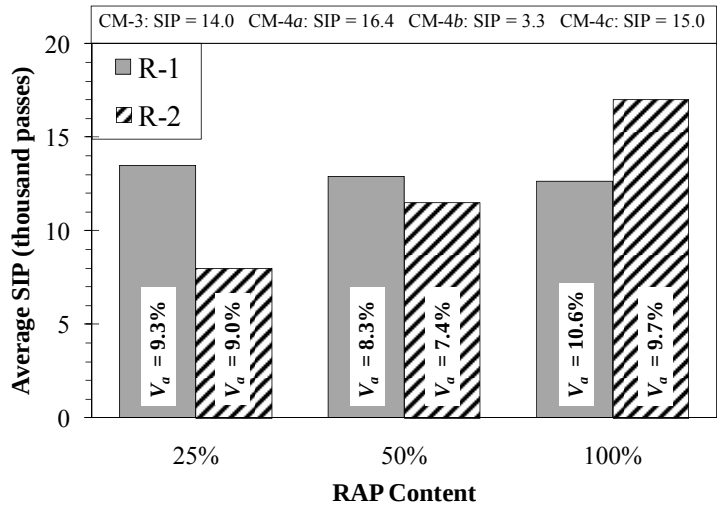
It is not known if the 64 C submerged specimen high pressure loaded wheel PURWheel wet protocol test is overly aggressive in relation to potential conditions experienced by Mississippi mixtures in the field. However, any mixture that can reliably survive the PURWheel wet protocol test without exhibiting evidence of moisture damage is thought likely to give good performance in the field. The lower limit of PURWheel wet test results that correlates to acceptable performance in the field has not yet been established.

TSR results for 100% RAP indicated that some potential for moisture sensitivity might exist with the recycled mixtures containing *R-2* RAP but no such problems were observed in the *TSR* test results for 25 and 50% RAP mixtures. Testing of designed 100% RAP mixtures in the PURWheel wet test indicated that *R-2* RAP would likely give better moisture damage resistance in recycled mixtures. However, PURWheel wet testing of 25 and 50% RAP mixtures indicated that the *R-1* RAP source provided better moisture damage

resistance than the *R-2* RAP source. Overall, results of PURWheel testing indicated that high RAP-WMA mixtures are somewhat more prone to moisture damage than the current practice HMA mixtures tested. Due to the aggressive nature of the test it is not known if these results would necessarily translate into unacceptable poor field performance.



a) TSR Test Results



b) PURWheel Wet Protocol Test Results

Figure 8.9 Effect of RAP Source on Moisture Damage Susceptibility

8.6 Skid Resistance

To evaluate the potential effects on skid resistance by inclusion of high amounts of RAP in surface mixtures, three mixtures were tested that included 0, 50, and 100% RAP. One factor ANOVA tests were performed to evaluate the significance of RAP levels to measured pavement friction using both IFI parameters of S_P and *F60* as response variables; the results are located in Tables 8.1 and 8.2. For both response variables RAP was not found

to have a statistically significant effect on pavement friction parameters at a 95% confidence level.

Table 8.1 ANOVA Test for RAP Friction, S_p as Response Variable

Source	df	SS	MS	F_{calc}	P_{value}	Conclusion
RAP	2	107.0	53.5	0.53	0.604	Not Significant
Error	12	1218.5	101.5			
Total	14	1325.5				

Note: Significance testing at the 95% confidence level.

Table 8.2 ANOVA Test for RAP Friction, *F60* as Response Variable

Source	df	SS	MS	F_{calc}	P_{value}	Conclusion
RAP	2	0.001158	0.000579	0.40	0.678	Not Significant
Error	12	0.017341	0.001445			
Total	14	0.018499				

Note: Significance testing at the 95% confidence level.

Using the correlation proposed by Khasawneh and Liang (2008) given in Eq. 2.4, the *DFTester* results at 64 km/hr (40 mph) were converted to locked wheel skid trailer ribbed tire *SN* values at 65 km/hr (40 mph); the values are presented in Table 8.3. The *SN* values are reduced as the amount of RAP is increased but remain at generally acceptable levels. Based on this limited laboratory assessment, mixes with 0 to 50% RAP are likely adequate for MDOT skid resistance requirements immediately after construction when designed as MT mixes. Properties of mixtures over time under traffic and environmental conditions are needed for long term assessment.

Table 8.3 Correlation of *DFTester* Results to Skid Number

Mixture	RAP (%)	Rep	*DFTester* @ 64 km/hr	*SN* @ 65 km/hr
9.5-0/CM-5	0	1	0.571	65
		2	0.498	54
		3	0.570	64
		4	0.547	61
		5	0.528	59
		Avg.	**0.543**	**61**
		Std. Dev.	**0.031**	**4**
9.5-50/RM-1b	50	1	0.442	47
		2	0.541	60
		3	0.449	48
		4	0.453	48
		5	0.528	59
		Avg.	**0.483**	**52**
		Std. Dev.	**0.048**	**7**
9.5-100/RM-1	100	1	0.432	45
		2	0.454	48
		3	0.406	42
		4	0.449	48
		5	0.447	47
		Avg.	**0.438**	**46**
		Std. Dev.	**0.019**	**3**

8.7 RAP Characterization

Characterization of RAP volumetrics showed that the virgin asphalt demand of the *R-1* and *R-2* RAP sources varied depending on compaction temperature and other factors. This difference is evident in volumetric properties of the 25 and 50% RAP recycled mixtures produced at a warm mix temperature of 116 C. The 25% *R-1* RAP recycled mixture required 0.5% more virgin asphalt than did the mixture with 25% *R-2* RAP with the same virgin aggregate proportions and comparable total gradation. The 50% *R-1* RAP recycled mixture required 0.3% more virgin asphalt than did the mixture with 50% *R-2* RAP with the same virgin aggregate proportions and comparable total gradation. Testing a single source RAP with added virgin binder has promise in detecting asphalt demand in a new mixture as the data in Chapter 4 showed *R-1* bitumen was more difficult to re-liven than *R-2* bitumen, which agrees with the mixture data. Effects of parameters such as heating temperature and heating time can also be detected on 100% RAP, at least to some extent.

Characterization of RAP for performance was conducted in an effort to predict relative performance of mixtures containing 25 and 50% RAP. Two main categories of performance characterization were conducted: 1) measurement of recovered RAP asphalt properties; and 2) performance testing of compacted 100% RAP. Table 8.4 presents results of the RAP characterization testing and compares the predicted ranking of performance to the measured ranking of performance for mixtures containing 25% *R-1* or *R-2* RAP.

For each performance category, all relevant predictors from 100% RAP testing are located in the column corresponding to which RAP source they predicted to have better performance. Details of the symbols representing each predictor are given in the legend of Table 8.4. When results indicated that both RAP sources had essentially the same level of performance, the predictor is located in the columns for both RAP sources. For each mixture performance test method, the RAP source that actually had the best performance based on results of testing 25% RAP mixture is located in the final column of Table 8.4. The symbol for the test method is given first followed by the best performing RAP source according to the particular test method.

Table 8.4 RAP Characterization for Prediction of 25% RAP Mixture Performance

	Predicted from 100% RAP Testing		
Category	***R-1***	***R-2***	**Results of 25% RAP Mixture Testing**
Durability	none	*PG, ML*	same
Cracking	[-24], [-18], [-12], [-06]	*PG*	[-24] *R-1*, [-18] same, [-12] *R-1*, [-06] same
Rutting	*V, PG, APA_7, APA_{10}, PW*	*APA_7, APA_{10}*	[*APA_7*] *R-1*, [*APA_{10}*] same, [*PW*] *R-2*
Moisture	*V, PG, TSR*	*PW*	[*TSR*] same, [*PW*] *R-1*

Legend:

V	Result of viscosity testing of recovered RAP asphalt at 135 C
PG	Result of performance grading of recovered RAP asphalt (high or low temperature)
ML	Result of Cantabro testing for 100% RAP
[-24]	Result of *BBR* testing at -24 C
[-18]	Result of *BBR* testing at -18 C
[-12]	Result of *BBR* testing at -12 C
[-06]	Result of *BBR* testing at -06 C
APA_7	Result of *APA* testing at 7% air voids
APA_{10}	Result of *APA* testing at 10% air voids
PW	Result of PURWheel testing
TSR	Result of *TSR* testing

For durability the *R-2* RAP was predicted to have better performance. For cracking the *R-1* RAP was predicted to have better performance based on mixture stiffness measurement and the *R-2* RAP was predicted to have better performance based on testing of recovered RAP asphalt. For rutting the *R-1* RAP was predicted to have comparable or better performance to the other RAP. For moisture damage the *R-1* RAP was predicted to have better performance by binder and *TSR* testing; the *R-2* RAP was predicted to have better performance by PURWheel wet testing.

Durability performance of 25% RAP mixture was the same performance for both RAP sources. Cracking performance of 25% RAP was better for *R-1* in two cases and was the same for both RAPs in two cases. Rutting performance of 25% RAP mix followed the prediction in two cases and did not in one case. Moisture damage performance of 25% RAP was the same for *TSR* testing and *R-1* RAP performed better in PURWheel wet testing.

Table 8.5 compares the predicted ranking of performance based on 100% RAP testing to the measured ranking of performance for mixtures containing 50% of *R-1* or *R-2* RAP. The same symbols are utilized as in the previous table. Durability performance of 50% RAP mixture followed the characterization prediction. Cracking performance of 50% RAP mixture was the same in one case, followed the mixture stiffness prediction in one case and followed the binder testing prediction in two cases. Rutting performance of 50% RAP mixture followed the prediction in all three cases. Moisture damage performance of 50% RAP mixture followed the binder and *TSR* testing predictions in both *TSR* and PURWheel wet testing.

Table 8.5 RAP Characterization for Prediction of 50% RAP Mixture Performance

	Predicted from 100% RAP Testing		
Category	***R-1***	***R-2***	**Results of 50% RAP Mixture Testing**
Durability	none	*PG, ML*	*R-2*
Cracking	[-24], [-18], [-12], [-06]	*PG*	[-24] *R-2*, [-18] *R-1*, [-12] *R-2*, [-06] same
Rutting	*V, PG, APA_7, APA_{10}, PW*	*APA_7, APA_{10}*	[*APA_7*] *R-1*, [*APA_{10}*] *R-1*, [*PW*] *R-1*
Moisture	*V, PG, TSR*	*PW*	[*TSR*] *R-1*, [*PW*] *R-1*

Note: Symbols are same as used in Table 8.4.

Relative behaviors between RAP sources were observed with respect to some performance parameters though no significant findings were observed. In some instances, properties of extracted binder agreed with testing of designed 100% RAP mixture but in other cases it did not. In general, characterization of RAP provided better predictions of performance for mixtures containing 50% RAP than for those with 25% RAP which is a reasonable result. Prediction of durability performance was reasonable. Prediction of cracking performance was mixed. Prediction of rutting performance was good. Prediction of moisture damage potential was mixed. Mixture performance testing of 100% RAP provided mixed results and does not appear to be productive. The most productive use of testing 100% RAP with virgin binder was to asses RAP bitumen characteristics at the anticipated conditions in a new mixture. This approach is promising and could easily be coupled with durability testing of the same specimens. The eighteen specimen protocol discussed in Section 4.8 would work well.

CHAPTER 9 – CONCLUSIONS AND RECOMMENDATIONS

9.1 Conclusions

The overall conclusion of the research is that, based on laboratory testing, surface mixes incorporating 25% RAP and warm mix technologies are feasible in Mississippi. Mixes incorporating 50% RAP may be feasible, but their stiffness measured by the *BBR* prevented more compelling statements being made without additional investigation. Test results indicated that 25% and 50% RAP with warm mix technologies may be more prone to moisture damage than the currently used control mixtures tested in this report. Specific conclusions are presented in the following list.

- RAP aggregate does not absorb additional asphalt, either RAP asphalt or virgin binder.
- Measurement of G_{se} for RAP can be effectively performed using RAP coated with 2% virgin binder.
- Measurement of RAP absorbed asphalt by extracted aggregate G_{sb} with current techniques was shown likely to give unreasonable results for three RAP source tested. More reasonable estimates of absorbed asphalt for RAP sources from a single pavement can be made using measured RAP G_{se} and the regression equation developed in this study.
- Compaction temperature can have a relatively large effect on demand for virgin asphalt by RAP where considerably more virgin asphalt is required at WMA temperatures than at HMA temperatures; the magnitude of the effect is dependent on RAP source.
- Varying compactive effort causes approximately the same relative change in virgin asphalt demand by RAP as it does in conventional mixtures.
- RAP bitumen on the surface of RAP aggregate not all effective under some conditions.
- The Cantabro test was found useful for measurement of relative performance of mixtures for durability; specimen air voids were seen to have an effect on mass loss.
- Durability testing without aging indicated that 25% RAP mixes were comparable to current practice and performance of 50% RAP mixes was not dramatically worse than control mixes.
- Durability testing of aged specimens indicated that high RAP mixes may be somewhat more prone to durability issues over time than control mixtures.
- The *BBR* mixture test performed on small specimens was found useful for assessment of mixture stiffness at low temperatures.
- Mixture stiffness testing at temperatures bracketing the low PG temperature of virgin materials in Mississippi (-22 C) indicated that WMA-RAP mixes performed within the range of ST and HT control mixes.
- Mixture stiffness testing at temperatures slightly above the low PG temperature showed a relatively small increase in stiffness for 25% RAP mixes compared to controls and moderate increase in stiffness for 50% RAP mixes.

- PURWheel dry protocol testing at 64 C provided the same relative ranking of mixtures as did the *APA* test method although the magnitude of rutting in the PURWheel was higher.
- *MRTCR* testing was able to differentiate effects of warm mix additives in compacted 100% RAP specimens for some experimental combinations.
- Rut testing in both the *APA* and PURWheel dry protocol indicated that high RAP-WMA mixes are highly rut resistant and were comparable to HT control mixes in most cases.
- Mixes with 50% of some RAP sources can provide rut resistance equal to HT PG 76-22 mixtures; however not all RAP sources can necessarily provide this level of performance.
- Designing high RAP mixes as MT (i.e. 65 gyrations) balanced rut and crack resistance effectively.
- Testing of submerged specimens at 64 C in the PURWheel wet protocol test was an aggressive test method that allowed for relative ranking of mixture performance for moisture damage potential.
- *TSR* testing of high RAP mixes did not indicate any potential for moisture damage.
- PURWheel wet protocol testing indicated the potential for moisture damage in control and high RAP-WMA mixes, whereas *TSR* testing did not.
- MT designed mixes with RAP were shown in a limited laboratory investigation to provide adequate skid resistance during initial service life.
- Characterization of 100% RAP compacted with virgin binder was able to evaluate effect of temperature and inherent characteristics of the RAP source.
- Mixture performance testing of 100% RAP provided mixed results and does not appear to be productive.

9.2 Recommendations

Until further information becomes available, it is recommended to design high RAP with warm mix technologies as MT (65 gyration) mixes. This report indicated that this type of design should balance rut and crack resistance as the stiff RAP binder can offset the additional virgin binder in terms of rut resistance and the additional virgin binder can help to offset the stiff RAP binder in terms of crack resistance. A series of recommendations for future investigation are outlined in the following list.

- Produce 25% RAP mix at full scale and place on surface of low volume roadway for monitoring. Samples of the raw materials and plant produced mix should be sampled for laboratory testing similar to that conducted in this report.
- Test multiple RAP sources throughout Mississippi in the manner described in Chapter 4 and compare the results to conventional methods. A key component of the investigation should be absorbed asphalt and G_{sb}.
- Perform a suite of Cantabaro durability tests on dense graded mixes compacted to specific air void levels. A study where a variety of mixes are compacted to 4, 7, and 10% voids would provide a baseline of information for use in evaluating the durability of alternative mixtures. The information provided in this report would be strengthened provided this data were available.

- Perform suite of Cantabaro durability tests to investigate the effect of aging on mass loss. Field and laboratory aging should be included in the study.
- Perform indirect tensile (IDT) testing of mixes at temperatures that correspond to those tested in the *BBR*. Low temperature IDT and *BBR* testing on the same mixtures should provide more indication of crack resistance than either test individually. The data should be helpful in resolving the relative differences in stiffness of high RAP-WMA and control mixes as test temperature increased.
- Test the performance of paired hot mixed and warm mixed asphalt with and without high RAP in terms of moisture damage. These mixes should be tested as a function of temperature and water exposure in the PURWheel to provide a comparison of their performance. The comparison should include PG 67-22 and PG 76-22 virgin binder.

CHAPTER 10 – REFERENCES

Alabama Department of Transportation. (2008). *Standard Specifications for Highway Construction*. Alabama Department of Transportation, Montgomery, AL.

Alvarez, A.E., Martin, A.E., Estakhri, C., and Izzo, R. (2008). "Evaluation of Durability Tools for Porous Friction Courses." *Transportation Research Board 87th Annual Meeting*, Paper No. 08-2370, pp.15.

Al-Qadi, I.L., Carpenter, S.H., Roberts, G., Ozer, H., Aurangzeb, Q., Elseifi, M., and Trepanier, J. (2009). *Determination of Usable Residual Asphalt Binder in RAP*. Report No. FHWA-ICT-09-031, Illinois Department of Transportation, pp. 94.

Arkansas Department of Transportation. (2003). *Standard Specifications for Highway Construction*. Arkansas Department of Transportation. Little Rock, AR.

Ashenbrener, T. (1995). "Evaluation of Hamburg Wheel-Tracking Device to Predict Moisture Damage in Hot-Mix Asphalt." *Transportation Research Record: Journal of the Transportation Research Board*, No. 1492, pp. 193-201.

Azari, H. (2010). *Precision Estimates of AASHTO T 283: Resistance of Compacted Hot Mix Asphalt (HMA) to Moisture-Induced Damage*. NCHRP Web-Only Document 166, National Cooperative Highway Research Program, Transportation Research Board of the National Academies, Washington D.C.

Badaruddin, S.R.B., and White, T.D. (1994). *Asphalt Mix Design and Performances*. Report No. FHWA/IN/JHRP-94/3, Joint Highway Research Project, pp. 179.

Bagampadde, U., Isacsson, U., and Kiggundu, B.M. (2006). "Impact of Bitumen and Aggregate Composition on Stripping in Bituminous Mixtures." *Materials and Structures*, Vol. 39, No. 3, pp. 303-315.

Brown, E.R. (1990). "Density of Asphalt Concrete-How Much is Needed?" *Transportation Research Record: Journal of the Transportation Research Board*, No. 1282, pp. 27-32.

Buchanan, S. (2000). "An Evaluation of Selected Methods for Measuring the Bulk Specific Gravity of Compacted Hot Mix Asphalt (HMA) Samples." *Journal of the Association of Asphalt Paving Technologists*, Vol. 69, pp. 608-634.

Buchanan, M.S., and Smith, B.J. (2005). "Performance Evaluation of Hot-Mix Asphalt Using Rotary Loaded-Wheel Testing." *Transportation Research Record: Journal of the Transportation Research Board*, No. 1929, pp. 157-164.

Brown, E.R., and Cross, S.A. (1989). "A Study of In-Place Rutting of Asphalt Pavements." *Proceedings of the Association of Asphalt Paving Technologists*, Vol. 58, pp. 1-39.

Castro-Fernandez, P.L. (1996). *Evaluation of Hot Asphalt Concrete Mixes Containing Recycled Materials as an Alternative for Pavement Rehabilitation*. MS Thesis, University of Nevada, Reno.

Chen, J.S., Chu, P.Y., Lin, Y.Y., and Lin, K.Y. (2007). "Characterization of Binder and Mix Properties to Detect Reclaimed Asphalt Pavement Content in Bituminous Mixtures." *Canadian Journal of Civil Engineering,* Vol. 34, No. 5, pp. 581-588.

Cooley Jr., L.A. (2003). *Evaluation of Pavement Permeability in Mississippi*. Report to Mississippi Department of Transportation Research Division, pp. 51.

Cooper, S.B. (2009). *Evaluation of HMA Mixtures Containing Sasobit®*. Report No. 06-1TA, Louisiana Transportation Research Center, pp. 36.

Cross, S.A., Voth, M.D., and Fager, G.A. (2000). "Effects of Sample Preconditioning on Asphalt Pavement Analyzer Wet Rut Depths." *Proceedings of Mid-Continent Transportation Symposium 2000,* May 15-16, Ames, IA.

Doyle, J.D., and Howard, I.L. (2010). *Linear Asphalt Compactor Operator's Manual*. Manual Number CMRC M 10-1 Version 1, Construction Materials Research Center, Mississippi State University, pp. 16.

Doyle, J.D., Mejias-Santiago, M., Brown, E.R., and Howard, I.L. (2011). "Performance of High RAP-WMA Surface Mixtures." *Journal of the Association of Asphalt Paving Technologists,* Vol. 80, In Press.

Florida Department of Transportation. (2010). *Standard Specifications for Road and Bridge Construction*. Florida Department of Transportation. Tallahassee, FL.

Georgia Department of Transportation. (2001). *Standard Specifications: Construction of Roads and Bridges*. Georgia Department of Transportation. Atlanta, GA.

Hall, K.D., and Williams, S.G. (1999*a*). "Effects of the Ignition Method on Aggregate Properties." *Journal of the Association of Asphalt Paving Technologists,* Vol. 68, pp. 574-588.

Hall, K.D., and Williams, S.G. (1999*b*). *Acquisition and Evaluation of Hamburg Wheel-Tracking Device*. Report No. FR 1044. Mack-Blackwell Transportation Center, University of Arkansas, pp. 18.

Hicks, R.G. (1991). *Moisture Damage in Asphalt Concrete.* National Cooperative Highway Research Program Synthesis of Highway Practice 175, Washington, D.C.

Hossain, M., Metcalf, D.G., and Scofield, L.A. (1993). "Performance of Recycled Asphalt Concrete Overlays in Southwestern Arizona." *Transportation Research Record Journal of the Transportation Research Board,* No. 1427, pp. 30-37.

Howard, I.L., Cooley Jr., L.A., and Doyle, J.D. (2009). *Laboratory Testing and Economic Analysis of High RAP Warm Mixed Asphalt.* Report FHWA/MS-DOT-RD-09-200, Mississippi Department of Transportation, pp. 104.

Howard, I.L., Doyle, J.D., White, T.D., Ivy, J., and Booth, O. (2010). *PURWheel Laboratory Wheel Tracker Operator's Manual*. Manual Number CMRC M 10-2 Version 1, Construction Materials Research Center, Mississippi State University, pp. 65.

Huber, G.A., and Heiman, G.H. (1987). "Effect of Asphalt Concrete Parameters on Rutting Performance: A Field Investigation." *Proceedings of the Association of Asphalt Paving Technologists*, Vol. 56, pp. 33-61.

Hughes, C.S. (1989). *Compaction of Asphalt Pavement.* National Cooperative Highway Research Program Synthesis of Highway Practice 152, Washington, D.C.

Hunter, E.R., and Ksaibati, K. (2002). *Evaluating Moisture Susceptibility of Asphalt Mixes*. MPC Report No 02-138, University of Wyoming. pp. 159.

Izzo, R.P., and Tahmoressi, M. (1999). "Testing Repeatability of the Hamburg Wheel-Tracking Device and Replicating Wheel-Tracking Devices Among Different Laboratories." *Proceedings of the Association of Asphalt Paving Technologists*, Vol. 68, pp. 589-611.

Khasawneh, M.A., and Liang, R.Y. (2008). "Correlation Study between Locked-Wheel Skid Trailer and Dynamic Friction Tester." *Transportation Research Board 87th Annual Meeting*, Paper No. 08-2442, pp. 27.

Kandhal, P.S., and Khatri, M.A. (1992). "Relating Asphalt Absorption to Properties of Asphalt Cement and Aggregates." *Transportation Research Record: Journal of the Transportation Research Board*, No. 1342, pp. 76-84.

Kandhal, P.S. (1992). *Moisture Susceptibility of HMA mixes: Identification of Problem and Recommended Solutions.* NCAT Report 92-01, National Center for Asphalt Technology, Auburn, AL, pp. 35.

Kiggundu, B.N., and Roberts, F.L. (1988*a*). *The Success/Failure of the Test Methods*. NCAT Report 88-02, National Center for Asphalt Technology, Auburn, AL, pp. 42.

Kiggundu, B.N., and Roberts, F.L. (1988*b*). *Stripping in HMA Mixtures: State-of-the-art and Critical Review of Test Methods*. NCAT Report 88-02, National Center for Asphalt Technology, Auburn, AL, pp. 42.

Kim, Y.R., and Lutif, J.E.S. (2006). *Material Selection and Design Consideration for Moisture Damage of Asphalt Pavement*. Report No. P564, Nebraska Dept of Roads, pp. 68.

Kowalski, K.J., McDaniel, R.S., and Olek, J. (2010). "Influence of Reclaimed Asphalt Pavement (RAP) on Surface Friction." *Transportation Research Board 89th Annual Meeting*, Paper No. 10-0434, pp. 15.

Kowalski, K.J., McDaniel, R.S., and Olek, J. (2008). "Development of a Laboratory Procedure to Evaluate the Influence of Aggregate Type and Mixture Proportions on the Frictional Characteristics of Flexible Pavements." *Journal of the Association of Asphalt Paving Technologists*, Vol. 77, pp. 35-70.

Kraus, Z.R. (2008). *The Morphology of Polymer Modified Asphalt and its Relationship to Rheology and Durability*. MS Thesis, Texas A&M University.

Kvasnak, A., West, R., Michael, J., Loria, L., Hajj, E.Y., and Tran, N. (2010). "Evaluation of the Effect of Reclaimed Asphalt Pavement Aggregate Bulk Specific Gravity on Voids in Mineral Aggregate." *Transportation Research Board 89th Annual Meeting*, Paper No. 10-2170, pp. 18.

Lachance, A.M. (2002). *Properties of Asphalt Mixtures Containing RAP*. MS Thesis, University of New Hampshire.

Linden, R.N., Mahoney, J.P., and Jackson, N.C. (1989). "Effect of Compaction on Asphalt Concrete Performance." *Transportation Research Record: Journal of the Transportation Research Board*, No. 1217, pp. 20-28.

Louisiana Department of Transportation and Development. (2006). *Standard Specifications for Roads and Bridges*. Louisiana Department of Transportation and Development, Baton Rouge, LA.

Lu, Q. (2005). *Investigation of Conditions for Moisture Damage in Asphalt Concrete and Appropriate Laboratory Test Methods.* PhD Dissertation, University of California at Berkley.

Mathy Technology and Engineering Services. (2002). *Report to NCAT-Rejuvenator Study*. Onalaska, WI. pp. 29

Mathy Technology and Engineering Services. (2003). *Report to Foundation for Pavement Preservation*. Onalaska, WI. pp. 17.

Marasteanu, M.O., and Anderson, D.A. (2001). "Techniques for Determining Errors in Asphalt Binder Rheological Data." *Transportation Research Record: Journal of the Transportation Research Board*, No. 1766. pp. 32-39.

Marasteanu, M., Velasquez, R., Flachetto, A.C., and Zofka, A. (2009). *Development of a Simple Test to Determine the Low Temperature Creep Compliance of Asphalt Mixtures.* IDEA Program Final Report for Project 133, Transportation Research Board, Washington D.C., pp. 51.

McDaniel, R.S., Soleymani, H., Anderson, R.M., Turner, P., and Peterson, R. (2000). *Recommended Use of Reclaimed Asphalt Pavement in the Superpave Mix Design Method.* NCHRP Web Document 30 (Project D9-12): Contractor's Final Report.

McDaniel, R., and Anderson, R.M. (2001). *Recommended Use of Reclaimed Asphalt Pavement in the Superpave Mix Design Method: Technician's Manual*. National Cooperative Highway Research Program, Report 452, Transportation Research Board, Washington D.C.

Mississippi Department of Transportation. (2004). *Mississippi Standard Specifications for Road and Bridge Construction*. Mississippi Department of Transportation, Jackson, MS.

Nielson, J. (2010). *Development of a Testing Temperature to be used with the Hamburg Wheel Tracking Device on Asphalt Mixtures that Utilize Performance Grade Binders*. MS Thesis, University of Utah.

Newcomb, D.E., Brown, E.R., and Epps, J.A. (2007). *Designing HMA Mixtures with High RAP Content: A Practical Guide.* Quality Improvement Series 124, NAPA, pp. 36.

North Carolina Department of Transportation. (2002). *Standard Specifications for Roads and Structures.* North Carolina Department of Transportation, Raleigh, NC.

Pan, C., and White, T.D. (1999). *Conditions for Stripping Using Accelerated Testing*. Report No. FHWA/IN/JTRP/97-13, Joint Transportation Research Program, pp. 190.

Prowell, B.D., and Carter, C.B. (2000). *Evaluation of the Effect on Extracted Aggregate Properties of Samples Extracted Using the Ignition Furnace*. Interim Report No. VTRC 00-IR1, Virginia Transportation Research Council, pp. 18.

Prowell, B.D., and Brown, E.R. (2007). *Superpave Mix Design: Verifying Gyration Levels in the N_{design} Table*. National Cooperative Highway Research Program, Report 573, Transportation Research Board, Washington D.C.

Reinke, G., and Glidden, S. (2004). "Development of Mixture Creep Performance Tests Using a Dynamic Shear Rheometer." *Transportation Research Circular,* No. E-C068, Transportation Research Board, Washington, D.C., pp. 41.

Roberts, F.L., Kandhal, P.S., Brown, E.R., Lee, D.Y., and Kennedy, T.W. (1991). *Hot mix Asphalt Materials, Mixture Design and Construction.* NAPA Education Foundation, Lanham, Maryland. pp. 585.

Seo, Y., El-Haggan, O., King, M., Lee, S.J., and Kim, Y.R. (2007). "Air Void Models for the Dynamic Modulus, Fatigue Cracking, and Rutting of Asphalt Concrete." *Journal of Materials in Civil Engineering,* Vol. 19, No. 10, pp. 874-883.

Shiwakoti, H. (2007). *Development of a Rapid Test to Determine Moisture Sensitivity of HMA (Superpave) Mixtures*. MS Thesis, University of Kansas.

Sivasubramaniam, S., Galal, K.A., Noureldin, A.S., White, T.D., and Haddock, J.E. (2004). "Laboratory, Prototype, and In-Service Accelerated Pavement Testing to Model Permanent Deformation." *Transportation Research Record: Journal of the Transportation Research Board*, No. 1896, pp. 189-198.

South Carolina Department of Transportation. (2010). *Supplemental Technical Specification for Hot Mix Asphalt (HMA) Quality Assurance*. South Carolina Department of Transportation, Columbia, SC.

Terrel, R.L., and Al-Swailmi, S. (1993). "Role of Pessium Voids Concept in Understanding Moisture Damage to Asphalt Concrete Mixtures." *Transportation Research Record: Journal of the Transportation Research Board*, No. 1386. pp. 31-37

Texas Department of Transportation. (2004). *Standard Specifications for Construction and Maintenance of Highways, Streets, and Bridges*. Texas Dept of Transportation. Austin, TX.

Velasquez, R.A. (2009). *On the Representative Volume Element of Asphalt Concrete with Applications to Low Temperature*. PhD Dissertation, University of Minnesota.

Watson, D.E., Cooley Jr., L.A., Moore, K.A., and Williams, K. (2004). "Laboratory Performance Testing of Open-Graded Friction Course Mixtures." *Transportation Research Record: Journal of the Transportation Research Board*, No. 1891, pp. 40-47.

Watson, D.E., Moore, K.A., Williams, K., and Cooley Jr., L.A. (2003). "Refinement of New-Generation Open-Graded Friction Course Mix Design." *Transportation Research Record: Journal of the Transportation Research Board*, No. 1832, pp. 78-85.

West, R.C., Zhang, J., and Cooley Jr., A. (2004). *Evaluation of the Asphalt Pavement Analyzer for Moisture Sensitivity Testing*. NCAT Report 04-04, National Center for Asphalt Technology, Auburn, AL, pp. 37.

Williams, R.C., and Breakah, T.M. (2010). *Evaluation of Hot Mix Asphalt Moisture Sensitivity Using the Nottingham Asphalt Test Equipment*. Report No. IHRB Project TR-555, Iowa Highway Research Board, Iowa Dept of Transportation, pp. 138.

Zaniewski, J., and Viswanathan, A.G. (2006). *Investigation of Moisture Sensitivity of Hot Mix Asphalt Concrete*. Report Submitted to West Virginia Division of Highways, pp. 87.

Zofka, A., Marasteanu, M., Li, X., Clyne, T., and McGraw, J. (2005). "Simple Method to Obtain Asphalt Binder Low Temperatures from Asphalt Mixture Properties." *Journal of the Association of Asphalt Paving Technologists*. Vol. 74. pp 255-282.

Zofka, A., Marasteanu, M., and Turos, M. (2008). "Determination of Asphalt Mixture Creep Compliance at Low Temperatures Using Thin Beam Specimens." *Transportation Research Record: Journal of the Transportation Research Board*, No. 2057, pp. 134-139.

APPENDIX A – 100% RAP VOLUMETRIC DATA

Table A.1 Test Results for *9.5-100/RM-1* Relative Heating Experiment

Short Term[1] Age Time (min)	G_{mm}	Rep	H_I (mm)	H_F (mm)	Mass (g)	G_{mb} (---)	V_a (%)
60	2.334[2]	1	140.9	117.2	4520.1	2.230	4.5
		2	140.7	117.3	4518.3	2.221	4.9
		3	140.1	116.6	4511.9	2.235	4.3
		Avg.	**140.6**	**117.0**	**4516.8**	**2.229**	**4.5**
90	2.334	1	141.3	117.1	4514.1	2.230	4.5
		2	141.2	116.9	4520.8	2.236	4.2
		3	141.2	117.0	4507.3	2.227	4.6
		Avg.	**141.2**	**117.0**	**4514.1**	**2.231**	**4.4**
180	2.334	1	140.6	116.6	4517.7	2.241	4.0
		2	139.7	116.0	4513.7	2.253	3.5
		3	140.0	116.1	4511.8	2.248	3.7
		Avg.	**140.1**	**116.2**	**4514.4**	**2.247**	**3.7**
360	2.334	1	142.1	117.6	4513.4	2.231	4.4
		2	141.7	117.5	4511.3	2.231	4.4
		3	142.1	117.5	4512.6	2.229	4.5
		Avg.	**142.0**	**117.5**	**4512.4**	**2.230**	**4.5**
1440	2.334	1	145.3	120.7	4519.4	2.182	6.5
		2	144.7	120.3	4518.1	2.178	6.7
		3	144.6	120.3	4523.4	2.181	6.6
		Avg.	**144.9**	**120.4**	**4520.3**	**2.180**	**6.6**

1: The short term aging temperature was 146 C

2: Average of 2.330 and 2.333 tested at 60 minute age and 2.343 and 2.333 at 1440 minute age

Table A.2 G_{mm} Test Results for *R-1* at Varying Conditions

Short Term Aging Temperature (C)	Warm Mix Additive	Rep	P_{AC}[1] 8.1	7.1	6.0
116	None	1	2.292	2.336	2.369
		2	2.289	2.321	2.365
	Sasobit®	1	2.297	2.327	2.358
		2	2.300	2.329	2.355
	Evotherm 3G™	1	2.287	2.315	2.380
		2	2.283	2.326	2.370
		Avg.	**2.291**	**2.326**	**2.366**
		Range	**0.017**	**0.021**	**0.025**
		Std. Dev.	**0.006**	**0.007**	**0.009**
138	None	1	2.299	2.345	2.375
		2	2.296	2.337	2.370
	Sasobit®	1	2.293	2.332	2.364
		2	2.287	2.333	2.368
	Evotherm 3G™	1	2.295	2.325	2.363
		2	2.303	2.320	2.367
		Avg.	**2.296**	**2.332**	**2.368**
		Range	**0.016**	**0.025**	**0.012**
		Std. Dev.	**0.005**	**0.009**	**0.004**
	Avg.	**---**	**2.293**	**2.329**	**2.367**
	Range	**---**	**0.020**	**0.030**	**0.025**
	Std. Dev.	**---**	**0.006**	**0.008**	**0.007**

1: Total asphalt content including RAP bitumen and added virgin binder

Table A.3 G_{mm} Test Results for *R-2*

Short Term Aging Temperature (C)	Rep	P_{AC} [1] 8.2	7.2	6.2
138	1	2.317	2.350	2.382
	2	2.308	2.351	2.382
	Avg.	**2.313**	**2.350**	**2.382**
	Range	**0.009**	**0.001**	**0.000**

1: Total asphalt content including RAP bitumen and added virgin binder

Table A.4 G_{mm} Test Results for *R-3*

Short Term Aging Temperature (C)	Rep	P_{AC} [1] 7.4	6.4	5.5
138	1	2.343	2.382	2.420
	2	2.344	2.380	2.412
	Avg.	**2.343**	**2.381**	**2.416**
	Range	**0.001**	**0.002**	**0.008**

1: Total asphalt content including RAP bitumen and added virgin binder

Table A.5 G_{mm} Test Results for *R-1* and *R-3* RAP for a Variety of Conditions

Material Tested	Condition	P_{AC} [1]	Rep	G_{mm}
R-1	As received	5.5	1	2.386
			2	2.377
			Avg.	**2.382**
	2 hr heat at 171 C	5.5	1	2.371
			2	2.374
			Avg.	**2.373**
R-1 + 2% $P_{be(V)}$ [2]	2 hr heat at 171 C, no aging	7.4	1	2.565
			2	2.578
			Avg.	**2.315**
	2 hr heat at 171 C, 4 hr aging at 146 C	7.4	1	2.570
			2	2.583
			Avg.	**2.319**
R-3	As received	5.0	1	2.416
			2	4.414
			Avg.	**2.415**
	2 hr heat at 171 C	5.0	1	2.419
			2	2.426
			Avg.	**2.422**
R-3 + 2% $P_{be(V)}$	2 hr heat at 171 C, no aging	6.9	1	2.350
			2	2.353
			Avg.	**2.351**
	2 hr heat at 171 C, 4 hr aging at 146 C	6.9	1	2.354
			2	2.363
			Avg.	**2.358**

1: Total asphalt content including RAP bitumen and added virgin binder
2: Virgin binder added to RAP

Table A.6 *R-1* Compaction Data at 116 C Without Warm Mix Additives

Gyrations	G_{mm}	P_{AC}[1]	Rep	H_I (mm)	H_F (mm)	Mass (g)	G_{mb}	V_a
50	2.293	8.1	1	141.7	118.1	4566.1	2.231	2.7
			2	141.2	117.8	4569.9	2.239	2.4
			3	141.9	118.4	4565.1	2.231	2.7
			4	141.3	117.5	4566.1	2.245	2.1
			5	141.0	117.9	4554.4	2.233	2.6
			Avg.	**141.4**	**117.9**	**4564.3**	**2.236**	**2.5**
	2.329	7.1	1	141.8	118.5	4509.5	2.204	5.4
			2	139.9	117.1	4522.1	2.233	4.1
			3	140.6	117.6	4513.6	2.222	4.6
			4	140.8	117.5	4518.3	2.233	4.1
			5	142.7	119.3	4504.6	2.237	4.0
			6	141.6	118.7	4523.4	2.209	5.2
			Avg.	**141.2**	**118.1**	**4515.3**	**2.223**	**4.6**
	2.367	6.0	1	142.1	119.5	4449.4	2.157	8.9
			2	142.3	119.7	4460.6	2.159	8.8
			3	143.9	120.7	4460.5	2.165	8.5
			4	142.4	119.5	4448.5	2.186	7.6
			5	142.8	120.5	4473.7	2.157	8.9
			6	145.9	122.1	4474.2	2.143	9.5
			7	144.1	121.1	4472.0	2.148	9.3
			Avg.	**143.4**	**120.4**	**4462.7**	**2.159**	**8.8**

1: Total asphalt content including RAP bitumen and added virgin binder

Table A.7 *R-1* Compaction Data at 116 C Without Warm Mix Additives

Gyrations	G_{mm}	P_{AC}[1]	Rep	H_I (mm)	H_F (mm)	Mass (g)	G_{mb}	V_a
65	2.293	8.1	1	141.1	116.9	4575.2	2.259	1.5
			2	140.9	116.8	4568.7	2.257	1.6
			3	141.6	117.0	4561.7	2.251	1.8
			4	140.5	116.5	4574.4	2.263	1.3
			5	141.1	117.2	4569.8	2.252	1.8
			Avg.	**141.0**	**116.9**	**4570.0**	**2.256**	**1.6**
	2.329	7.1	1	140.4	116.6	4514.0	2.238	3.9
			2	140.8	116.8	4517.5	2.236	4.0
			3	141.5	117.2	4513.3	2.226	4.4
			4	141.1	116.8	4520.0	2.255	3.2
			5	142.2	118.1	4521.6	2.217	4.8
			Avg.	**141.2**	**117.1**	**4517.3**	**2.234**	**4.1**
	2.367	6.0	1	141.8	118.4	4465.1	2.188	7.6
			2	137.7	115.2	4360.8	2.198	7.1
			3	146.0	121.2	4465.7	2.144	9.4
			4	143.5	119.2	4461.1	2.186	7.6
			5	142.4	118.9	4465.2	2.177	8.0
			Avg.	**142.3**	**118.6**	**4443.6**	**2.179**	**8.0**

1: Total asphalt content including RAP bitumen and added virgin binder

Table A.8 *R-1* Compaction Data at 116 C Without Warm Mix Additives

Gyrations	G_{mm}	P_{AC}[1]	Rep	H_I (mm)	H_F (mm)	Mass (g)	G_{mb}	V_a
85	2.293	8.1	1	141.7	116.6	4575.6	2.262	1.4
			2	140.0	115.9	4570.8	2.274	0.8
			3	140.5	115.9	4564.7	2.269	1.0
			4	140.0	115.9	4569.1	2.272	0.9
			5	142.6	117.3	4578.5	2.256	1.6
			Avg.	**141.0**	**116.3**	**4571.7**	**2.267**	**1.2**
	2.329	7.1	1	140.1	115.7	4506.7	2.254	3.2
			2	140.9	116.3	4514.7	2.247	3.5
			3	141.4	116.2	4509.5	2.244	3.6
			4	140.1	115.2	4512.7	2.263	2.8
			5	142.6	117.7	4523.8	2.225	4.5
			Avg.	**141.0**	**116.2**	**4513.5**	**2.247**	**3.5**
	2.367	6.0	1	142.7	117.9	4456.3	2.224	6.0
			2	141.6	117.1	4451.8	2.211	6.6
			3	143.2	118.2	4459.4	2.198	7.1
			4	141.5	116.8	4455.8	2.223	6.1
			5	142.8	118.4	4470.4	2.189	7.5
			Avg.	**142.4**	**117.7**	**4458.7**	**2.209**	**6.7**

1: Total asphalt content including RAP bitumen and added virgin binder

Table A.9 *R-1* Compaction Data at 116 C with Sasobit®

Gyrations	G_{mm}	P_{AC}[1]	Rep	H_I (mm)	H_F (mm)	Mass (g)	G_{mb}	V_a
50	2.293	8.1	1	141.3	117.9	4575.3	2.241	2.3
			2	141.4	117.8	4568.9	2.241	2.3
			3	140.4	117.5	4564.7	2.244	2.1
			4	143.3	118.9	4572.2	2.228	2.8
			5	140.5	118.1	4580.5	2.241	2.3
			Avg.	**141.4**	**118.0**	**4572.3**	**2.239**	**2.4**
	2.329	7.1	1	140.2	117.2	4515.1	2.228	4.3
			2	140.9	118.0	4512.1	2.218	4.8
			3	142.0	118.4	4517.4	2.212	5.0
			4	140.5	117.2	4518.9	2.239	3.9
			5	142.1	119.0	4513.7	2.242	3.7
			6	141.6	118.5	4523.5	2.215	4.9
			Avg.	**141.2**	**118.1**	**4516.8**	**2.226**	**4.4**
	2.367	6.0	1	143.2	120.1	4460.2	2.166	8.5
			2	144.0	120.5	4461.5	2.159	8.8
			3	143.3	120.1	4459.2	2.161	8.7
			4	144.3	121.1	4473.0	2.168	8.4
			Avg.	**143.7**	**120.5**	**4463.5**	**2.164**	**8.6**

1: Total asphalt content including RAP bitumen and added virgin binder

Table A.10 *R-1* Compaction Data at 116 C with Sasobit®

Gyrations	G_{mm}	P_{AC}[1]	Rep	H_I (mm)	H_F (mm)	Mass (g)	G_{mb}	V_a
65	2.293	8.1	1	140.9	116.7	4572.2	2.259	1.5
			2	140.4	117.0	4573.5	2.260	1.4
			3	139.8	116.6	4567.7	2.262	1.4
			4	140.3	116.8	4572.9	2.258	1.5
			5	142.1	117.8	4565.4	2.240	2.3
			6	141.6	117.6	4569.8	2.248	2.0
			Avg.	**140.9**	**117.1**	**4570.3**	**2.255**	**1.7**
	2.329	7.1	1	141.3	117.3	4513.8	2.224	4.5
			2	140.8	116.9	4513.8	2.232	4.2
			3	141.8	117.8	4514.1	2.217	4.8
			4	139.7	116.4	4516.4	2.249	3.4
			5	141.0	117.6	4522.8	2.225	4.5
			Avg.	**140.9**	**117.2**	**4516.2**	**2.229**	**4.3**
	2.367	6.0	1	142.6	118.9	4456.3	2.173	8.2
			2	141.4	117.7	4460.4	2.197	7.2
			3	143.0	119.4	4466.8	2.178	8.0
			4	141.9	118.3	4474.2	2.197	7.2
			5	142.4	118.7	4473.6	2.182	7.8
			Avg.	**142.3**	**118.6**	**4466.3**	**2.185**	**7.7**

1: Total asphalt content including RAP bitumen and added virgin binder

Table A.11 *R-1* Compaction Data at 116 C with Sasobit®

Gyrations	G_{mm}	P_{AC}[1]	Rep	H_I (mm)	H_F (mm)	Mass (g)	G_{mb}	V_a
85	2.293	8.1	1	140.5	116.3	4578.3	2.261	1.4
			2	141.5	116.4	4571.9	2.265	1.2
			3	140.7	116.1	4565.3	2.266	1.2
			4	139.5	116.4	4575.8	2.267	1.1
			5	140.2	116.5	4574.4	2.264	1.3
			Avg.	**140.5**	**116.3**	**4573.1**	**2.265**	**1.2**
	2.329	7.1	1	141.2	116.3	4517.6	2.244	3.6
			2	140.8	115.9	4515.4	2.254	3.2
			3	141.7	116.8	4508.8	2.240	3.8
			4	142.0	116.9	4518.7	2.246	3.6
			5	145.0	118.8	4521.2	2.243	3.7
			6	140.9	116.4	4536.6	2.253	3.3
			Avg.	**141.9**	**116.9**	**4519.7**	**2.247**	**3.5**
	2.367	6.0	1	142.8	118.3	4464.8	2.191	7.4
			2	141.8	117.7	4463.9	2.204	6.9
			3	142.8	118.4	4468.3	2.185	7.7
			4	143.0	117.9	4470.5	2.203	6.9
			Avg.	**142.6**	**118.1**	**4466.9**	**2.196**	**7.2**

1: Total asphalt content including RAP bitumen and added virgin binder

Table A.12 *R-1* Compaction Data at 116 C with Evotherm 3G™

Gyrations	G_{mm}	P_{AC}[1]	Rep	H_I (mm)	H_F (mm)	Mass (g)	G_{mb}	V_a
50	2.293	8.1	1	140.7	117.7	4577.4	2.245	2.1
			2	140.4	117.6	4569.5	2.245	2.1
			3	139.7	117.2	4565.4	2.248	2.0
			4	138.9	116.6	4559.0	2.247	2.0
			5	139.9	118.0	4572.6	2.241	2.3
			Avg.	**139.9**	**117.4**	**4568.8**	**2.245**	**2.1**
	2.329	7.1	1	141.5	118.6	4520.5	2.203	5.4
			2	140.4	117.8	4507.9	2.213	5.0
			3	140.8	118.2	4517.0	2.207	5.2
			4	138.4	116.2	4515.6	2.239	3.9
			5	141.8	118.9	4520.4	2.230	4.3
			6	141.1	118.1	4520.5	2.217	4.8
			Avg.	**140.7**	**118.0**	**4517.0**	**2.218**	**4.8**
	2.367	6.0	1	141.9	119.5	4456.8	2.166	8.5
			2	141.6	119.3	4462.8	2.174	8.2
			3	141.9	119.4	4463.2	2.169	8.4
			4	143.9	120.9	4477.0	2.169	8.4
			5	141.6	119.6	4465.3	2.166	8.5
			Avg.	**142.2**	**119.7**	**4465.0**	**2.169**	**8.4**

1: Total asphalt content including RAP bitumen and added virgin binder

Table A.13 *R-1* Compaction Data at 116 C with Evotherm 3G™

Gyrations	G_{mm}	P_{AC}[1]	Rep	H_I (mm)	H_F (mm)	Mass (g)	G_{mb}	V_a
65	2.293	8.1	1	140.6	116.9	4572.1	2.251	1.8
			2	141.3	117.4	4574.2	2.245	2.1
			3	140.8	116.9	4566.2	2.249	1.9
			4	138.3	115.9	4561.8	2.253	1.7
			5	140.2	117.0	4577.7	2.253	1.7
			Avg.	**140.2**	**116.8**	**4570.4**	**2.250**	**1.9**
	2.329	7.1	1	141.7	117.7	4507.0	2.214	4.9
			2	140.5	116.9	4513.6	2.231	4.2
			3	141.9	117.7	4516.9	2.220	4.7
			4	138.7	115.7	4515.3	2.248	3.5
			5	141.4	117.6	4528.7	2.228	4.3
			Avg.	**140.8**	**117.1**	**4516.3**	**2.228**	**4.3**
	2.367	6.0	1	142.1	118.6	4458.1	2.179	7.9
			2	141.2	118.2	4457.4	2.186	7.6
			3	141.2	118.2	4460.2	2.177	8.0
			4	143.0	119.4	4479.3	2.184	7.7
			5	142.6	119.3	4474.6	2.174	8.2
			Avg.	**142.0**	**118.7**	**4465.9**	**2.180**	**7.9**

1: Total asphalt content including RAP bitumen and added virgin binder

Table A.14 *R-1* Compaction Data at 116 C with Evotherm 3G™

Gyrations	G_{mm}	P_{AC}[1]	Rep	H_I (mm)	H_F (mm)	Mass (g)	G_{mb}	V_a
85	2.293	8.1	1	139.6	116.0	4564.2	2.267	1.1
			2	139.1	115.7	4578.6	2.275	0.8
			3	140.7	116.4	4570.9	2.263	1.3
			4	138.6	116.3	4560.5	2.252	1.8
			5	141.0	117.2	4577.7	2.254	1.7
			Avg.	**139.8**	**116.3**	**4570.4**	**2.262**	**1.3**
	2.329	7.1	1	138.1	115.2	4461.6	2.231	4.2
			2	145.7	119.0	4525.0	2.213	5.0
			3	141.9	117.1	4516.3	2.253	3.3
			4	138.6	114.9	4513.8	2.258	3.0
			5	140.9	116.7	4509.3	2.255	3.2
			6	140.8	116.6	4530.7	2.245	3.6
			Avg.	**141.0**	**116.6**	**4509.5**	**2.243**	**3.7**
	2.367	6.0	1	141.7	117.8	4512.7	2.224	6.0
			2	142.0	117.8	4463.6	2.195	7.3
			3	143.1	118.4	4471.9	2.193	7.4
			4	145.1	119.7	4475.9	2.180	7.9
			5	141.8	118.1	4467.4	2.197	7.2
			Avg.	**142.7**	**118.4**	**4478.3**	**2.198**	**7.1**

1: Total asphalt content including RAP bitumen and added virgin binder

Table A.15 *R-1* Compaction Data at 138 C Without Warm Mix Additives

Gyrations	G_{mm}	P_{AC}[1]	Rep	H_I (mm)	H_F (mm)	Mass (g)	G_{mb}	V_a
50	2.293	8.1	1	138.6	116.3	4571.1	2.268	1.1
			2	138.7	116.1	4568.0	2.272	0.9
			3	139.0	116.6	4572.1	2.265	1.2
			4	137.3	116.0	4572.2	2.274	0.8
			5	139.3	116.6	4574.9	2.269	1.0
			Avg.	**138.6**	**116.3**	**4571.7**	**2.270**	**1.0**
	2.329	7.1	1	140.1	116.8	4508.3	2.242	3.7
			2	140.4	117.2	4521.9	2.236	4.0
			3	139.4	116.4	4517.8	2.251	3.3
			4	138.1	115.5	4515.9	2.267	2.7
			5	139.3	116.2	4523.0	2.252	3.3
			Avg.	**139.5**	**116.4**	**4517.4**	**2.250**	**3.4**
	2.367	6.0	1	140.8	117.9	4455.1	2.197	7.2
			2	141.0	118.0	4465.3	2.198	7.1
			3	140.6	117.7	4465.9	2.205	6.8
			4	141.1	118.0	4458.5	2.201	7.0
			5	140.5	117.8	4475.4	2.204	6.9
			Avg.	**140.8**	**117.9**	**4464.0**	**2.201**	**7.0**

1: Total asphalt content including RAP bitumen and added virgin binder

Table A.16 *R-1* Compaction Data at 138 C Without Warm Mix Additives

Gyrations	G_{mm}	P_{AC}[1]	Rep	H_I (mm)	H_F (mm)	Mass (g)	G_{mb}	V_a
65	2.293	8.1	1	138.9	116.3	4577.8	2.275	0.8
			2	139.0	115.8	4568.4	2.277	0.7
			3	140.0	116.1	4570.5	2.271	1.0
			4	138.0	115.8	4570.1	2.276	0.7
			5	140.9	116.6	4580.1	2.266	1.2
			6	140.4	116.1	4526.0	2.256	1.6
			Avg.	**139.5**	**116.1**	**4565.5**	**2.270**	**1.0**
	2.329	7.1	1	140.6	116.1	4521.1	2.252	3.3
			2	139.9	115.6	4517.7	2.263	2.8
			3	140.9	116.6	4522.3	2.248	3.5
			4	138.8	115.2	4520.7	2.273	2.4
			5	142.7	117.9	4528.1	2.224	4.5
			6	140.3	116.6	4483.2	2.230	4.3
			Avg.	**140.5**	**116.3**	**4515.5**	**2.248**	**3.5**
	2.367	6.0	1	140.8	117.1	4467.3	2.214	6.5
			2	140.3	116.7	4469.6	2.223	6.1
			3	141.9	117.4	4471.2	2.209	6.7
			4	138.9	115.1	4453.8	2.248	5.0
			5	141.0	117.4	4471.5	2.206	6.8
			6	140.1	116.6	4418.1	2.203	6.9
			Avg.	**140.5**	**116.7**	**4458.6**	**2.217**	**6.3**

1: Total asphalt content including RAP bitumen and added virgin binder

Table A.17 *R-1* Compaction Data at 138 C Without Warm Mix Additives

Gyrations	G_{mm}	P_{AC}[1]	Rep	H_I (mm)	H_F (mm)	Mass (g)	G_{mb}	V_a
85	2.293	8.1	1	140.1	115.6	4572.5	2.280	0.6
			2	139.4	115.4	4572.1	2.286	0.3
			3	140.0	114.8	4565.7	2.275	0.8
			4	139.1	115.3	4561.7	2.280	0.6
			5	140.2	115.8	4573.7	2.280	0.6
			Avg.	**139.8**	**115.4**	**4569.1**	**2.280**	**0.6**
	2.329	7.1	1	139.8	114.8	4510.5	2.274	2.4
			2	139.7	114.8	4519.5	2.275	2.3
			3	140.1	115.4	4526.4	2.275	2.3
			4	137.9	114.2	4514.7	2.283	2.0
			5	138.4	115.1	4508.5	2.291	1.6
			6	140.9	115.9	4517.8	2.261	2.9
			Avg.	**139.5**	**115.0**	**4516.2**	**2.277**	**2.3**
	2.367	6.0	1	142.5	117.0	4464.1	2.222	6.1
			2	141.2	116.4	4473.5	2.230	5.8
			3	141.0	116.6	4479.2	2.232	5.7
			4	138.7	114.4	4459.4	2.258	4.6
			5	143.7	118.2	4475.2	2.200	7.1
			Avg.	**141.4**	**116.5**	**4470.3**	**2.228**	**5.9**

1: Total asphalt content including RAP bitumen and added virgin binder

Table A.18 *R-1* Compaction Data at 138 C with Sasobit®

Gyrations	G_{mm}	P_{AC}[1]	Rep	H_I (mm)	H_F (mm)	Mass (g)	G_{mb}	V_a
50	2.293	8.1	1	139.0	116.5	4572.6	2.267	1.1
			2	140.0	116.7	4574.0	2.266	1.2
			3	138.5	116.2	4571.1	2.272	0.9
			4	140.2	116.8	4566.9	2.265	1.2
			5	130.3	117.4	4560.5	2.271	1.0
			6	140.5	117.3	4577.1	2.257	1.6
			Avg.	**138.1**	**116.8**	**4570.4**	**2.266**	**1.2**
	2.329	7.1	1	140.0	116.6	4516.9	2.244	3.6
			2	140.6	117.2	4521.7	2.238	3.9
			3	140.7	117.1	4520.3	2.236	4.0
			4	136.8	114.8	4510.6	2.275	2.3
			5	138.6	116.9	4505.9	2.276	2.3
			6	141.0	117.6	4521.9	2.233	4.1
			Avg.	**139.6**	**116.7**	**4516.2**	**2.250**	**3.4**
	2.367	6.0	1	140.6	117.7	4465.8	2.203	6.9
			2	141.0	117.9	4463.6	2.204	6.9
			3	140.3	117.6	4464.4	2.214	6.5
			4	141.3	118.2	4464.0	2.202	7.0
			5	141.1	118.1	4473.9	2.194	7.3
			Avg.	**140.9**	**117.9**	**4466.3**	**2.203**	**6.9**

1: Total asphalt content including RAP bitumen and added virgin binder

Table A.19 *R-1* Compaction Data at 138 C with Sasobit®

Gyrations	G_{mm}	P_{AC}[1]	Rep	H_I (mm)	H_F (mm)	Mass (g)	G_{mb}	V_a
65	2.293	8.1	1	140.6	116.2	4573.6	2.273	0.9
			2	138.4	115.8	4575.9	2.279	0.6
			3	138.5	115.6	4568.9	2.279	0.6
			4	136.4	115.9	4566.9	2.277	0.7
			5	138.8	116.1	4580.5	2.279	0.6
			6	138.6	115.5	4566.0	2.281	0.5
			7	137.9	115.2	4562.8	2.286	0.3
			Avg.	**138.5**	**115.8**	**4570.7**	**2.279**	**0.6**
	2.329	7.1	1	138.7	115.4	4519.7	2.263	2.8
			2	139.0	115.2	4517.6	2.269	2.6
			3	139.6	116.0	4514.2	2.258	3.0
			4	140.2	116.0	4512.5	2.258	3.0
			5	139.4	115.5	4520.9	2.268	2.6
			6	141.0	116.5	4518.9	2.249	3.4
			7	141.0	116.5	4522.7	2.247	3.5
			Avg.	**139.8**	**115.9**	**4518.1**	**2.259**	**3.0**
	2.367	6.0	1	140.0	116.4	4458.8	2.244	5.2
			2	139.5	116.0	4459.3	2.235	5.6
			3	139.3	116.0	4462.3	2.230	5.8
			4	139.6	115.4	4463.2	2.251	4.9
			Avg.	**139.6**	**116.0**	**4460.9**	**2.240**	**5.4**

1: Total asphalt content including RAP bitumen and added virgin binder

Table A.20 *R-1* Compaction Data at 138 C with Sasobit®

Gyrations	G_{mm}	P_{AC}[1]	Rep	H_I (mm)	H_F (mm)	Mass (g)	G_{mb}	V_a
85	2.293	8.1	1	140.9	115.5	4565.4	2.286	0.3
			2	139.6	115.2	4566.3	2.290	0.1
			3	140.0	115.3	4569.4	2.287	0.3
			4	140.1	115.4	4564.7	2.282	0.5
			5	139.0	115.6	4575.4	2.283	0.4
			Avg.	**139.9**	**115.4**	**4568.2**	**2.286**	**0.3**
	2.329	7.1	1	141.6	116.0	4518.1	2.261	2.9
			2	140.0	114.9	4517.1	2.276	2.3
			3	140.6	115.2	4510.9	2.269	2.6
			4	139.4	114.6	4519.3	2.286	1.8
			5	141.4	116.1	4526.8	2.256	3.1
			6	140.7	116.7	4501.4	2.249	3.4
			Avg.	**140.6**	**115.6**	**4515.6**	**2.266**	**2.7**
	2.367	6.0	1	137.4	114.1	4470.5	2.265	4.3
			2	139.8	115.5	4470.2	2.240	5.4
			3	141.0	115.9	4463.5	2.238	5.4
			4	140.1	115.0	4463.5	2.258	4.6
			5	143.7	118.4	4480.3	2.194	7.3
			6	140.4	115.9	4441.7	2.191	7.4
			Avg.	**140.4**	**115.8**	**4465.0**	**2.231**	**5.7**

1: Total asphalt content including RAP bitumen and added virgin binder

Table A.21 *R-1* Compaction Data at 138 C with Evotherm 3G™

Gyrations	G_{mm}	P_{AC}[1]	Rep	H_I (mm)	H_F (mm)	Mass (g)	G_{mb}	V_a
50	2.293	8.1	1	136.7	115.7	4568.3	2.279	0.6
			2	137.5	115.4	4562.0	2.282	0.5
			3	139.0	116.0	4563.6	2.272	0.9
			4	136.0	115.3	4544.7	2.281	0.5
			5	139.4	116.7	4576.0	2.266	1.2
			Avg.	**137.7**	**115.8**	**4562.9**	**2.276**	**0.7**
	2.329	7.1	1	140.0	117.2	4518.5	2.234	4.1
			2	138.4	116.1	4518.4	2.256	3.1
			3	139.4	116.7	4514.3	2.237	4.0
			4	140.7	117.6	4520.6	2.244	3.6
			5	140.7	117.7	4501.6	2.261	2.9
			6	139.5	116.7	4523.5	2.245	3.6
			Avg.	**139.8**	**117.0**	**4516.2**	**2.246**	**3.6**
	2.367	6.0	1	139.3	117.6	4458.6	2.202	7.0
			2	138.6	115.9	4463.3	2.235	5.6
			3	140.5	118.0	4497.6	2.217	6.3
			4	139.3	116.7	4467.7	2.222	6.1
			5	140.3	117.9	4460.8	2.199	7.1
			Avg.	**139.6**	**117.2**	**4469.6**	**2.215**	**6.4**

1: Total asphalt content including RAP bitumen and added virgin binder

Table A.22 *R-1* Compaction Data at 138 C with Evotherm 3G™

Gyrations	G_{mm}	P_{AC}[1]	Rep	H_I (mm)	H_F (mm)	Mass (g)	G_{mb}	V_a
65	2.293	8.1	1	139.6	116.1	4569.8	2.276	0.7
			2	138.2	115.3	4561.6	2.281	0.5
			3	138.4	115.7	4565.0	2.280	0.6
			4	136.5	115.7	4560.3	2.282	0.5
			5	139.4	115.9	4575.6	2.278	0.7
			6	139.2	116.3	4568.1	2.264	1.3
			Avg.	**138.6**	**115.8**	**4566.7**	**2.277**	**0.7**
	2.329	7.1	1	138.6	115.5	4514.1	2.262	2.9
			2	137.4	114.4	4510.0	2.280	2.1
			3	139.1	115.4	4513.7	2.268	2.6
			4	137.9	114.8	4513.3	2.278	2.2
			5	140.1	116.1	4526.0	2.261	2.9
			Avg.	**138.6**	**115.2**	**4515.4**	**2.270**	**2.5**
	2.367	6.0	1	139.9	116.4	4462.0	2.218	6.3
			2	138.0	115.0	4462.4	2.245	5.2
			3	138.7	115.4	4467.0	2.241	5.3
			4	140.6	116.9	4468.7	2.226	6.0
			Avg.	**139.3**	**115.9**	**4465.0**	**2.233**	**5.7**

1: Total asphalt content including RAP bitumen and added virgin binder

Table A.23 *R-1* Compaction Data at 138 C with Evotherm 3G™

Gyrations	G_{mm}	P_{AC}[1]	Rep	H_I (mm)	H_F (mm)	Mass (g)	G_{mb}	V_a
85	2.293	8.1	1	138.5	114.7	4565.3	2.293	0.0
			2	138.6	115.0	4563.3	2.287	0.3
			3	139.2	114.8	4563.9	2.291	0.1
			4	136.5	115.8	4566.3	2.276	0.7
			5	138.4	115.7	4572.3	2.279	0.6
			6	142.7	117.9	4571.8	2.267	1.1
			Avg.	**139.0**	**115.7**	**4567.2**	**2.282**	**0.5**
	2.329	7.1	1	138.0	114.3	4514.1	2.281	2.1
			2	137.9	114.1	4512.4	2.286	1.8
			3	141.8	116.5	4514.9	2.244	3.6
			4	137.6	114.3	4528.0	2.292	1.6
			5	138.7	114.5	4528.8	2.281	2.1
			Avg.	**138.8**	**114.7**	**4519.6**	**2.277**	**2.2**
	2.367	6.0	1	138.3	114.9	4463.3	2.250	4.9
			2	142.4	117.4	4466.0	2.208	6.7
			3	140.6	116.4	4461.7	2.222	6.1
			4	140.6	115.5	4470.4	2.248	5.0
			5	139.6	115.9	4474.9	2.243	5.2
			6	140.5	116.2	4477.5	2.234	5.6
			7	141.0	116.4	4471.6	2.235	5.6
			Avg.	**140.4**	**116.1**	**4469.3**	**2.234**	**5.6**

1: Total asphalt content including RAP bitumen and added virgin binder

Table A.24 *R-1* Compaction Data at 154 C and 65 Gyrations

Additive	G_{mm}	P_{AC}[1]	Rep	H_I (mm)	H_F (mm)	Mass (g)	G_{mb}	V_a
None	2.293	8.1	1	137.7	115.9	4551.9	2.280	0.6
			2	136.0	115.6	4557.0	2.282	0.5
			Avg.	**136.9**	**115.8**	**4554.5**	**2.281**	**0.5**
	2.329	7.1	1	138.3	115.3	4515.9	2.280	2.1
			2	137.9	115.1	4518.7	2.283	2.0
			Avg.	**138.1**	**115.2**	**4517.3**	**2.282**	**2.0**
	2.367	6.0	1	138.1	115.5	4472.7	2.270	4.1
			2	139.4	116.1	4471.6	2.267	4.2
			Avg.	**138.8**	**115.8**	**4472.2**	**2.269**	**4.2**
Sasobit®	2.293	8.1	1	135.6	115.6	4550.8	2.281	0.5
			2	136.2	116.2	4564.2	2.271	1.0
			Avg.	**135.9**	**115.9**	**4557.5**	**2.276**	**0.7**
	2.329	7.1	1	136.8	114.7	4519.9	2.290	1.7
			2	136.9	114.5	4518.9	2.289	1.7
			Avg.	**136.9**	**114.6**	**4519.4**	**2.290**	**1.7**
	2.367	6.0	1	139.6	116.6	4483.9	2.268	4.2
			2	139.8	116.2	4483.9	2.272	4.0
			Avg.	**139.7**	**116.4**	**4483.9**	**2.270**	**4.1**
Evotherm 3G™	2.293	8.1	1	136.4	115.7	4564.6	2.286	0.3
			2	137.6	116.0	4562.5	2.279	0.6
			Avg.	**137.0**	**115.9**	**4563.6**	**2.283**	**0.5**
	2.329	7.1	1	137.2	115.0	4520.8	2.282	2.0
			2	137.3	114.9	4523.1	2.285	1.9
			Avg.	**137.3**	**115.0**	**4522.0**	**2.284**	**2.0**
	2.367	6.0	1	138.1	115.2	4478.3	2.268	4.2
			2	138.4	115.6	4476.7	2.279	3.7
			Avg.	**138.3**	**115.4**	**4477.5**	**2.274**	**4.0**

1: Total asphalt content including RAP bitumen and added virgin binder

Table A.25 *R-2* Compaction Data at 116 C and 65 Gyrations

Additive	G_{mm}	P_{AC}[1]	Rep	H_I (mm)	H_F (mm)	Mass (g)	G_{mb}	V_a
None	2.313	8.2	1	135.5	115.3	4559.6	2.283	1.3
			2	135.1	115.1	4558.1	2.286	1.2
			Avg.	**135.3**	**115.2**	**4558.9**	**2.285**	**1.2**
	2.350	7.2	1	135.9	114.1	4519.8	2.285	2.8
			2	135.3	113.7	4511.6	2.289	2.6
			Avg.	**135.6**	**113.9**	**4515.7**	**2.287**	**2.7**
	2.382	6.2	1	136.5	114.5	4474.5	2.265	4.9
			2	135.9	114.3	4464.2	2.263	5.0
			Avg.	**136.2**	**114.4**	**4469.4**	**2.264**	**5.0**
Evotherm 3G™	2.313	8.2	1	134	115.4	4537.4	2.274	1.7
			2	135	115.3	4559.7	2.284	1.3
			Avg.	**134.5**	**115.4**	**4548.6**	**2.279**	**1.5**
	2.350	7.2	1	134.8	113.6	4517.5	2.292	2.5
			2	135.4	113.8	4506.6	2.287	2.7
			Avg.	**135.1**	**113.7**	**4512.1**	**2.290**	**2.6**
	2.382	6.2	1	137.4	114.9	4471.7	2.264	5.0
			2	136.5	114.6	4470.1	2.261	5.1
			Avg.	**137.0**	**114.8**	**4470.9**	**2.263**	**5.0**

1: Total asphalt content including RAP bitumen and added virgin binder

Table A.26 *R-2* Compaction Data at 138 C and 65 Gyrations

Additive	G_{mm}	P_{AC}[1]	Rep	H_I (mm)	H_F (mm)	Mass (g)	G_{mb}	V_a
None	2.313	8.2	1	131.1	114.8	4545.8	2.274	1.7
			2	131.1	114.9	4548.1	2.278	1.5
			Avg.	**131.1**	**114.9**	**4547.0**	**2.276**	**1.6**
	2.350	7.2	1	132.2	112.7	4508.0	2.296	2.3
			2	132.4	112.8	4512.5	2.297	2.3
			Avg.	**132.3**	**112.8**	**4510.3**	**2.297**	**2.3**
	2.382	6.2	1	133.2	112.2	4463.9	2.290	3.9
			2	134.1	112.7	4465.9	2.284	4.1
			Avg.	**133.7**	**112.5**	**4464.9**	**2.287**	**4.0**
Sasobit®	2.313	8.2	1	132.7	115.4	4549.7	2.270	1.9
			2	131.4	115.1	4545.9	2.270	1.9
			Avg.	**132.1**	**115.3**	**4547.8**	**2.270**	**1.9**
	2.350	7.2	1	132.4	113.0	4512.7	2.299	2.2
			2	133.1	113.0	4510.2	2.296	2.3
			Avg.	**132.8**	**113.0**	**4511.5**	**2.298**	**2.2**
	2.382	6.2	1	133.3	112.2	4468.3	2.287	4.0
			2	134.2	112.3	4462.0	2.285	4.1
			Avg.	**133.8**	**112.3**	**4465.2**	**2.286**	**4.0**
Evotherm 3G™	2.313	8.2	1	132.5	115.0	4553.1	2.274	1.7
			2	131.6	115.0	4548.3	2.276	1.6
			Avg.	**132.1**	**115.0**	**4550.7**	**2.275**	**1.6**
	2.350	7.2	1	133.7	113.4	4526.0	2.291	2.5
			2	133.0	112.9	4511.5	2.298	2.2
			Avg.	**133.4**	**113.2**	**4518.8**	**2.295**	**2.4**
	2.382	6.2	1	133.7	112.2	4461.4	2.291	3.8
			2	133.9	112.4	4457.0	2.284	4.1
			Avg.	**133.8**	**112.3**	**4459.2**	**2.288**	**4.0**

1: Total asphalt content including RAP bitumen and added virgin binder

Table A.27 *R-2* Compaction Data at 154 C and 65 Gyrations

Additive	G_{mm}	P_{AC}[1]	Rep	H_I (mm)	H_F (mm)	Mass (g)	G_{mb}	V_a
None	2.313	8.2	1	131.8	114.7	4546.2	2.292	0.9
			2	132.8	114.4	4526.1	2.293	0.9
			Avg.	**132.3**	**114.6**	**4536.2**	**2.293**	**0.9**
	2.350	7.2	1	134.0	113.1	4507.2	2.302	2.0
			2	132.6	112.6	4483.7	2.301	2.1
			Avg.	**133.3**	**112.9**	**4495.5**	**2.302**	**2.1**
	2.382	6.2	1	135.4	113.4	4465.3	2.282	4.2
			2	134.7	113.0	4467.9	2.288	3.9
			Avg.	**135.1**	**113.2**	**4466.6**	**2.285**	**4.1**
Sasobit®	2.313	8.2	1	132.1	110.6	4558.1	2.301	0.5
	2.350	7.2	1	131.1	112.0	4516.5	2.305	1.9
	2.382	6.2	1	129.8	114.4	4490.0	2.314	3.3

1: Total asphalt content including RAP bitumen and added virgin binder

Table A.28 *R-3* Compaction Data at 116 C and 65 Gyrations

Additive	G_{mm}	P_{AC}[1]	Rep	H_I (mm)	H_F (mm)	Mass (g)	G_{mb}	V_a
None	2.343	7.4	1	131.2	113.2	4514.1	2.304	1.7
			2	131.1	113.7	4513.1	2.289	2.3
			Avg.	**131.2**	**113.5**	**4513.6**	**2.297**	**2.0**
	2.381	6.4	1	133.1	113.5	4484.4	2.291	3.8
			2	132.3	113.1	4484.4	2.290	3.8
			Avg.	**132.7**	**113.3**	**4484.4**	**2.291**	**3.8**
	2.416	5.5	1	133.9	115.0	4428.9	2.236	7.5
			2	133.6	114.1	4444.2	2.255	6.7
			Avg.	**133.8**	**114.6**	**4436.6**	**2.246**	**7.1**
Sasobit®	2.343	7.4	1	131.8	112.0	4467.6	2.289	2.3
	2.381	6.4	1	132.7	112.7	4488.2	2.288	3.9
	2.416	5.5	1	134.1	114.5	4409..9	2.211	8.5
Evotherm 3G™	2.343	7.4	1	131.3	113.7	4515.6	2.293	2.1
			2	132.2	114.3	4526.0	2.291	2.2
			Avg.	**131.8**	**114.0**	**4520.8**	**2.292**	**2.2**
	2.381	6.4	1	132.0	112.8	4479.8	2.296	3.6
			2	132.6	113.1	4480.7	2.295	3.6
			Avg.	**132.3**	**113.0**	**4480.3**	**2.296**	**3.6**
	2.416	5.5	1	133.0	113.6	4435.0	2.260	6.5
			2	133.9	114.4	4446.9	2.256	6.6
			Avg.	**133.5**	**114.0**	**4441.0**	**2.258**	**6.5**

1: Total asphalt content including RAP bitumen and added virgin binder

Table A.29 *R-3* Compaction Data at 138 C and 65 Gyrations

Additive	G_{mm}	P_{AC}[1]	Rep	H_I (mm)	H_F (mm)	Mass (g)	G_{mb}	V_a
None	2.343	7.4	1	129.1	112.8	4510.5	2.295	2.0
			2	129.0	113.2	4520.3	2.290	2.3
			Avg.	**129.1**	**113.0**	**4515.4**	**2.293**	**2.2**
	2.381	6.4	1	130.8	111.9	4482.8	2.296	3.6
			2	130.4	111.6	4479.5	2.301	3.4
			Avg.	**130.6**	**111.8**	**4481.2**	**2.299**	**3.5**
	2.416	5.5	1	131.5	112.2	4426.8	2.269	6.1
			2	131.5	112.2	4436.9	2.269	6.1
			Avg.	**131.5**	**112.2**	**4431.9**	**2.269**	**6.1**
Sasobit®	2.343	7.4	1	129.8	113.6	4519.5	2.290	2.3
			2	129.8	113.5	4520.1	2.292	2.2
			Avg.	**129.8**	**113.6**	**4519.8**	**2.291**	**2.2**
	2.381	6.4	1	129.5	111.5	4468.9	2.312	2.9
			2	130.7	111.1	4481.6	2.302	3.3
			Avg.	**130.1**	**111.3**	**4475.3**	**2.307**	**3.1**
	2.416	5.5	1	132.1	112.6	4438.0	2.274	5.9
			2	132.0	112.7	4438.6	2.268	6.1
			Avg.	**132.1**	**112.7**	**4438.3**	**2.271**	**6.0**
Evotherm 3G™	2.343	7.4	1	129.3	113.3	4519.8	2.295	2.0
			2	129.4	113.5	4514.3	2.290	2.3
			Avg.	**129.4**	**113.4**	**4517.1**	**2.293**	**2.2**
	2.381	6.4	1	130.8	112.1	4485.3	2.302	3.3
			2	130.2	111.4	4473.2	2.302	3.3
			Avg.	**130.5**	**111.8**	**4479.3**	**2.302**	**3.3**
	2.416	5.5	1	131.5	112.2	4445.4	2.278	5.7
			2	131.9	112.6	4442.7	2.267	6.2
			Avg.	**131.7**	**112.4**	**4444.1**	**2.273**	**5.9**

1: Total asphalt content including RAP bitumen and added virgin binder

Table A.30 *R-3* Compaction Data at 154 C and 65 Gyrations

Additive	G_{mm}	P_{AC}[1]	Rep	H_I (mm)	H_F (mm)	Mass (g)	G_{mb}	V_a
None	2.343	7.4	1	129.5	113.6	4534.8	2.306	1.6
			2	129.5	113.3	4513.0	2.304	1.7
			Avg.	**129.5**	**113.5**	**4523.9**	**2.305**	**1.6**
	2.381	6.4	1	130.7	112.0	4487.2	2.313	2.9
			2	131.5	112.6	4509.6	2.315	2.8
			Avg.	**131.1**	**112.3**	**4498.4**	**2.314**	**2.8**
	2.416	5.5	1	131.9	112.9	4427.0	2.267	6.2
			2	131.8	112.6	4432.8	2.279	5.7
			Avg.	**131.9**	**112.8**	**4429.9**	**2.273**	**5.9**
Sasobit®	2.343	7.4	1	126.7	109.1	4398.5	2.315	1.2
	2.381	6.4	1	131.0	111.1	4441.1	2.308	3.1
	2.416	5.5	1	133.1	112.9	4423.6	2.263	6.3
Evotherm 3G™	2.343	7.4	1	130.1	113.6	4523.6	2.302	1.7
			2	129.1	112.9	4507.7	2.303	1.7
			Avg.	**129.6**	**113.3**	**4515.7**	**2.303**	**1.7**
	2.381	6.4	1	130.6	111.9	4477.2	2.311	2.9
			2	129.7	111.3	4456.9	2.316	2.7
			Avg.	**130.2**	**111.6**	**4467.1**	**2.314**	**2.8**
	2.416	5.5	1	130.7	111.4	4407.1	2.285	5.4
			2	132.4	113.1	4438.2	2.272	6.0
			Avg.	**131.6**	**112.3**	**4422.7**	**2.279**	**5.7**

1: Total asphalt content including RAP bitumen and added virgin binder

APPENDIX B – *BBR* DATA

Table B.1 *BBR* Mixture Data for *9.5-100/RM-1*

V_a	Test		Test Time (sec) and Mixture Stiffness (GPa)								Test Time (sec) and Mixture m-value							
(%)	Temp (C)	Rep	8	15	30	60	120	240	480	960	8	15	30	60	120	240	480	960
4.1	-24	1	17.90	17.43	16.71	15.83	14.81	13.68	12.48	11.24	0.035	0.051	0.069	0.087	0.105	0.124	0.142	0.160
		2	17.18	16.68	16.05	15.33	14.55	13.72	12.84	11.94	0.042	0.051	0.061	0.071	0.080	0.090	0.100	0.110
		3	21.08	20.39	19.58	18.72	17.81	16.88	15.92	14.95	0.050	0.055	0.062	0.068	0.075	0.081	0.087	0.094
		4*	5.55	5.50	5.42	5.33	5.23	5.12	4.99	4.85	0.013	0.017	0.021	0.026	0.030	0.035	0.039	0.043
		5*	6.83	6.77	6.67	6.56	6.43	6.30	6.14	5.97	0.016	0.021	0.026	0.032	0.037	0.043	0.048	0.053
		Avg	**18.72**	**18.17**	**17.45**	**16.63**	**15.72**	**14.76**	**13.75**	**12.71**	**0.042**	**0.052**	**0.064**	**0.075**	**0.087**	**0.098**	**0.110**	**0.121**
		StdDev	**2.08**	**1.96**	**1.88**	**1.83**	**1.81**	**1.84**	**1.89**	**1.97**	**0.008**	**0.002**	**0.004**	**0.010**	**0.016**	**0.023**	**0.029**	**0.034**
	-18	1	22.99	22.36	21.44	20.30	18.99	17.54	16.01	14.43	0.036	0.052	0.070	0.088	0.105	0.123	0.141	0.159
		2	20.47	19.76	18.93	18.06	17.14	16.20	15.25	14.29	0.053	0.059	0.065	0.072	0.078	0.084	0.091	0.097
		3	18.08	17.52	16.83	16.10	15.31	14.50	13.66	12.80	0.047	0.054	0.061	0.068	0.075	0.083	0.090	0.097
		4	17.86	17.35	16.60	15.67	14.60	13.43	12.19	10.91	0.037	0.055	0.074	0.093	0.111	0.130	0.149	0.168
		5	15.56	15.14	14.52	13.74	12.85	11.87	10.83	9.76	0.036	0.052	0.070	0.088	0.106	0.124	0.142	0.160
		Avg	**18.99**	**18.43**	**17.66**	**16.77**	**15.78**	**14.71**	**13.59**	**12.44**	**0.042**	**0.054**	**0.068**	**0.082**	**0.095**	**0.109**	**0.123**	**0.136**
		StdDev	**2.83**	**2.74**	**2.63**	**2.50**	**2.36**	**2.24**	**2.13**	**2.06**	**0.008**	**0.003**	**0.005**	**0.011**	**0.017**	**0.023**	**0.030**	**0.036**
	-12	1	16.19	15.79	15.23	14.54	13.75	12.87	11.94	10.96	0.033	0.046	0.060	0.074	0.088	0.102	0.116	0.130
		2	13.55	13.13	12.59	11.98	11.33	10.63	9.91	9.17	0.046	0.056	0.066	0.076	0.086	0.097	0.107	0.117
		3	16.43	15.92	15.31	14.66	13.98	13.28	12.55	11.82	0.047	0.053	0.059	0.065	0.072	0.078	0.084	0.090
		4	16.61	16.05	15.34	14.55	13.70	12.80	11.87	10.92	0.049	0.059	0.070	0.081	0.092	0.104	0.115	0.126
		5*	6.48	6.28	6.02	5.73	5.42	5.08	4.74	4.38	0.022	0.027	0.032	0.036	0.041	0.046	0.051	0.056
		Avg	**15.69**	**15.22**	**14.62**	**13.93**	**13.19**	**12.40**	**11.57**	**10.72**	**0.044**	**0.053**	**0.064**	**0.074**	**0.085**	**0.095**	**0.105**	**0.116**
		StdDev	**1.44**	**1.40**	**1.35**	**1.30**	**1.25**	**1.20**	**1.15**	**1.11**	**0.007**	**0.006**	**0.005**	**0.007**	**0.009**	**0.012**	**0.015**	**0.018**
	-06	1	22.75	21.58	20.27	18.94	17.62	16.30	15.01	13.76	0.081	0.087	0.094	0.101	0.108	0.115	0.122	0.130
		2	13.74	13.24	12.60	11.89	11.12	10.32	9.49	8.65	0.054	0.065	0.078	0.090	0.102	0.115	0.127	0.140
		3	15.84	15.47	14.93	14.27	13.51	12.67	11.77	10.83	0.032	0.044	0.058	0.072	0.086	0.100	0.113	0.127
		4	17.94	17.12	16.14	15.09	13.99	12.87	11.74	10.62	0.069	0.080	0.091	0.103	0.115	0.127	0.139	0.150
		5	17.01	16.32	15.46	14.54	13.55	12.54	11.50	10.47	0.061	0.072	0.083	0.095	0.107	0.118	0.130	0.142
		Avg	**17.46**	**16.75**	**15.88**	**14.95**	**13.96**	**12.94**	**11.90**	**10.86**	**0.059**	**0.070**	**0.081**	**0.092**	**0.104**	**0.115**	**0.126**	**0.138**
		StdDev	**3.35**	**3.07**	**2.79**	**2.55**	**2.33**	**2.15**	**1.98**	**1.84**	**0.018**	**0.016**	**0.014**	**0.012**	**0.011**	**0.010**	**0.009**	**0.009**

* Outlier that was omitted from analysis.

Table B.2 *BBR* Mixture Data for *9.5-100/RM-2*

V_a	Test		Test Time (sec) and Mixture Stiffness (GPa)								Test Time (sec) and Mixture m-value							
(%)	Temp (C)	Rep	8	15	30	60	120	240	480	960	8	15	30	60	120	240	480	960
4.1	-24	1	17.97	17.47	16.86	16.17	15.43	14.64	13.81	12.96	0.040	0.048	0.056	0.064	0.072	0.080	0.088	0.096
		2	20.58	19.90	19.09	18.23	17.33	16.40	15.45	14.48	0.050	0.056	0.063	0.070	0.076	0.083	0.090	0.096
		3	19.88	19.28	18.55	17.76	16.92	16.04	15.14	14.21	0.046	0.052	0.059	0.066	0.073	0.080	0.088	0.095
		4	22.23	21.58	20.74	19.77	18.71	17.57	16.38	15.15	0.042	0.052	0.063	0.074	0.085	0.096	0.107	0.118
		5*	5.99	5.93	5.84	5.72	5.58	5.41	5.22	5.02	0.013	0.019	0.026	0.033	0.040	0.047	0.054	0.061
		Avg	**20.17**	**19.56**	**18.81**	**17.98**	**17.10**	**16.16**	**15.20**	**14.20**	**0.045**	**0.052**	**0.060**	**0.069**	**0.077**	**0.085**	**0.093**	**0.101**
		StdDev	**1.76**	**1.70**	**1.60**	**1.48**	**1.35**	**1.21**	**1.06**	**0.92**	**0.004**	**0.003**	**0.003**	**0.004**	**0.006**	**0.008**	**0.009**	**0.011**
	-18	1	23.11	22.10	20.98	19.85	18.72	17.60	16.50	15.42	0.069	0.073	0.078	0.082	0.087	0.091	0.096	0.100
		2	19.91	19.17	18.29	17.37	16.40	15.41	14.40	13.38	0.057	0.064	0.071	0.079	0.086	0.094	0.102	0.109
		3	24.66	23.84	22.79	21.60	20.32	18.95	17.53	16.09	0.049	0.059	0.071	0.083	0.094	0.106	0.118	0.130
		4	17.73	17.23	16.50	15.62	14.62	13.52	12.35	11.15	0.038	0.053	0.071	0.088	0.105	0.122	0.139	0.156
		5	15.99	15.63	15.10	14.43	13.65	12.78	11.85	10.86	0.029	0.043	0.058	0.073	0.088	0.102	0.117	0.132
		Avg	**20.28**	**19.59**	**18.73**	**17.77**	**16.74**	**15.65**	**14.53**	**13.38**	**0.048**	**0.058**	**0.070**	**0.081**	**0.092**	**0.103**	**0.114**	**0.125**
		StdDev	**3.61**	**3.38**	**3.16**	**2.95**	**2.78**	**2.62**	**2.49**	**2.39**	**0.016**	**0.011**	**0.007**	**0.006**	**0.008**	**0.012**	**0.017**	**0.022**
	-12	1	16.86	16.37	15.79	15.18	14.54	13.88	13.20	12.52	0.044	0.049	0.054	0.059	0.065	0.070	0.075	0.080
		2	17.70	17.11	16.38	15.59	14.73	13.84	12.91	11.97	0.049	0.058	0.067	0.077	0.086	0.095	0.105	0.114
		3	18.87	18.11	17.21	16.27	15.28	14.28	13.26	12.25	0.062	0.069	0.077	0.086	0.094	0.102	0.111	0.119
		4	21.96	20.95	19.81	18.66	17.52	16.38	15.25	14.15	0.073	0.078	0.083	0.089	0.094	0.100	0.105	0.111
		5	20.04	19.27	18.33	17.31	16.23	15.11	13.97	12.82	0.058	0.067	0.077	0.088	0.098	0.108	0.118	0.129
		Avg	**19.08**	**18.36**	**17.51**	**16.60**	**15.66**	**14.70**	**13.72**	**12.74**	**0.057**	**0.064**	**0.072**	**0.080**	**0.087**	**0.095**	**0.103**	**0.110**
		StdDev	**2.01**	**1.81**	**1.60**	**1.41**	**1.23**	**1.07**	**0.94**	**0.85**	**0.011**	**0.011**	**0.011**	**0.012**	**0.013**	**0.015**	**0.017**	**0.018**
	-06	1	26.08	24.63	22.87	21.01	19.08	17.13	15.21	13.36	0.084	0.098	0.115	0.131	0.147	0.163	0.179	0.196
		2	20.58	19.67	18.51	17.24	15.87	14.44	13.00	11.58	0.065	0.079	0.095	0.111	0.127	0.144	0.160	0.176
		3	21.41	20.42	19.24	18.00	16.71	15.40	14.09	12.80	0.071	0.080	0.091	0.102	0.112	0.123	0.134	0.144
		4	15.00	14.26	13.43	12.60	11.79	10.98	10.20	9.43	0.079	0.083	0.089	0.094	0.099	0.105	0.110	0.115
		5	16.76	16.19	15.39	14.44	13.37	12.22	11.02	9.81	0.046	0.063	0.082	0.101	0.120	0.139	0.158	0.177
		Avg	**19.96**	**19.03**	**17.89**	**16.66**	**15.36**	**14.04**	**12.71**	**11.40**	**0.069**	**0.081**	**0.094**	**0.108**	**0.121**	**0.135**	**0.148**	**0.162**
		StdDev	**4.32**	**4.02**	**3.65**	**3.25**	**2.86**	**2.46**	**2.09**	**1.75**	**0.015**	**0.013**	**0.012**	**0.014**	**0.018**	**0.022**	**0.027**	**0.032**

* Outlier that was omitted from analysis.

Table B.3 *BBR* Mixture Data for *12.5-100/RM-3*

V_a	Test		Test Time (sec) and Mixture Stiffness (GPa)								Test Time (sec) and Mixture m-value							
(%)	Temp (C)	Rep	8	15	30	60	120	240	480	960	8	15	30	60	120	240	480	960
5.5	-24	1	17.32	16.82	16.23	15.60	14.93	14.23	13.52	12.78	0.044	0.049	0.055	0.060	0.066	0.072	0.078	0.083
		2	18.01	17.58	16.98	16.27	15.47	14.58	13.63	12.65	0.033	0.044	0.056	0.067	0.079	0.091	0.103	0.114
		3	24.26	23.56	22.65	21.63	20.52	19.33	18.08	16.80	0.043	0.052	0.061	0.071	0.081	0.091	0.101	0.111
		4*	5.14	5.10	5.03	4.94	4.82	4.69	4.53	4.36	0.009	0.016	0.023	0.031	0.038	0.045	0.052	0.060
		5*	6.32	6.27	6.19	6.08	5.93	5.77	5.57	5.36	0.011	0.020	0.028	0.038	0.047	0.055	0.064	0.074
		Avg	**19.86**	**19.32**	**18.62**	**17.83**	**16.97**	**16.05**	**15.08**	**14.08**	**0.040**	**0.048**	**0.057**	**0.066**	**0.075**	**0.085**	**0.094**	**0.103**
		StdDev	**3.82**	**3.69**	**3.51**	**3.31**	**3.08**	**2.85**	**2.60**	**2.36**	**0.006**	**0.004**	**0.003**	**0.006**	**0.008**	**0.011**	**0.014**	**0.017**
	-18	1	18.68	18.12	17.37	16.49	15.50	14.43	13.30	12.15	0.042	0.054	0.068	0.082	0.096	0.110	0.124	0.138
		2	19.43	18.87	18.13	17.29	16.35	15.34	14.28	13.19	0.041	0.052	0.063	0.075	0.086	0.098	0.109	0.121
		3	21.06	20.32	19.42	18.46	17.45	16.39	15.31	14.22	0.053	0.061	0.069	0.077	0.086	0.094	0.103	0.111
		4	15.25	14.85	14.31	13.66	12.94	12.15	11.32	10.45	0.037	0.048	0.060	0.072	0.085	0.097	0.109	0.121
		5	20.53	19.71	18.78	17.81	16.83	15.83	14.83	13.84	0.062	0.067	0.073	0.079	0.085	0.091	0.097	0.103
		Avg	**18.99**	**18.37**	**17.60**	**16.74**	**15.81**	**14.83**	**13.81**	**12.77**	**0.047**	**0.056**	**0.067**	**0.077**	**0.088**	**0.098**	**0.108**	**0.119**
		StdDev	**2.28**	**2.14**	**1.99**	**1.87**	**1.76**	**1.66**	**1.58**	**1.52**	**0.010**	**0.008**	**0.005**	**0.004**	**0.005**	**0.007**	**0.010**	**0.013**
	-12	1	15.73	15.38	14.89	14.30	13.64	12.90	12.11	11.28	0.031	0.041	0.052	0.063	0.074	0.086	0.097	0.108
		2	12.57	12.25	11.82	11.33	10.79	10.21	9.59	8.95	0.037	0.046	0.056	0.066	0.076	0.085	0.095	0.105
		3	16.45	15.87	15.15	14.36	13.51	12.63	11.72	10.80	0.053	0.062	0.072	0.082	0.092	0.103	0.113	0.123
		4	16.42	15.85	15.23	14.59	13.96	13.32	12.69	12.07	0.054	0.057	0.060	0.063	0.066	0.069	0.072	0.075
		5	19.04	18.28	17.41	16.53	15.64	14.75	13.86	12.98	0.063	0.068	0.072	0.077	0.082	0.087	0.092	0.097
		Avg	**16.04**	**15.53**	**14.90**	**14.22**	**13.51**	**12.76**	**11.99**	**11.21**	**0.048**	**0.055**	**0.063**	**0.070**	**0.078**	**0.086**	**0.094**	**0.101**
		StdDev	**2.32**	**2.16**	**2.00**	**1.86**	**1.74**	**1.65**	**1.57**	**1.51**	**0.013**	**0.011**	**0.009**	**0.009**	**0.010**	**0.012**	**0.015**	**0.018**
	-06	1	18.18	17.62	16.87	16.00	15.03	13.98	12.88	11.76	0.043	0.056	0.070	0.083	0.097	0.111	0.125	0.139
		2*	3.75	3.72	3.68	3.63	3.56	3.49	3.41	3.33	0.012	0.015	0.019	0.023	0.027	0.031	0.035	0.038
		3	15.87	15.24	14.42	13.49	12.47	11.41	10.31	9.22	0.057	0.072	0.088	0.104	0.121	0.137	0.153	0.170
		4	18.54	17.60	16.60	15.63	14.71	13.83	12.98	12.17	0.082	0.084	0.085	0.087	0.089	0.090	0.092	0.094
		5	18.48	17.95	17.21	16.33	15.32	14.21	13.04	11.84	0.038	0.053	0.069	0.084	0.100	0.116	0.132	0.147
		Avg	**17.77**	**17.10**	**16.28**	**15.36**	**14.38**	**13.36**	**12.30**	**11.25**	**0.055**	**0.066**	**0.078**	**0.090**	**0.102**	**0.114**	**0.126**	**0.138**
		StdDev	**1.27**	**1.25**	**1.26**	**1.28**	**1.30**	**1.31**	**1.33**	**1.36**	**0.020**	**0.014**	**0.010**	**0.010**	**0.014**	**0.019**	**0.025**	**0.032**

* Outlier that was omitted from analysis.

Table B.4 *BBR* Mixture Data for *9.5-0/CM-1* at -24 C

Specimen	V_a		Test Time (sec) and Mixture Stiffness (GPa)								Test Time (sec) and Mixture m-value							
Rep	**(%)**	**Rep**	**8**	**15**	**30**	**60**	**120**	**240**	**480**	**960**	**8**	**15**	**30**	**60**	**120**	**240**	**480**	**960**
1	4.2	1	26.58	25.96	25.21	24.40	23.53	22.62	21.67	20.69	0.035	0.040	0.045	0.050	0.055	0.060	0.064	0.069
		2	25.85	25.16	24.23	23.13	21.90	20.56	19.14	17.66	0.038	0.049	0.061	0.073	0.085	0.097	0.109	0.122
		3	28.53	27.47	26.25	24.99	23.70	22.40	21.08	19.77	0.058	0.063	0.068	0.074	0.079	0.084	0.090	0.095
		4	18.74	18.28	17.73	17.15	16.53	15.88	15.21	14.51	0.037	0.041	0.046	0.051	0.055	0.060	0.065	0.069
		5	22.36	21.67	20.83	19.91	18.92	17.89	16.81	15.72	0.046	0.053	0.061	0.069	0.077	0.085	0.093	0.101
		Avg	**24.41**	**23.71**	**22.85**	**21.91**	**20.92**	**19.87**	**18.78**	**17.67**	**0.043**	**0.049**	**0.056**	**0.063**	**0.070**	**0.077**	**0.084**	**0.091**
		StdDev	**3.88**	**3.71**	**3.51**	**3.31**	**3.11**	**2.93**	**2.76**	**2.61**	**0.009**	**0.009**	**0.010**	**0.012**	**0.014**	**0.017**	**0.019**	**0.022**
2	3.8	1*	12.20	12.08	11.86	11.56	11.17	10.72	10.20	9.63	0.010	0.021	0.032	0.043	0.055	0.066	0.077	0.089
		2	25.99	25.31	24.36	23.24	21.97	20.58	19.10	17.57	0.036	0.048	0.061	0.075	0.088	0.101	0.114	0.127
		3	28.96	27.91	26.74	25.58	24.42	23.27	22.13	21.00	0.058	0.060	0.063	0.066	0.068	0.071	0.074	0.077
		4	25.81	24.98	24.02	23.02	21.98	20.92	19.85	18.76	0.050	0.054	0.059	0.064	0.069	0.074	0.079	0.083
		5	28.71	27.80	26.69	25.47	24.18	22.82	21.42	19.99	0.048	0.055	0.063	0.071	0.079	0.087	0.096	0.104
		Avg	**27.37**	**26.50**	**25.45**	**24.33**	**23.14**	**21.90**	**20.62**	**19.33**	**0.048**	**0.054**	**0.062**	**0.069**	**0.076**	**0.083**	**0.091**	**0.098**
		StdDev	**1.70**	**1.57**	**1.46**	**1.39**	**1.34**	**1.34**	**1.39**	**1.49**	**0.009**	**0.005**	**0.002**	**0.005**	**0.009**	**0.014**	**0.018**	**0.023**
3	4.3	1*	10.45	10.36	10.21	10.03	9.80	9.53	9.24	8.90	0.011	0.017	0.023	0.030	0.036	0.043	0.049	0.056
		2	21.05	20.70	20.11	19.33	18.38	17.29	16.09	14.81	0.020	0.034	0.049	0.065	0.081	0.096	0.112	0.127
		3	21.57	21.09	20.47	19.74	18.92	18.03	17.07	16.06	0.031	0.039	0.048	0.057	0.066	0.074	0.083	0.092
		4	23.02	22.18	21.10	19.87	18.53	17.11	15.65	14.17	0.052	0.065	0.079	0.094	0.108	0.122	0.136	0.150
		5	18.82	18.41	17.87	17.22	16.50	15.70	14.85	13.95	0.031	0.039	0.048	0.058	0.067	0.076	0.085	0.094
		Avg	**21.12**	**20.60**	**19.89**	**19.04**	**18.08**	**17.03**	**15.91**	**14.75**	**0.033**	**0.044**	**0.056**	**0.068**	**0.080**	**0.092**	**0.104**	**0.116**
		StdDev	**1.74**	**1.58**	**1.41**	**1.23**	**1.08**	**0.97**	**0.93**	**0.95**	**0.014**	**0.014**	**0.015**	**0.017**	**0.020**	**0.022**	**0.025**	**0.028**
Avg	**4.1**	**---**	**24.30**	**23.60**	**22.73**	**21.76**	**20.71**	**19.60**	**18.44**	**17.25**	**0.041**	**0.049**	**0.058**	**0.067**	**0.075**	**0.084**	**0.093**	**0.102**
StdDev	**---**	**---**	**3.61**	**3.41**	**3.21**	**3.03**	**2.87**	**2.74**	**2.64**	**2.58**	**0.011**	**0.010**	**0.010**	**0.012**	**0.014**	**0.017**	**0.021**	**0.025**

* Outlier that was omitted from analysis.

Table B.5 *BBR* Mixture Data for *9.5-0/CM-1* at -18 C

Specimen	V_a		Test Time (sec) and Mixture Stiffness (GPa)								Test Time (sec) and Mixture m-value							
Rep	**(%)**	**Rep**	**8**	**15**	**30**	**60**	**120**	**240**	**480**	**960**	**8**	**15**	**30**	**60**	**120**	**240**	**480**	**960**
1	4.2	1	22.45	21.85	21.03	20.09	19.03	17.88	16.67	15.41	0.038	0.049	0.061	0.072	0.084	0.096	0.107	0.119
		2	19.12	18.33	17.42	16.47	15.50	14.51	13.53	12.55	0.064	0.070	0.077	0.084	0.091	0.098	0.105	0.112
		3	17.13	16.52	15.79	15.00	14.16	13.29	12.40	11.50	0.053	0.061	0.070	0.078	0.087	0.096	0.104	0.113
		4	17.11	16.42	15.62	14.79	13.93	13.06	12.18	11.31	0.062	0.069	0.076	0.083	0.090	0.097	0.104	0.111
		5	19.98	19.27	18.42	17.52	16.58	15.62	14.63	13.64	0.055	0.061	0.068	0.076	0.083	0.090	0.098	0.105
		Avg	**19.16**	**18.48**	**17.66**	**16.77**	**15.84**	**14.87**	**13.88**	**12.88**	**0.054**	**0.062**	**0.070**	**0.079**	**0.087**	**0.095**	**0.104**	**0.112**
		StdDev	**2.23**	**2.24**	**2.22**	**2.16**	**2.08**	**1.97**	**1.84**	**1.69**	**0.010**	**0.008**	**0.007**	**0.005**	**0.004**	**0.003**	**0.004**	**0.005**
2	3.8	1	23.52	22.65	21.60	20.48	19.30	18.08	16.83	15.58	0.056	0.064	0.073	0.081	0.090	0.099	0.107	0.116
		2	22.40	21.59	20.56	19.41	18.16	16.83	15.47	14.09	0.052	0.064	0.077	0.090	0.103	0.116	0.128	0.141
		3	19.61	18.89	18.00	17.04	16.03	14.98	13.90	12.82	0.056	0.064	0.074	0.084	0.093	0.103	0.112	0.122
		4	21.54	20.60	19.49	18.32	17.10	15.86	14.61	13.37	0.066	0.075	0.085	0.094	0.104	0.114	0.123	0.133
		5	27.44	26.45	25.20	23.81	22.30	20.72	19.09	17.45	0.053	0.064	0.076	0.088	0.100	0.112	0.124	0.136
		Avg	**22.90**	**22.04**	**20.97**	**19.81**	**18.58**	**17.29**	**15.98**	**14.66**	**0.057**	**0.066**	**0.077**	**0.087**	**0.098**	**0.109**	**0.119**	**0.130**
		StdDev	**2.91**	**2.83**	**2.71**	**2.57**	**2.41**	**2.24**	**2.05**	**1.87**	**0.006**	**0.005**	**0.005**	**0.005**	**0.006**	**0.007**	**0.009**	**0.010**
3	4.3	1	16.70	16.22	15.69	15.15	14.60	14.05	13.50	12.95	0.045	0.047	0.049	0.052	0.054	0.056	0.059	0.061
		2	21.97	21.11	20.05	18.90	17.68	16.41	15.12	13.82	0.059	0.069	0.080	0.091	0.102	0.113	0.124	0.135
		3	17.97	17.43	16.74	15.95	15.09	14.18	13.22	12.24	0.044	0.053	0.064	0.075	0.085	0.096	0.106	0.117
		4	20.53	19.86	19.01	18.04	16.99	15.87	14.71	13.53	0.048	0.058	0.069	0.081	0.092	0.104	0.115	0.127
		5	17.49	16.87	16.12	15.31	14.46	13.58	12.67	11.76	0.054	0.061	0.070	0.078	0.087	0.095	0.104	0.112
		Avg	**18.93**	**18.30**	**17.52**	**16.67**	**15.76**	**14.82**	**13.85**	**12.86**	**0.050**	**0.058**	**0.066**	**0.075**	**0.084**	**0.093**	**0.102**	**0.110**
		StdDev	**2.23**	**2.09**	**1.91**	**1.70**	**1.47**	**1.24**	**1.03**	**0.86**	**0.006**	**0.008**	**0.011**	**0.014**	**0.018**	**0.022**	**0.025**	**0.029**
Avg	**4.1**	**---**	**20.33**	**19.60**	**18.72**	**17.75**	**16.73**	**15.66**	**14.57**	**13.47**	**0.054**	**0.062**	**0.071**	**0.080**	**0.090**	**0.099**	**0.108**	**0.117**
StdDev	**---**	**---**	**2.97**	**2.85**	**2.70**	**2.52**	**2.31**	**2.10**	**1.88**	**1.67**	**0.008**	**0.008**	**0.009**	**0.010**	**0.012**	**0.014**	**0.017**	**0.019**

Table B.6 *BBR* Mixture Data for *9.5-0/CM-1* at -12 C

Specimen	V_a		Test Time (sec) and Mixture Stiffness (GPa)								Test Time (sec) and Mixture m-value							
Rep	**(%)**	**Rep**	**8**	**15**	**30**	**60**	**120**	**240**	**480**	**960**	**8**	**15**	**30**	**60**	**120**	**240**	**480**	**960**
1	4.2	1	17.94	17.17	16.14	14.95	13.65	12.28	10.89	9.52	0.060	0.079	0.100	0.121	0.142	0.163	0.183	0.204
		2	14.63	13.87	12.97	12.03	11.06	10.08	9.11	8.16	0.079	0.090	0.103	0.115	0.127	0.140	0.152	0.164
		3	16.81	15.99	14.98	13.88	12.72	11.53	10.34	9.17	0.073	0.087	0.102	0.118	0.134	0.149	0.165	0.181
		4	18.72	17.59	16.30	14.98	13.65	12.33	11.05	9.82	0.093	0.104	0.116	0.128	0.140	0.152	0.164	0.176
		5	18.38	17.31	16.08	14.82	13.55	12.28	11.05	9.86	0.090	0.101	0.112	0.124	0.135	0.147	0.159	0.170
		Avg	**17.30**	**16.39**	**15.29**	**14.13**	**12.92**	**11.70**	**10.49**	**9.31**	**0.079**	**0.092**	**0.107**	**0.121**	**0.136**	**0.150**	**0.165**	**0.179**
		StdDev	**1.66**	**1.53**	**1.40**	**1.26**	**1.11**	**0.97**	**0.82**	**0.70**	**0.013**	**0.010**	**0.007**	**0.005**	**0.006**	**0.008**	**0.012**	**0.015**
2	3.8	1	18.39	17.37	16.21	15.04	13.85	12.68	11.53	10.42	0.086	0.095	0.104	0.114	0.123	0.132	0.142	0.151
		2	18.43	17.50	16.33	15.07	13.74	12.38	11.02	9.69	0.075	0.091	0.108	0.125	0.142	0.159	0.176	0.193
		3	18.86	17.83	16.61	15.32	13.98	12.64	11.30	10.01	0.082	0.095	0.110	0.124	0.139	0.153	0.168	0.182
		4	16.73	15.95	15.00	13.99	12.92	11.84	10.75	9.68	0.071	0.082	0.095	0.107	0.120	0.133	0.146	0.158
		5	21.19	20.23	19.06	17.79	16.46	15.09	13.71	12.34	0.068	0.080	0.093	0.106	0.119	0.132	0.145	0.158
		Avg	**18.72**	**17.78**	**16.64**	**15.44**	**14.19**	**12.92**	**11.66**	**10.43**	**0.076**	**0.089**	**0.102**	**0.115**	**0.129**	**0.142**	**0.155**	**0.169**
		StdDev	**1.60**	**1.55**	**1.48**	**1.41**	**1.33**	**1.25**	**1.18**	**1.11**	**0.008**	**0.007**	**0.008**	**0.009**	**0.011**	**0.013**	**0.016**	**0.018**
3	4.3	1	19.50	18.54	17.38	16.16	14.88	13.59	12.29	11.02	0.075	0.086	0.099	0.112	0.125	0.138	0.151	0.164
		2	14.02	13.42	12.70	11.93	11.12	10.29	9.44	8.61	0.064	0.074	0.085	0.096	0.107	0.118	0.129	0.140
		3	19.80	18.98	17.93	16.76	15.49	14.17	12.83	11.48	0.060	0.074	0.090	0.105	0.121	0.136	0.152	0.167
		4	17.36	16.51	15.50	14.43	13.33	12.20	11.08	9.97	0.074	0.085	0.097	0.109	0.121	0.133	0.145	0.158
		5	18.45	17.58	16.52	15.37	14.17	12.93	11.68	10.45	0.070	0.083	0.097	0.111	0.125	0.139	0.153	0.167
		Avg	**17.83**	**17.01**	**16.01**	**14.93**	**13.80**	**12.63**	**11.46**	**10.31**	**0.069**	**0.081**	**0.094**	**0.107**	**0.120**	**0.133**	**0.146**	**0.159**
		StdDev	**2.33**	**2.22**	**2.06**	**1.89**	**1.70**	**1.51**	**1.31**	**1.11**	**0.006**	**0.006**	**0.006**	**0.007**	**0.007**	**0.009**	**0.010**	**0.012**
Avg	**4.1**	**---**	**17.95**	**17.06**	**15.98**	**14.83**	**13.64**	**12.42**	**11.20**	**10.01**	**0.075**	**0.087**	**0.101**	**0.114**	**0.128**	**0.142**	**0.155**	**0.169**
StdDev	**---**	**---**	**1.86**	**1.76**	**1.65**	**1.53**	**1.41**	**1.29**	**1.17**	**1.06**	**0.010**	**0.009**	**0.009**	**0.009**	**0.010**	**0.012**	**0.014**	**0.017**

Table B.7 *BBR* Mixture Data for *9.5-0/CM-1* at -06 C

Specimen	V_a		Test Time (sec) and Mixture Stiffness (GPa)								Test Time (sec) and Mixture m-value							
Rep	**(%)**	**Rep**	**8**	**15**	**30**	**60**	**120**	**240**	**480**	**960**	**8**	**15**	**30**	**60**	**120**	**240**	**480**	**960**
1	4.2	1	19.04	17.85	16.42	14.91	13.37	11.83	10.34	8.92	0.095	0.111	0.130	0.148	0.167	0.185	0.204	0.222
		2	15.61	14.75	13.78	12.80	11.83	10.86	9.92	9.01	0.086	0.094	0.102	0.110	0.118	0.127	0.135	0.143
		3	17.79	16.65	15.28	13.82	12.34	10.86	9.42	8.07	0.096	0.114	0.134	0.154	0.174	0.194	0.214	0.234
		4	17.78	16.56	15.18	13.79	12.42	11.08	9.81	8.60	0.108	0.119	0.132	0.145	0.158	0.170	0.183	0.196
		5	15.41	14.46	13.32	12.12	10.90	9.69	8.52	7.39	0.094	0.110	0.127	0.144	0.161	0.178	0.195	0.212
		Avg	**17.13**	**16.05**	**14.79**	**13.49**	**12.17**	**10.87**	**9.60**	**8.40**	**0.096**	**0.110**	**0.125**	**0.140**	**0.156**	**0.171**	**0.186**	**0.202**
		StdDev	**1.56**	**1.42**	**1.25**	**1.07**	**0.90**	**0.77**	**0.69**	**0.67**	**0.008**	**0.010**	**0.013**	**0.017**	**0.022**	**0.026**	**0.031**	**0.036**
2	3.8	1	21.49	20.37	19.13	17.89	16.68	15.48	14.32	13.20	0.083	0.088	0.093	0.099	0.104	0.110	0.115	0.121
		2	15.32	14.29	13.06	11.77	10.47	9.18	7.94	6.77	0.102	0.120	0.140	0.160	0.180	0.199	0.219	0.239
		3*	5.20	5.07	4.90	4.70	4.47	4.21	3.94	3.66	0.033	0.044	0.055	0.067	0.078	0.090	0.102	0.113
		4	17.15	15.96	14.59	13.19	11.79	10.43	9.12	7.89	0.108	0.122	0.138	0.154	0.169	0.185	0.201	0.217
		5	18.88	17.52	15.95	14.33	12.70	11.12	9.61	8.20	0.110	0.127	0.145	0.164	0.183	0.201	0.220	0.238
		Avg	**18.21**	**17.04**	**15.68**	**14.30**	**12.91**	**11.55**	**10.25**	**9.02**	**0.101**	**0.114**	**0.129**	**0.144**	**0.159**	**0.174**	**0.189**	**0.204**
		StdDev	**2.63**	**2.59**	**2.58**	**2.62**	**2.67**	**2.74**	**2.80**	**2.86**	**0.012**	**0.018**	**0.024**	**0.030**	**0.037**	**0.043**	**0.050**	**0.056**
3	4.3	1	16.88	15.98	14.84	13.58	12.26	10.91	9.57	8.28	0.078	0.097	0.117	0.138	0.158	0.178	0.199	0.219
		2	14.77	13.95	12.96	11.89	10.77	9.64	8.53	7.45	0.082	0.098	0.116	0.133	0.151	0.168	0.186	0.203
		3	15.57	14.69	13.60	12.41	11.16	9.90	8.66	7.47	0.083	0.102	0.122	0.142	0.163	0.183	0.203	0.223
		4	19.21	17.98	16.55	15.06	13.56	12.07	10.62	9.25	0.098	0.112	0.128	0.144	0.160	0.176	0.192	0.208
		5	14.75	13.88	12.82	11.67	10.47	9.27	8.09	6.97	0.087	0.105	0.125	0.146	0.166	0.186	0.206	0.226
		Avg	**16.23**	**15.30**	**14.15**	**12.92**	**11.64**	**10.36**	**9.10**	**7.88**	**0.086**	**0.103**	**0.122**	**0.141**	**0.159**	**0.178**	**0.197**	**0.216**
		StdDev	**1.87**	**1.72**	**1.56**	**1.41**	**1.26**	**1.13**	**1.01**	**0.90**	**0.007**	**0.006**	**0.005**	**0.005**	**0.006**	**0.007**	**0.008**	**0.010**
Avg	**4.1**	**---**	**17.12**	**16.06**	**14.82**	**13.52**	**12.19**	**10.88**	**9.61**	**8.39**	**0.094**	**0.109**	**0.125**	**0.142**	**0.158**	**0.174**	**0.191**	**0.207**
StdDev	**---**	**---**	**2.02**	**1.90**	**1.78**	**1.69**	**1.63**	**1.60**	**1.58**	**1.58**	**0.011**	**0.012**	**0.014**	**0.018**	**0.022**	**0.026**	**0.030**	**0.034**

* Outlier that was omitted from analysis.

Table B.8 *BBR* Mixture Data for *9.5-15/CM-2* at -24 C

Specimen	V_a		Test Time (sec) and Mixture Stiffness (GPa)								Test Time (sec) and Mixture m-value							
Rep	**(%)**	**Rep**	**8**	**15**	**30**	**60**	**120**	**240**	**480**	**960**	**8**	**15**	**30**	**60**	**120**	**240**	**480**	**960**
1	5.2	1	16.03	15.58	15.01	14.36	13.66	12.91	12.12	11.31	0.041	0.050	0.059	0.068	0.077	0.086	0.095	0.105
		2	16.98	16.25	15.35	14.37	13.34	12.26	11.17	10.09	0.064	0.076	0.089	0.102	0.115	0.128	0.141	0.154
		3	19.75	19.14	18.21	17.05	15.72	14.26	12.73	11.18	0.039	0.060	0.083	0.106	0.129	0.152	0.175	0.198
		4	23.80	22.75	21.47	20.10	18.65	17.16	15.66	14.17	0.066	0.077	0.089	0.102	0.114	0.126	0.138	0.150
		5*	9.15	8.97	8.71	8.39	8.02	7.61	7.16	6.69	0.026	0.037	0.048	0.059	0.071	0.082	0.093	0.105
		Avg	**19.14**	**18.43**	**17.51**	**16.47**	**15.34**	**14.15**	**12.92**	**11.69**	**0.053**	**0.066**	**0.080**	**0.095**	**0.109**	**0.123**	**0.137**	**0.152**
		StdDev	**3.48**	**3.27**	**3.00**	**2.73**	**2.44**	**2.17**	**1.94**	**1.74**	**0.014**	**0.013**	**0.014**	**0.018**	**0.022**	**0.027**	**0.033**	**0.038**
2	5.2	1	18.25	17.51	16.65	15.77	14.86	13.95	13.03	12.12	0.063	0.069	0.076	0.082	0.088	0.095	0.101	0.108
		2	20.95	20.12	19.11	18.02	16.86	15.66	14.44	13.21	0.059	0.069	0.080	0.090	0.101	0.112	0.123	0.134
		3	21.17	20.25	19.06	17.74	16.32	14.84	13.34	11.85	0.063	0.078	0.095	0.112	0.129	0.146	0.162	0.179
		4	21.13	20.19	19.04	17.82	16.54	15.23	13.91	12.60	0.068	0.078	0.090	0.102	0.113	0.125	0.137	0.149
		5	20.57	19.92	19.00	17.91	16.69	15.37	13.98	12.57	0.044	0.059	0.077	0.094	0.111	0.128	0.145	0.162
		Avg	**20.42**	**19.60**	**18.57**	**17.45**	**16.25**	**15.01**	**13.74**	**12.47**	**0.059**	**0.071**	**0.083**	**0.096**	**0.108**	**0.121**	**0.134**	**0.146**
		StdDev	**1.23**	**1.17**	**1.08**	**0.95**	**0.80**	**0.66**	**0.56**	**0.52**	**0.009**	**0.008**	**0.009**	**0.011**	**0.015**	**0.019**	**0.023**	**0.027**
Avg	**5.2**	**---**	**19.85**	**19.08**	**18.10**	**17.02**	**15.85**	**14.63**	**13.38**	**12.12**	**0.056**	**0.068**	**0.082**	**0.095**	**0.109**	**0.122**	**0.135**	**0.149**
StdDev		**---**	**2.40**	**2.25**	**2.07**	**1.87**	**1.67**	**1.48**	**1.32**	**1.20**	**0.012**	**0.010**	**0.011**	**0.014**	**0.017**	**0.022**	**0.026**	**0.030**

* Outlier that was omitted from analysis.

Table B.9 *BBR* Mixture Data for *9.5-15/CM-2* at -18 C

Specimen	V_a		Test Time (sec) and Mixture Stiffness (GPa)								Test Time (sec) and Mixture m-value							
Rep	**(%)**	**Rep**	**8**	**15**	**30**	**60**	**120**	**240**	**480**	**960**	**8**	**15**	**30**	**60**	**120**	**240**	**480**	**960**
1	5.2	1	18.68	17.71	16.58	15.42	14.23	13.04	11.86	10.72	0.080	0.090	0.100	0.110	0.121	0.131	0.142	0.152
		2	14.82	14.08	13.20	12.26	11.28	10.28	9.29	8.31	0.075	0.087	0.100	0.113	0.127	0.140	0.154	0.167
		3	14.01	13.40	12.67	11.88	11.06	10.21	9.35	8.50	0.065	0.076	0.087	0.098	0.109	0.121	0.132	0.143
		4	14.37	13.63	12.75	11.81	10.83	9.85	8.87	7.92	0.078	0.090	0.104	0.117	0.131	0.144	0.157	0.171
		5	17.15	16.41	15.47	14.43	13.32	12.17	10.99	9.82	0.063	0.077	0.092	0.108	0.123	0.139	0.154	0.170
		Avg	**15.81**	**15.05**	**14.13**	**13.16**	**12.14**	**11.11**	**10.07**	**9.05**	**0.072**	**0.084**	**0.097**	**0.109**	**0.122**	**0.135**	**0.148**	**0.161**
		StdDev	**2.02**	**1.91**	**1.78**	**1.66**	**1.53**	**1.41**	**1.29**	**1.17**	**0.008**	**0.007**	**0.007**	**0.007**	**0.008**	**0.009**	**0.011**	**0.012**
2	5.2	1	13.11	12.58	11.95	11.28	10.57	9.85	9.11	8.37	0.061	0.070	0.079	0.089	0.098	0.107	0.117	0.126
		2	15.64	14.91	13.97	12.92	11.79	10.63	9.45	8.30	0.068	0.085	0.103	0.122	0.141	0.160	0.178	0.197
		3	17.01	16.09	15.01	13.90	12.76	11.62	10.50	9.41	0.083	0.094	0.106	0.117	0.129	0.141	0.152	0.164
		4	16.98	16.12	15.08	13.98	12.83	11.66	10.50	9.36	0.076	0.089	0.103	0.117	0.131	0.145	0.158	0.172
		5	17.09	16.16	15.06	13.91	12.72	11.54	10.36	9.22	0.083	0.095	0.108	0.122	0.135	0.148	0.161	0.175
		Avg	**15.97**	**15.17**	**14.22**	**13.20**	**12.14**	**11.06**	**9.99**	**8.93**	**0.074**	**0.086**	**0.100**	**0.113**	**0.127**	**0.140**	**0.153**	**0.167**
		StdDev	**1.71**	**1.54**	**1.35**	**1.16**	**0.97**	**0.80**	**0.66**	**0.55**	**0.010**	**0.010**	**0.012**	**0.014**	**0.017**	**0.020**	**0.023**	**0.026**
Avg	**5.2**	**---**	**15.89**	**15.11**	**14.17**	**13.18**	**12.14**	**11.08**	**10.03**	**8.99**	**0.073**	**0.085**	**0.098**	**0.111**	**0.124**	**0.138**	**0.151**	**0.164**
StdDev		**---**	**1.76**	**1.64**	**1.49**	**1.35**	**1.21**	**1.08**	**0.96**	**0.87**	**0.008**	**0.008**	**0.009**	**0.011**	**0.013**	**0.015**	**0.017**	**0.019**

Table B.10 *BBR* Mixture Data for *9.5-15/CM-2* at -12 C

Specimen	V_a		Test Time (sec) and Mixture Stiffness (GPa)								Test Time (sec) and Mixture m-value							
Rep	**(%)**	**Rep**	**8**	**15**	**30**	**60**	**120**	**240**	**480**	**960**	**8**	**15**	**30**	**60**	**120**	**240**	**480**	**960**
1	5.2	1	16.54	15.53	14.39	13.23	12.08	10.94	9.84	8.79	0.095	0.105	0.116	0.126	0.137	0.148	0.158	0.169
		2	12.58	11.70	10.66	9.59	8.52	7.46	6.45	5.50	0.107	0.124	0.143	0.162	0.181	0.200	0.219	0.238
		3	15.17	14.10	12.84	11.53	10.20	8.90	7.66	6.50	0.107	0.125	0.146	0.166	0.186	0.206	0.227	0.247
		4	12.26	11.38	10.36	9.29	8.23	7.19	6.19	5.26	0.109	0.127	0.146	0.166	0.186	0.205	0.225	0.245
		5	16.35	15.01	13.58	12.21	10.90	9.68	8.53	7.48	0.132	0.140	0.149	0.158	0.168	0.177	0.186	0.195
		Avg	**14.58**	**13.55**	**12.37**	**11.17**	**9.99**	**8.83**	**7.74**	**6.71**	**0.110**	**0.124**	**0.140**	**0.156**	**0.172**	**0.187**	**0.203**	**0.219**
		StdDev	**2.05**	**1.90**	**1.78**	**1.69**	**1.62**	**1.56**	**1.51**	**1.46**	**0.013**	**0.013**	**0.014**	**0.017**	**0.021**	**0.025**	**0.030**	**0.035**
2	5.2	1	15.90	14.81	13.52	12.18	10.83	9.50	8.23	7.03	0.105	0.122	0.141	0.160	0.179	0.198	0.217	0.236
		2	13.83	12.92	11.82	10.66	9.46	8.28	7.13	6.05	0.098	0.118	0.139	0.161	0.182	0.204	0.226	0.247
		3	12.56	11.63	10.53	9.39	8.25	7.14	6.08	5.10	0.112	0.132	0.154	0.176	0.198	0.220	0.242	0.264
		4	14.40	13.41	12.21	10.94	9.65	8.37	7.15	6.01	0.103	0.124	0.147	0.170	0.193	0.216	0.239	0.262
		5	14.51	13.38	12.07	10.72	9.39	8.10	6.88	5.77	0.119	0.138	0.160	0.181	0.202	0.224	0.245	0.267
		Avg	**14.24**	**13.23**	**12.03**	**10.78**	**9.52**	**8.28**	**7.10**	**5.99**	**0.107**	**0.127**	**0.148**	**0.170**	**0.191**	**0.212**	**0.234**	**0.255**
		StdDev	**1.21**	**1.14**	**1.06**	**0.99**	**0.92**	**0.84**	**0.77**	**0.69**	**0.008**	**0.008**	**0.009**	**0.009**	**0.010**	**0.011**	**0.012**	**0.013**
Avg	**5.2**	**---**	**14.41**	**13.39**	**12.20**	**10.97**	**9.75**	**8.56**	**7.42**	**6.35**	**0.109**	**0.125**	**0.144**	**0.163**	**0.181**	**0.200**	**0.218**	**0.237**
StdDev		**---**	**1.59**	**1.49**	**1.40**	**1.32**	**1.27**	**1.22**	**1.18**	**1.14**	**0.011**	**0.010**	**0.012**	**0.015**	**0.018**	**0.023**	**0.027**	**0.031**

Table B.11 *BBR* Mixture Data for *9.5-15/CM-2* at -06 C

Specimen	V_a		Test Time (sec) and Mixture Stiffness (GPa)								Test Time (sec) and Mixture m-value							
Rep	**(%)**	**Rep**	**8**	**15**	**30**	**60**	**120**	**240**	**480**	**960**	**8**	**15**	**30**	**60**	**120**	**240**	**480**	**960**
1	5.2	1	12.23	10.92	9.44	8.00	6.65	5.41	4.32	3.38	0.168	0.195	0.224	0.253	0.282	0.311	0.340	0.369
		2	7.75	6.98	6.12	5.28	4.48	3.74	3.08	2.49	0.157	0.178	0.202	0.225	0.248	0.271	0.294	0.318
		3	14.25	12.73	11.05	9.41	7.88	6.48	5.23	4.14	0.168	0.191	0.218	0.244	0.270	0.296	0.322	0.348
		4	12.49	11.08	9.53	8.05	6.67	5.42	4.32	3.38	0.178	0.203	0.231	0.258	0.286	0.313	0.341	0.368
		5	14.18	12.52	10.75	9.09	7.56	6.19	4.99	3.96	0.187	0.208	0.231	0.254	0.277	0.299	0.322	0.345
		Avg	**12.18**	**10.84**	**9.38**	**7.97**	**6.65**	**5.45**	**4.39**	**3.47**	**0.172**	**0.195**	**0.221**	**0.247**	**0.272**	**0.298**	**0.324**	**0.350**
		StdDev	**2.64**	**2.31**	**1.96**	**1.63**	**1.33**	**1.06**	**0.84**	**0.65**	**0.011**	**0.011**	**0.012**	**0.013**	**0.015**	**0.017**	**0.019**	**0.021**
2	5.2	1	8.38	7.49	6.52	5.57	4.68	3.86	3.14	2.50	0.167	0.189	0.214	0.239	0.264	0.288	0.313	0.338
		2	9.50	8.69	7.72	6.71	5.71	4.75	3.87	3.08	0.127	0.155	0.187	0.218	0.250	0.281	0.312	0.344
		3	8.94	8.05	7.03	6.01	5.03	4.13	3.32	2.61	0.154	0.181	0.211	0.241	0.271	0.300	0.330	0.360
		4	8.62	7.78	6.81	5.84	4.90	4.02	3.24	2.55	0.150	0.177	0.208	0.238	0.268	0.298	0.329	0.359
		5	11.76	10.78	9.63	8.44	7.27	6.16	5.12	4.18	0.127	0.150	0.176	0.202	0.228	0.254	0.279	0.305
		Avg	**9.44**	**8.56**	**7.54**	**6.51**	**5.52**	**4.58**	**3.74**	**2.99**	**0.145**	**0.171**	**0.199**	**0.227**	**0.256**	**0.284**	**0.313**	**0.341**
		StdDev	**1.36**	**1.32**	**1.25**	**1.16**	**1.05**	**0.94**	**0.82**	**0.71**	**0.017**	**0.017**	**0.017**	**0.017**	**0.018**	**0.019**	**0.020**	**0.022**
Avg	**5.2**	**---**	**10.81**	**9.70**	**8.46**	**7.24**	**6.08**	**5.02**	**4.06**	**3.23**	**0.158**	**0.183**	**0.210**	**0.237**	**0.264**	**0.291**	**0.318**	**0.346**
StdDev		**---**	**2.45**	**2.14**	**1.83**	**1.54**	**1.28**	**1.05**	**0.85**	**0.69**	**0.020**	**0.019**	**0.018**	**0.018**	**0.018**	**0.018**	**0.019**	**0.021**

Table B.12 *BBR* Mixture Data for *9.5-15/CM-3* at -24 C

Specimen	V_a		Test Time (sec) and Mixture Stiffness (GPa)								Test Time (sec) and Mixture m-value							
Rep	**(%)**	**Rep**	**8**	**15**	**30**	**60**	**120**	**240**	**480**	**960**	**8**	**15**	**30**	**60**	**120**	**240**	**480**	**960**
1	3.0	1	31.95	30.07	28.01	25.98	23.98	22.04	20.17	18.37	0.093	0.099	0.106	0.112	0.118	0.125	0.131	0.138
		2	29.90	28.69	27.15	25.45	23.62	21.70	19.75	17.80	0.059	0.072	0.086	0.101	0.115	0.129	0.143	0.157
		3	28.45	27.42	26.05	24.49	22.78	20.96	19.08	17.18	0.052	0.066	0.081	0.097	0.112	0.128	0.143	0.159
		4	30.46	29.17	27.66	26.06	24.40	22.71	21.01	19.32	0.065	0.073	0.081	0.090	0.099	0.108	0.117	0.126
		5	21.20	20.22	19.16	18.11	17.10	16.11	15.14	14.22	0.074	0.077	0.079	0.082	0.085	0.087	0.090	0.093
		Avg	**28.39**	**27.11**	**25.61**	**24.02**	**22.38**	**20.70**	**19.03**	**17.38**	**0.069**	**0.077**	**0.087**	**0.096**	**0.106**	**0.115**	**0.125**	**0.134**
		StdDev	**4.21**	**3.97**	**3.68**	**3.36**	**3.01**	**2.65**	**2.28**	**1.93**	**0.016**	**0.013**	**0.011**	**0.011**	**0.014**	**0.018**	**0.022**	**0.027**
2	3.0	1*	20.14	19.47	18.60	17.60	16.52	15.36	14.16	12.93	0.048	0.060	0.073	0.086	0.098	0.111	0.124	0.137
		2	32.96	31.47	29.63	27.63	25.52	23.35	21.15	18.98	0.067	0.080	0.094	0.108	0.122	0.136	0.149	0.163
		3	24.62	23.56	22.41	21.28	20.17	19.09	18.03	17.00	0.069	0.071	0.074	0.076	0.079	0.081	0.084	0.086
		4	32.73	31.35	29.61	27.68	25.60	23.44	21.23	19.04	0.061	0.075	0.090	0.105	0.120	0.135	0.150	0.165
		5	26.21	25.28	24.02	22.56	20.93	19.20	17.40	15.58	0.050	0.065	0.082	0.099	0.116	0.133	0.151	0.168
		Avg	**29.13**	**27.92**	**26.42**	**24.79**	**23.06**	**21.27**	**19.45**	**17.65**	**0.062**	**0.073**	**0.085**	**0.097**	**0.109**	**0.121**	**0.134**	**0.146**
		StdDev	**4.34**	**4.10**	**3.76**	**3.35**	**2.91**	**2.45**	**2.02**	**1.67**	**0.009**	**0.006**	**0.009**	**0.014**	**0.020**	**0.027**	**0.033**	**0.040**
Avg	**3.0**	**---**	**28.72**	**27.47**	**25.97**	**24.36**	**22.68**	**20.96**	**19.22**	**17.50**	**0.066**	**0.075**	**0.086**	**0.097**	**0.107**	**0.118**	**0.129**	**0.139**
StdDev		**---**	**4.01**	**3.79**	**3.50**	**3.17**	**2.80**	**2.42**	**2.05**	**1.71**	**0.013**	**0.010**	**0.010**	**0.012**	**0.016**	**0.021**	**0.026**	**0.031**

* Outlier that was omitted from analysis.

Table B.13 *BBR* Mixture Data for *9.5-15/CM-3* at -18 C

Specimen	V_a		Test Time (sec) and Mixture Stiffness (GPa)								Test Time (sec) and Mixture m-value							
Rep	**(%)**	**Rep**	**8**	**15**	**30**	**60**	**120**	**240**	**480**	**960**	**8**	**15**	**30**	**60**	**120**	**240**	**480**	**960**
1	3.0	1	23.27	22.09	20.70	19.22	17.70	16.17	14.64	13.14	0.077	0.088	0.100	0.113	0.125	0.137	0.149	0.162
		2	22.72	21.60	20.13	18.48	16.70	14.87	13.04	11.25	0.070	0.090	0.113	0.135	0.157	0.179	0.201	0.223
		3	24.63	23.22	21.63	20.01	18.41	16.82	15.27	13.78	0.090	0.098	0.107	0.116	0.125	0.135	0.144	0.153
		4	18.79	17.95	16.94	15.87	14.75	13.60	12.45	11.30	0.068	0.078	0.089	0.100	0.111	0.122	0.134	0.145
		5	22.73	21.59	20.17	18.62	16.98	15.31	13.63	12.00	0.074	0.090	0.107	0.124	0.141	0.158	0.176	0.193
		Avg	**22.43**	**21.29**	**19.91**	**18.44**	**16.91**	**15.35**	**13.81**	**12.30**	**0.076**	**0.089**	**0.103**	**0.118**	**0.132**	**0.146**	**0.161**	**0.175**
		StdDev	**2.18**	**1.98**	**1.77**	**1.56**	**1.38**	**1.24**	**1.15**	**1.13**	**0.009**	**0.007**	**0.009**	**0.013**	**0.017**	**0.022**	**0.027**	**0.032**
2	3.0	1	21.04	19.92	18.74	17.61	16.55	15.53	14.57	13.66	0.087	0.088	0.089	0.090	0.091	0.092	0.093	0.094
		2	32.95	31.14	29.05	26.90	24.72	22.55	20.42	18.35	0.085	0.095	0.106	0.116	0.127	0.138	0.149	0.159
		3*	15.70	15.09	14.32	13.47	12.55	11.60	10.62	9.64	0.057	0.069	0.082	0.095	0.108	0.121	0.134	0.147
		4	26.32	24.72	22.99	21.29	19.64	18.05	16.52	15.06	0.097	0.102	0.108	0.113	0.119	0.125	0.131	0.136
		5	26.98	25.64	23.94	22.06	20.06	18.00	15.94	13.93	0.072	0.089	0.108	0.128	0.147	0.166	0.185	0.204
		Avg	**26.82**	**25.36**	**23.68**	**21.97**	**20.24**	**18.53**	**16.86**	**15.25**	**0.085**	**0.094**	**0.103**	**0.112**	**0.121**	**0.130**	**0.140**	**0.148**
		StdDev	**4.87**	**4.60**	**4.23**	**3.82**	**3.37**	**2.93**	**2.51**	**2.15**	**0.010**	**0.006**	**0.009**	**0.016**	**0.023**	**0.031**	**0.038**	**0.046**
Avg	**3.0**	**---**	**24.38**	**23.10**	**21.59**	**20.01**	**18.39**	**16.77**	**15.16**	**13.61**	**0.080**	**0.091**	**0.103**	**0.115**	**0.127**	**0.139**	**0.151**	**0.163**
StdDev		**---**	**4.08**	**3.81**	**3.50**	**3.18**	**2.88**	**2.60**	**2.37**	**2.19**	**0.010**	**0.007**	**0.009**	**0.014**	**0.020**	**0.026**	**0.032**	**0.039**

* Outlier that was omitted from analysis.

Table B.14 *BBR* Mixture Data for *9.5-15/CM-3* at -12 C

Specimen	V_a		Test Time (sec) and Mixture Stiffness (GPa)								Test Time (sec) and Mixture m-value							
Rep	**(%)**	**Rep**	**8**	**15**	**30**	**60**	**120**	**240**	**480**	**960**	**8**	**15**	**30**	**60**	**120**	**240**	**480**	**960**
1	3.0	1	17.62	16.47	15.11	13.69	12.24	10.81	9.43	8.12	0.098	0.115	0.134	0.152	0.170	0.189	0.207	0.225
		2	17.58	16.28	14.82	13.36	11.92	10.54	9.22	7.99	0.116	0.128	0.143	0.157	0.171	0.186	0.200	0.214
		3	18.42	17.15	15.67	14.17	12.67	11.20	9.79	8.47	0.107	0.121	0.137	0.154	0.170	0.186	0.202	0.218
		4	14.42	13.40	12.20	10.96	9.70	8.48	7.31	6.22	0.108	0.126	0.145	0.165	0.185	0.204	0.224	0.244
		5	17.50	16.43	15.13	13.74	12.32	10.89	9.51	8.19	0.092	0.110	0.129	0.148	0.167	0.187	0.206	0.225
		Avg	**17.11**	**15.95**	**14.59**	**13.18**	**11.77**	**10.38**	**9.05**	**7.79**	**0.104**	**0.120**	**0.138**	**0.155**	**0.173**	**0.190**	**0.208**	**0.225**
		StdDev	**1.55**	**1.46**	**1.37**	**1.28**	**1.19**	**1.09**	**0.99**	**0.90**	**0.009**	**0.008**	**0.007**	**0.006**	**0.007**	**0.008**	**0.010**	**0.011**
2	3.0	1	19.73	18.61	17.20	15.66	14.04	12.40	10.79	9.24	0.083	0.103	0.124	0.146	0.168	0.190	0.212	0.234
		2	15.64	14.70	13.55	12.33	11.06	9.80	8.56	7.39	0.090	0.108	0.127	0.146	0.165	0.185	0.204	0.223
		3	15.53	14.47	13.26	12.04	10.83	9.65	8.52	7.45	0.107	0.119	0.133	0.146	0.159	0.173	0.186	0.200
		4*	6.06	5.64	5.16	4.67	4.18	3.71	3.25	2.83	0.108	0.122	0.136	0.151	0.166	0.181	0.196	0.210
		5*	4.33	4.08	3.79	3.48	3.18	2.87	2.57	2.28	0.089	0.101	0.114	0.127	0.140	0.152	0.165	0.178
		Avg	**16.97**	**15.93**	**14.67**	**13.34**	**11.98**	**10.62**	**9.29**	**8.03**	**0.093**	**0.110**	**0.128**	**0.146**	**0.164**	**0.183**	**0.201**	**0.219**
		StdDev	**2.39**	**2.33**	**2.20**	**2.01**	**1.79**	**1.55**	**1.30**	**1.05**	**0.012**	**0.008**	**0.005**	**0.000**	**0.005**	**0.009**	**0.013**	**0.017**
Avg	**3.0**	**---**	**17.06**	**15.94**	**14.62**	**13.24**	**11.85**	**10.47**	**9.14**	**7.88**	**0.100**	**0.116**	**0.134**	**0.152**	**0.169**	**0.188**	**0.205**	**0.223**
StdDev		**---**	**1.74**	**1.66**	**1.57**	**1.45**	**1.32**	**1.17**	**1.03**	**0.89**	**0.011**	**0.009**	**0.007**	**0.007**	**0.007**	**0.008**	**0.011**	**0.013**

* Outlier that was omitted from analysis.

Table B.15 *BBR* Mixture Data for *9.5-15/CM-3* at -06 C

Specimen	V_a		Test Time (sec) and Mixture Stiffness (GPa)								Test Time (sec) and Mixture m-value							
Rep	**(%)**	**Rep**	**8**	**15**	**30**	**60**	**120**	**240**	**480**	**960**	**8**	**15**	**30**	**60**	**120**	**240**	**480**	**960**
1	3.0	1	11.83	10.88	9.77	8.64	7.50	6.41	5.39	4.46	0.121	0.143	0.167	0.191	0.215	0.239	0.262	0.286
		2	13.68	12.42	10.98	9.53	8.13	6.82	5.61	4.54	0.142	0.165	0.191	0.216	0.242	0.267	0.293	0.318
		3	9.91	8.95	7.85	6.74	5.67	4.67	3.77	2.98	0.148	0.175	0.205	0.235	0.264	0.294	0.323	0.353
		4	13.80	12.53	11.06	9.58	8.14	6.78	5.54	4.45	0.141	0.166	0.194	0.221	0.249	0.277	0.304	0.332
		5	11.64	10.44	9.07	7.72	6.43	5.24	4.19	3.28	0.160	0.188	0.218	0.248	0.278	0.309	0.339	0.369
		Avg	**12.17**	**11.04**	**9.75**	**8.44**	**7.17**	**5.99**	**4.90**	**3.94**	**0.143**	**0.168**	**0.195**	**0.222**	**0.250**	**0.277**	**0.304**	**0.332**
		StdDev	**1.62**	**1.49**	**1.35**	**1.22**	**1.09**	**0.97**	**0.86**	**0.75**	**0.014**	**0.016**	**0.019**	**0.022**	**0.024**	**0.027**	**0.029**	**0.032**
2	3.0	1	11.75	10.75	9.60	8.44	7.31	6.24	5.24	4.34	0.132	0.152	0.174	0.196	0.218	0.240	0.262	0.284
		2	14.19	12.92	11.54	10.21	8.93	7.74	6.63	5.63	0.142	0.155	0.170	0.185	0.200	0.215	0.230	0.245
		3	12.69	11.56	10.33	9.13	7.99	6.91	5.92	5.02	0.141	0.155	0.170	0.185	0.201	0.216	0.231	0.247
		4	13.81	12.71	11.43	10.12	8.82	7.57	6.40	5.32	0.122	0.142	0.165	0.187	0.209	0.232	0.254	0.277
		5	13.94	12.87	11.66	10.44	9.24	8.08	6.99	5.98	0.120	0.135	0.151	0.168	0.184	0.201	0.217	0.234
		Avg	**13.28**	**12.16**	**10.91**	**9.67**	**8.46**	**7.31**	**6.24**	**5.26**	**0.131**	**0.148**	**0.166**	**0.184**	**0.203**	**0.221**	**0.239**	**0.257**
		StdDev	**1.03**	**0.97**	**0.91**	**0.85**	**0.79**	**0.73**	**0.68**	**0.63**	**0.010**	**0.009**	**0.009**	**0.010**	**0.013**	**0.015**	**0.018**	**0.022**
Avg	**3.0**	**---**	**12.72**	**11.60**	**10.33**	**9.05**	**7.82**	**6.65**	**5.57**	**4.60**	**0.137**	**0.158**	**0.180**	**0.203**	**0.226**	**0.249**	**0.272**	**0.294**
StdDev		**---**	**1.40**	**1.32**	**1.25**	**1.18**	**1.13**	**1.07**	**1.01**	**0.95**	**0.013**	**0.016**	**0.021**	**0.026**	**0.031**	**0.036**	**0.042**	**0.047**

Table B.16 *BBR* Mixture Data for *9.5-15/CM-4a* at -24 C

Specimen	V_a		Test Time (sec) and Mixture Stiffness (GPa)								Test Time (sec) and Mixture m-value							
Rep	**(%)**	**Rep**	**8**	**15**	**30**	**60**	**120**	**240**	**480**	**960**	**8**	**15**	**30**	**60**	**120**	**240**	**480**	**960**
1	6.0	1	23.09	22.33	21.28	20.02	18.61	17.09	15.50	13.88	0.045	0.061	0.079	0.097	0.114	0.132	0.150	0.168
		2	22.83	21.93	20.78	19.48	18.08	16.61	15.10	13.59	0.057	0.071	0.085	0.100	0.115	0.130	0.145	0.159
		3	20.73	19.85	18.78	17.64	16.45	15.22	13.97	12.74	0.064	0.074	0.085	0.096	0.107	0.117	0.128	0.139
		4	24.01	22.91	21.63	20.27	18.88	17.46	16.04	14.64	0.070	0.079	0.088	0.098	0.108	0.118	0.127	0.137
		5	21.37	20.39	19.25	18.05	16.81	15.56	14.30	13.06	0.070	0.079	0.088	0.098	0.107	0.117	0.126	0.136
		Avg	**22.40**	**21.48**	**20.34**	**19.09**	**17.77**	**16.39**	**14.98**	**13.58**	**0.061**	**0.073**	**0.085**	**0.098**	**0.110**	**0.123**	**0.135**	**0.148**
		StdDev	**1.33**	**1.31**	**1.26**	**1.18**	**1.08**	**0.97**	**0.85**	**0.74**	**0.010**	**0.007**	**0.004**	**0.002**	**0.004**	**0.008**	**0.011**	**0.015**
2	6.0	1*	8.26	8.19	8.04	7.83	7.57	7.25	6.89	6.50	0.010	0.020	0.032	0.044	0.055	0.067	0.079	0.091
		2	26.68	25.59	24.30	22.93	21.50	20.03	18.55	17.07	0.062	0.070	0.079	0.088	0.097	0.106	0.115	0.124
		3	26.77	25.70	24.41	23.05	21.62	20.15	18.66	17.16	0.061	0.069	0.078	0.088	0.097	0.106	0.116	0.125
		4	18.82	18.13	17.20	16.14	14.97	13.73	12.45	11.16	0.053	0.067	0.084	0.100	0.117	0.133	0.149	0.166
		5	20.86	19.95	18.90	17.81	16.70	15.58	14.46	13.35	0.067	0.074	0.082	0.089	0.097	0.104	0.111	0.119
		Avg	**23.28**	**22.34**	**21.20**	**19.98**	**18.70**	**17.37**	**16.03**	**14.69**	**0.061**	**0.070**	**0.081**	**0.091**	**0.102**	**0.112**	**0.123**	**0.134**
		StdDev	**4.06**	**3.89**	**3.71**	**3.54**	**3.38**	**3.23**	**3.08**	**2.95**	**0.006**	**0.003**	**0.003**	**0.006**	**0.010**	**0.014**	**0.018**	**0.022**
3	6.0	1	24.71	23.83	22.77	21.62	20.42	19.17	17.88	16.59	0.054	0.062	0.070	0.079	0.087	0.096	0.104	0.113
		2	23.29	22.04	20.60	19.14	17.66	16.19	14.74	13.34	0.084	0.092	0.102	0.111	0.121	0.130	0.140	0.149
		3	29.82	28.39	26.72	25.00	23.25	21.49	19.74	18.02	0.075	0.083	0.092	0.100	0.109	0.118	0.127	0.136
		4	21.93	21.15	20.07	18.80	17.38	15.87	14.30	12.71	0.049	0.066	0.085	0.104	0.122	0.141	0.160	0.178
		5	21.28	20.38	19.30	18.13	16.91	15.64	14.36	13.09	0.063	0.073	0.084	0.095	0.107	0.118	0.129	0.140
		Avg	**24.21**	**23.16**	**21.89**	**20.54**	**19.12**	**17.67**	**16.21**	**14.75**	**0.065**	**0.075**	**0.087**	**0.098**	**0.109**	**0.120**	**0.132**	**0.143**
		StdDev	**3.41**	**3.19**	**2.99**	**2.82**	**2.68**	**2.57**	**2.47**	**2.40**	**0.014**	**0.012**	**0.012**	**0.012**	**0.014**	**0.017**	**0.020**	**0.024**
4	6.0	1*	10.67	10.40	10.01	9.55	9.01	8.42	7.80	7.14	0.035	0.047	0.062	0.076	0.090	0.105	0.119	0.133
		2*	16.61	16.23	15.67	15.00	14.22	13.35	12.42	11.45	0.031	0.043	0.057	0.070	0.084	0.097	0.111	0.125
		3	28.75	27.43	25.88	24.27	22.62	20.94	19.27	17.62	0.071	0.079	0.088	0.097	0.106	0.116	0.125	0.134
		4	28.23	26.98	25.32	23.44	21.39	19.25	17.08	14.94	0.063	0.081	0.102	0.122	0.142	0.162	0.183	0.203
		5	21.38	20.35	19.13	17.83	16.49	15.13	13.77	12.43	0.073	0.084	0.095	0.107	0.119	0.130	0.142	0.154
		Avg	**26.12**	**24.92**	**23.44**	**21.85**	**20.17**	**18.44**	**16.71**	**15.00**	**0.069**	**0.081**	**0.095**	**0.109**	**0.122**	**0.136**	**0.150**	**0.164**
		StdDev	**4.11**	**3.96**	**3.75**	**3.50**	**3.24**	**2.99**	**2.77**	**2.60**	**0.005**	**0.003**	**0.007**	**0.013**	**0.018**	**0.024**	**0.030**	**0.036**
Avg	**6.0**	**---**	**23.80**	**22.78**	**21.55**	**20.21**	**18.81**	**17.36**	**15.89**	**14.43**	**0.064**	**0.074**	**0.086**	**0.098**	**0.110**	**0.122**	**0.134**	**0.146**
StdDev		**---**	**3.21**	**3.04**	**2.86**	**2.68**	**2.50**	**2.34**	**2.21**	**2.09**	**0.010**	**0.008**	**0.008**	**0.010**	**0.013**	**0.016**	**0.020**	**0.023**

Table B.17 *BBR* Mixture Data for *9.5-15/CM-4a* at -18 C

Specimen	V_a		Test Time (sec) and Mixture Stiffness (GPa)								Test Time (sec) and Mixture m-value							
Rep	**(%)**	**Rep**	**8**	**15**	**30**	**60**	**120**	**240**	**480**	**960**	**8**	**15**	**30**	**60**	**120**	**240**	**480**	**960**
1	6.0	1	15.99	15.27	14.36	13.34	12.25	11.12	9.97	8.84	0.065	0.081	0.098	0.115	0.131	0.148	0.165	0.182
		2	9.54	9.31	9.01	8.67	8.29	7.88	7.45	7.00	0.035	0.043	0.052	0.060	0.069	0.077	0.086	0.094
		3	18.83	18.12	17.23	16.26	15.22	14.13	13.01	11.89	0.056	0.067	0.078	0.090	0.101	0.113	0.124	0.136
		4	16.38	15.60	14.70	13.78	12.84	11.90	10.96	10.05	0.074	0.081	0.089	0.098	0.106	0.114	0.122	0.130
		5	20.24	19.30	18.15	16.91	15.61	14.27	12.93	11.60	0.069	0.081	0.095	0.109	0.122	0.136	0.150	0.163
		Avg	**16.20**	**15.52**	**14.69**	**13.79**	**12.84**	**11.86**	**10.86**	**9.87**	**0.060**	**0.071**	**0.082**	**0.094**	**0.106**	**0.118**	**0.129**	**0.141**
		StdDev	**4.11**	**3.86**	**3.57**	**3.25**	**2.93**	**2.62**	**2.31**	**2.02**	**0.015**	**0.017**	**0.019**	**0.021**	**0.024**	**0.027**	**0.030**	**0.034**
2	6.0	1	22.25	21.31	20.24	19.16	18.07	16.97	15.89	14.81	0.066	0.071	0.077	0.082	0.087	0.093	0.098	0.104
		2	22.18	21.00	19.59	18.09	16.55	14.99	13.45	11.95	0.081	0.094	0.108	0.122	0.136	0.150	0.164	0.178
		3	25.99	24.56	22.93	21.27	19.60	17.94	16.32	14.75	0.086	0.095	0.104	0.113	0.123	0.132	0.141	0.151
		4	26.95	25.45	23.68	21.83	19.95	18.06	16.21	14.41	0.085	0.097	0.111	0.124	0.137	0.150	0.163	0.176
		5	23.93	22.75	21.26	19.63	17.89	16.11	14.33	12.58	0.072	0.089	0.107	0.124	0.142	0.160	0.178	0.196
		Avg	**24.26**	**23.01**	**21.54**	**20.00**	**18.41**	**16.82**	**15.24**	**13.70**	**0.078**	**0.089**	**0.101**	**0.113**	**0.125**	**0.137**	**0.149**	**0.161**
		StdDev	**2.16**	**1.96**	**1.74**	**1.54**	**1.38**	**1.29**	**1.28**	**1.34**	**0.009**	**0.010**	**0.014**	**0.018**	**0.022**	**0.027**	**0.031**	**0.036**
3	6.0	1	16.79	15.99	15.02	13.98	12.88	11.75	10.62	9.51	0.071	0.083	0.097	0.111	0.125	0.139	0.153	0.167
		2	22.06	20.86	19.52	18.16	16.81	15.47	14.17	12.90	0.085	0.092	0.100	0.108	0.116	0.123	0.131	0.139
		3	15.16	14.59	13.85	13.02	12.11	11.15	10.17	9.17	0.054	0.068	0.082	0.097	0.112	0.126	0.141	0.155
		4	18.55	17.61	16.49	15.29	14.06	12.81	11.57	10.35	0.077	0.089	0.102	0.115	0.128	0.141	0.154	0.167
		5	16.31	15.69	14.60	13.18	11.53	9.79	8.06	6.43	0.042	0.082	0.126	0.170	0.214	0.259	0.303	0.347
		Avg	**17.77**	**16.95**	**15.90**	**14.72**	**13.48**	**12.19**	**10.92**	**9.67**	**0.066**	**0.083**	**0.101**	**0.120**	**0.139**	**0.158**	**0.176**	**0.195**
		StdDev	**2.69**	**2.44**	**2.24**	**2.12**	**2.09**	**2.13**	**2.23**	**2.33**	**0.018**	**0.009**	**0.016**	**0.029**	**0.043**	**0.057**	**0.071**	**0.086**
4	6.0	1	17.09	16.00	14.68	13.27	11.82	10.38	8.98	7.66	0.095	0.114	0.135	0.156	0.177	0.198	0.219	0.240
		2	16.65	15.97	15.08	14.07	12.97	11.81	10.63	9.45	0.058	0.074	0.091	0.109	0.126	0.144	0.161	0.179
		3	15.88	15.15	14.29	13.38	12.43	11.47	10.51	9.55	0.070	0.080	0.090	0.100	0.111	0.121	0.132	0.142
		4	18.87	18.04	17.03	15.96	14.83	13.67	12.50	11.34	0.066	0.077	0.088	0.100	0.112	0.123	0.135	0.146
		5	14.66	13.94	13.10	12.22	11.31	10.40	9.49	8.60	0.075	0.118	0.136	0.155	0.173	0.192	0.210	0.229
		Avg	**16.63**	**15.82**	**14.84**	**13.78**	**12.67**	**11.55**	**10.42**	**9.32**	**0.073**	**0.092**	**0.108**	**0.124**	**0.140**	**0.156**	**0.171**	**0.187**
		StdDev	**1.55**	**1.50**	**1.43**	**1.39**	**1.36**	**1.35**	**1.35**	**1.36**	**0.014**	**0.022**	**0.025**	**0.029**	**0.033**	**0.037**	**0.041**	**0.046**
Avg	**6.0**	**---**	**18.71**	**17.83**	**16.74**	**15.57**	**14.35**	**13.10**	**11.86**	**10.64**	**0.069**	**0.084**	**0.098**	**0.113**	**0.127**	**0.142**	**0.157**	**0.171**
StdDev		**---**	**4.21**	**3.93**	**3.62**	**3.33**	**3.07**	**2.83**	**2.63**	**2.47**	**0.015**	**0.016**	**0.020**	**0.026**	**0.032**	**0.039**	**0.047**	**0.055**

Table B.18 *BBR* Mixture Data for *9.5-15/CM-4a* at -12 C

Specimen	V_a		Test Time (sec) and Mixture Stiffness (GPa)								Test Time (sec) and Mixture m-value							
Rep	**(%)**	**Rep**	**8**	**15**	**30**	**60**	**120**	**240**	**480**	**960**	**8**	**15**	**30**	**60**	**120**	**240**	**480**	**960**
1	6.0	1	13.65	12.68	11.54	10.37	9.21	8.07	6.98	5.97	0.110	0.127	0.145	0.163	0.181	0.199	0.217	0.236
		2	16.99	15.98	14.83	13.66	12.49	11.33	10.21	9.13	0.093	0.103	0.113	0.124	0.134	0.145	0.156	0.166
		3	11.75	11.03	10.16	9.25	8.31	7.38	6.47	5.60	0.093	0.109	0.127	0.145	0.163	0.181	0.199	0.217
		4	15.74	14.83	13.72	12.53	11.29	10.05	8.83	7.66	0.086	0.103	0.122	0.140	0.159	0.177	0.196	0.214
		5	16.49	15.50	14.28	12.97	11.61	10.25	8.92	7.66	0.089	0.108	0.128	0.149	0.170	0.190	0.211	0.231
		Avg	**14.93**	**14.00**	**12.90**	**11.75**	**10.58**	**9.42**	**8.28**	**7.21**	**0.094**	**0.110**	**0.127**	**0.144**	**0.161**	**0.178**	**0.196**	**0.213**
		StdDev	**2.18**	**2.09**	**1.98**	**1.86**	**1.75**	**1.64**	**1.53**	**1.43**	**0.009**	**0.010**	**0.012**	**0.014**	**0.017**	**0.021**	**0.024**	**0.028**
2	6.0	1	12.65	12.07	11.37	10.63	9.86	9.07	8.28	7.50	0.070	0.080	0.092	0.103	0.114	0.126	0.137	0.149
		2	14.58	13.83	12.89	11.87	10.81	9.72	8.64	7.59	0.077	0.093	0.110	0.127	0.144	0.161	0.179	0.196
		3	14.31	13.46	12.48	11.47	10.44	9.42	8.42	7.46	0.091	0.103	0.116	0.129	0.142	0.155	0.168	0.181
		4	14.52	13.67	12.65	11.57	10.46	9.35	8.27	7.22	0.089	0.104	0.120	0.137	0.153	0.170	0.186	0.203
		5	15.02	14.20	13.22	12.17	11.08	9.98	8.90	7.85	0.082	0.096	0.112	0.127	0.143	0.158	0.174	0.189
		Avg	**14.22**	**13.45**	**12.52**	**11.54**	**10.53**	**9.51**	**8.50**	**7.52**	**0.082**	**0.095**	**0.110**	**0.125**	**0.139**	**0.154**	**0.169**	**0.184**
		StdDev	**0.91**	**0.82**	**0.70**	**0.58**	**0.46**	**0.35**	**0.27**	**0.23**	**0.009**	**0.010**	**0.011**	**0.013**	**0.015**	**0.017**	**0.019**	**0.021**
3	6.0	1	13.32	12.67	11.87	11.01	10.10	9.17	8.24	7.33	0.073	0.087	0.102	0.117	0.132	0.147	0.162	0.177
		2	12.62	11.75	10.77	9.78	8.81	7.85	6.94	6.08	0.107	0.119	0.132	0.145	0.158	0.172	0.185	0.198
		3	13.81	12.92	11.89	10.83	9.76	8.71	7.70	6.73	0.099	0.113	0.127	0.142	0.157	0.171	0.186	0.201
		4	14.38	13.57	12.62	11.64	10.65	9.66	8.69	7.75	0.087	0.098	0.110	0.123	0.135	0.147	0.159	0.171
		5	13.59	12.75	11.72	10.63	9.51	8.39	7.30	6.27	0.093	0.111	0.131	0.151	0.171	0.191	0.210	0.230
		Avg	**13.54**	**12.73**	**11.77**	**10.78**	**9.77**	**8.76**	**7.77**	**6.83**	**0.092**	**0.105**	**0.120**	**0.135**	**0.150**	**0.165**	**0.180**	**0.195**
		StdDev	**0.65**	**0.65**	**0.66**	**0.67**	**0.68**	**0.70**	**0.70**	**0.70**	**0.013**	**0.013**	**0.014**	**0.015**	**0.017**	**0.019**	**0.021**	**0.023**
4	6.0	1	15.67	14.82	13.80	12.72	11.61	10.49	9.39	8.32	0.082	0.096	0.110	0.124	0.139	0.153	0.168	0.182
		2	14.08	13.24	12.19	11.06	9.89	8.71	7.56	6.47	0.089	0.108	0.130	0.151	0.172	0.194	0.215	0.236
		3	14.91	14.01	12.93	11.79	10.61	9.43	8.27	7.17	0.090	0.107	0.125	0.143	0.161	0.180	0.198	0.216
		4	14.46	13.58	12.53	11.42	10.28	9.14	8.04	6.98	0.092	0.108	0.125	0.143	0.160	0.178	0.195	0.212
		5	12.71	11.86	10.87	9.82	8.77	7.73	6.72	5.77	0.101	0.118	0.136	0.155	0.173	0.192	0.210	0.229
		Avg	**14.37**	**13.50**	**12.46**	**11.36**	**10.23**	**9.10**	**8.00**	**6.94**	**0.091**	**0.107**	**0.125**	**0.143**	**0.161**	**0.179**	**0.197**	**0.215**
		StdDev	**1.10**	**1.09**	**1.08**	**1.06**	**1.04**	**1.01**	**0.98**	**0.94**	**0.007**	**0.008**	**0.010**	**0.012**	**0.014**	**0.016**	**0.018**	**0.021**
Avg	**6.0**	**---**	**14.26**	**13.42**	**12.42**	**11.36**	**10.28**	**9.20**	**8.14**	**7.13**	**0.090**	**0.104**	**0.121**	**0.137**	**0.153**	**0.169**	**0.185**	**0.202**
StdDev		**---**	**1.33**	**1.27**	**1.20**	**1.13**	**1.06**	**1.00**	**0.95**	**0.90**	**0.010**	**0.011**	**0.013**	**0.015**	**0.017**	**0.020**	**0.022**	**0.025**

Table B.19 *BBR* Mixture Data for *9.5-15/CM-4a* at -06 C

Specimen	V_a		Test Time (sec) and Mixture Stiffness (GPa)								Test Time (sec) and Mixture m-value							
Rep	**(%)**	**Rep**	**8**	**15**	**30**	**60**	**120**	**240**	**480**	**960**	**8**	**15**	**30**	**60**	**120**	**240**	**480**	**960**
1	6.0	1	13.25	12.28	11.20	10.13	9.08	8.07	7.11	6.21	0.116	0.127	0.139	0.152	0.164	0.176	0.189	0.201
		2	13.02	12.00	10.80	9.56	8.33	7.14	6.01	4.99	0.119	0.140	0.164	0.188	0.211	0.235	0.258	0.282
		3	12.38	11.44	10.37	9.31	8.27	7.27	6.33	5.45	0.119	0.133	0.148	0.163	0.178	0.193	0.209	0.224
		4	13.38	12.38	11.20	9.98	8.76	7.58	6.45	5.42	0.114	0.134	0.155	0.177	0.199	0.220	0.242	0.264
		5	11.02	10.13	9.07	7.99	6.91	5.88	4.91	4.04	0.124	0.146	0.171	0.196	0.221	0.246	0.271	0.296
		Avg	**12.61**	**11.64**	**10.53**	**9.39**	**8.27**	**7.19**	**6.16**	**5.22**	**0.118**	**0.136**	**0.156**	**0.175**	**0.195**	**0.214**	**0.234**	**0.253**
		StdDev	**0.97**	**0.92**	**0.88**	**0.85**	**0.83**	**0.81**	**0.81**	**0.80**	**0.004**	**0.007**	**0.013**	**0.018**	**0.023**	**0.029**	**0.034**	**0.040**
2	6.0	1	14.13	13.06	11.81	10.54	9.28	8.06	6.91	5.84	0.117	0.135	0.155	0.174	0.193	0.213	0.232	0.252
		2	11.78	10.87	9.83	8.76	7.70	6.67	5.70	4.81	0.118	0.136	0.156	0.176	0.196	0.216	0.236	0.257
		3	12.19	11.18	10.01	8.82	7.65	6.53	5.49	4.54	0.127	0.148	0.171	0.194	0.217	0.240	0.263	0.286
		4	10.26	9.39	8.40	7.40	6.43	5.50	4.64	3.85	0.131	0.150	0.171	0.193	0.214	0.235	0.257	0.278
		5	12.34	11.35	10.20	9.03	7.86	6.73	5.68	4.71	0.122	0.143	0.166	0.189	0.212	0.235	0.258	0.281
		Avg	**12.14**	**11.17**	**10.05**	**8.91**	**7.78**	**6.70**	**5.68**	**4.75**	**0.123**	**0.142**	**0.164**	**0.185**	**0.206**	**0.228**	**0.249**	**0.271**
		StdDev	**1.39**	**1.31**	**1.21**	**1.11**	**1.01**	**0.91**	**0.81**	**0.71**	**0.006**	**0.007**	**0.008**	**0.009**	**0.011**	**0.012**	**0.014**	**0.015**
3	6.0	1	10.00	8.97	7.83	6.71	5.64	4.66	3.79	3.02	0.161	0.184	0.210	0.236	0.262	0.288	0.314	0.340
		2	10.00	9.11	8.08	7.05	6.04	5.08	4.20	3.42	0.137	0.160	0.185	0.211	0.236	0.261	0.286	0.312
		3	10.64	9.66	8.55	7.43	6.35	5.32	4.39	3.56	0.141	0.164	0.190	0.215	0.240	0.266	0.291	0.316
		4	10.28	9.36	8.29	7.21	6.16	5.16	4.25	3.43	0.137	0.161	0.188	0.215	0.241	0.268	0.295	0.321
		5	12.66	11.50	10.19	8.89	7.63	6.45	5.36	4.39	0.142	0.163	0.186	0.209	0.232	0.254	0.277	0.300
		Avg	**10.72**	**9.72**	**8.59**	**7.46**	**6.36**	**5.34**	**4.40**	**3.56**	**0.144**	**0.167**	**0.192**	**0.217**	**0.242**	**0.267**	**0.293**	**0.318**
		StdDev	**1.12**	**1.03**	**0.93**	**0.84**	**0.75**	**0.67**	**0.58**	**0.51**	**0.010**	**0.010**	**0.010**	**0.011**	**0.012**	**0.013**	**0.014**	**0.015**
4	6.0	1	7.85	7.08	6.25	5.44	4.67	3.96	3.31	2.74	0.155	0.172	0.191	0.210	0.229	0.247	0.266	0.285
		2	11.37	10.30	9.10	7.91	6.78	5.72	4.76	3.90	0.148	0.168	0.190	0.212	0.234	0.256	0.278	0.300
		3	9.82	8.96	7.93	6.88	5.83	4.84	3.94	3.13	0.132	0.160	0.191	0.222	0.252	0.283	0.314	0.345
		4	9.05	8.39	7.56	6.66	5.75	4.85	4.00	3.23	0.106	0.135	0.166	0.198	0.229	0.261	0.292	0.324
		5	12.61	11.49	10.24	9.01	7.82	6.70	5.66	4.72	0.139	0.156	0.176	0.195	0.214	0.233	0.252	0.272
		Avg	**10.14**	**9.24**	**8.21**	**7.18**	**6.17**	**5.21**	**4.33**	**3.54**	**0.136**	**0.158**	**0.183**	**0.207**	**0.232**	**0.256**	**0.280**	**0.305**
		StdDev	**1.88**	**1.70**	**1.52**	**1.35**	**1.19**	**1.04**	**0.90**	**0.78**	**0.019**	**0.015**	**0.011**	**0.011**	**0.014**	**0.018**	**0.024**	**0.030**
Avg	**6.0**	**---**	**11.40**	**10.45**	**9.35**	**8.23**	**7.15**	**6.11**	**5.14**	**4.27**	**0.130**	**0.151**	**0.173**	**0.196**	**0.219**	**0.241**	**0.264**	**0.287**
StdDev		**---**	**1.64**	**1.55**	**1.46**	**1.37**	**1.28**	**1.18**	**1.09**	**0.99**	**0.015**	**0.016**	**0.018**	**0.021**	**0.024**	**0.028**	**0.032**	**0.036**

Table B.20 *BBR* Mixture Data for *9.5-15/CM-4b* at -24 C

Specimen	V_a		Test Time (sec) and Mixture Stiffness (GPa)								Test Time (sec) and Mixture m-value							
Rep	**(%)**	**Rep**	**8**	**15**	**30**	**60**	**120**	**240**	**480**	**960**	**8**	**15**	**30**	**60**	**120**	**240**	**480**	**960**
1	6.1	1	14.49	14.05	13.46	12.76	11.98	11.14	10.26	9.35	0.042	0.055	0.069	0.084	0.098	0.112	0.126	0.140
		2	13.86	13.28	12.62	11.94	11.23	10.52	9.81	9.10	0.064	0.070	0.077	0.084	0.091	0.098	0.105	0.112
		3	18.43	17.86	17.12	16.27	15.33	14.34	13.29	12.23	0.045	0.056	0.067	0.079	0.091	0.103	0.115	0.127
		4	18.70	17.72	16.62	15.54	14.47	13.42	12.40	11.41	0.084	0.089	0.095	0.100	0.106	0.112	0.117	0.123
		5	15.56	15.06	14.48	13.88	13.25	12.61	11.95	11.30	0.050	0.054	0.059	0.064	0.069	0.074	0.079	0.084
		Avg	**16.21**	**15.59**	**14.86**	**14.08**	**13.25**	**12.40**	**11.54**	**10.68**	**0.057**	**0.065**	**0.074**	**0.082**	**0.091**	**0.100**	**0.108**	**0.117**
		StdDev	**2.24**	**2.10**	**1.96**	**1.82**	**1.70**	**1.58**	**1.47**	**1.37**	**0.017**	**0.015**	**0.013**	**0.013**	**0.014**	**0.015**	**0.018**	**0.021**
2	6.0	1	16.55	16.10	15.58	15.03	14.45	13.84	13.23	12.60	0.041	0.045	0.050	0.055	0.059	0.064	0.068	0.073
		2	25.44	24.60	23.49	22.23	20.84	19.36	17.82	16.25	0.047	0.059	0.073	0.086	0.100	0.113	0.127	0.140
		3	15.29	14.85	14.30	13.68	13.01	12.30	11.55	10.78	0.042	0.050	0.059	0.068	0.077	0.086	0.095	0.104
		4	20.53	19.87	18.97	17.90	16.69	15.40	14.04	12.66	0.044	0.059	0.076	0.092	0.108	0.125	0.141	0.158
		5	16.25	15.60	14.84	14.07	13.28	12.49	11.69	10.90	0.063	0.068	0.074	0.080	0.086	0.092	0.098	0.104
		Avg	**18.81**	**18.20**	**17.44**	**16.58**	**15.66**	**14.68**	**13.67**	**12.64**	**0.048**	**0.057**	**0.066**	**0.076**	**0.086**	**0.096**	**0.106**	**0.116**
		StdDev	**4.21**	**4.07**	**3.84**	**3.56**	**3.24**	**2.90**	**2.55**	**2.21**	**0.009**	**0.009**	**0.011**	**0.015**	**0.019**	**0.024**	**0.029**	**0.034**
3	6.0	1	22.62	21.53	20.27	18.96	17.63	16.29	14.96	13.65	0.075	0.083	0.092	0.101	0.110	0.118	0.127	0.136
		2	20.18	19.53	18.61	17.51	16.27	14.92	13.52	12.09	0.044	0.061	0.079	0.097	0.115	0.134	0.152	0.170
		3	24.37	23.12	21.71	20.28	18.85	17.43	16.04	14.68	0.081	0.087	0.095	0.102	0.109	0.117	0.124	0.131
		4	26.21	25.07	23.67	22.16	20.56	18.92	17.25	15.60	0.065	0.076	0.089	0.102	0.114	0.127	0.139	0.152
		5	25.31	24.27	22.88	21.29	19.55	17.71	15.84	13.98	0.058	0.075	0.095	0.114	0.133	0.152	0.171	0.190
		Avg	**23.74**	**22.70**	**21.43**	**20.04**	**18.57**	**17.05**	**15.52**	**14.00**	**0.065**	**0.077**	**0.090**	**0.103**	**0.116**	**0.129**	**0.143**	**0.156**
		StdDev	**2.39**	**2.22**	**2.03**	**1.85**	**1.67**	**1.51**	**1.39**	**1.30**	**0.014**	**0.010**	**0.007**	**0.006**	**0.010**	**0.014**	**0.019**	**0.024**
Avg	**6.0**	**---**	**19.59**	**18.83**	**17.91**	**16.90**	**15.83**	**14.71**	**13.58**	**12.44**	**0.056**	**0.066**	**0.077**	**0.087**	**0.098**	**0.108**	**0.119**	**0.130**
StdDev		**---**	**4.31**	**4.08**	**3.78**	**3.46**	**3.11**	**2.76**	**2.42**	**2.10**	**0.015**	**0.014**	**0.014**	**0.016**	**0.019**	**0.023**	**0.027**	**0.031**

Table B.21 *BBR* Mixture Data for *9.5-15/CM-4b* at -18 C

Specimen	V_a		Test Time (sec) and Mixture Stiffness (GPa)								Test Time (sec) and Mixture m-value							
Rep	**(%)**	**Rep**	**8**	**15**	**30**	**60**	**120**	**240**	**480**	**960**	**8**	**15**	**30**	**60**	**120**	**240**	**480**	**960**
1	6.1	1	15.96	15.25	14.36	13.37	12.31	11.21	10.10	9.00	0.065	0.079	0.095	0.111	0.127	0.143	0.159	0.175
		2	13.76	13.08	12.23	11.30	10.31	9.29	8.28	7.28	0.072	0.088	0.106	0.123	0.141	0.159	0.176	0.194
		3	15.62	14.87	14.00	13.12	12.21	11.31	10.41	9.53	0.075	0.082	0.090	0.099	0.107	0.115	0.123	0.132
		4	18.46	17.71	16.76	15.70	14.56	13.37	12.15	10.93	0.059	0.072	0.087	0.102	0.116	0.131	0.145	0.160
		5	21.35	20.42	19.27	18.03	16.71	15.34	13.96	12.59	0.065	0.077	0.090	0.103	0.116	0.129	0.143	0.156
		Avg	**17.03**	**16.27**	**15.33**	**14.30**	**13.22**	**12.10**	**10.98**	**9.87**	**0.067**	**0.080**	**0.094**	**0.108**	**0.121**	**0.135**	**0.149**	**0.163**
		StdDev	**2.94**	**2.85**	**2.73**	**2.60**	**2.46**	**2.31**	**2.16**	**2.01**	**0.006**	**0.006**	**0.007**	**0.010**	**0.013**	**0.016**	**0.020**	**0.023**
2	6.0	1	18.74	17.95	17.02	16.04	15.04	14.01	12.98	11.95	0.065	0.073	0.081	0.089	0.098	0.106	0.115	0.123
		2	17.75	16.96	15.93	14.76	13.49	12.17	10.83	9.51	0.063	0.081	0.100	0.120	0.139	0.158	0.178	0.197
		3	23.77	22.74	21.42	19.94	18.35	16.69	15.00	13.33	0.063	0.078	0.095	0.112	0.128	0.145	0.162	0.179
		4	22.43	21.19	19.74	18.22	16.67	15.11	13.58	12.10	0.085	0.096	0.109	0.122	0.135	0.148	0.160	0.173
		5	21.74	20.63	19.31	17.91	16.47	15.01	13.55	12.13	0.078	0.089	0.102	0.115	0.128	0.140	0.153	0.166
		Avg	**20.89**	**19.90**	**18.68**	**17.37**	**16.00**	**14.60**	**13.19**	**11.81**	**0.071**	**0.083**	**0.097**	**0.111**	**0.126**	**0.140**	**0.154**	**0.168**
		StdDev	**2.54**	**2.38**	**2.20**	**2.01**	**1.83**	**1.66**	**1.51**	**1.40**	**0.010**	**0.009**	**0.011**	**0.013**	**0.016**	**0.020**	**0.024**	**0.027**
3	6.0	1	16.04	15.24	14.31	13.34	12.34	11.34	10.34	9.36	0.076	0.086	0.096	0.107	0.117	0.128	0.138	0.149
		2	16.44	15.66	14.70	13.66	12.57	11.44	10.31	9.20	0.071	0.084	0.099	0.113	0.128	0.142	0.157	0.172
		3	16.94	16.13	15.12	14.00	12.83	11.61	10.39	9.20	0.070	0.085	0.102	0.118	0.135	0.152	0.168	0.185
		4	17.22	16.47	15.56	14.58	13.55	12.49	11.43	10.37	0.066	0.076	0.088	0.100	0.111	0.123	0.134	0.146
		5	17.81	17.05	16.05	14.91	13.67	12.37	11.05	9.74	0.061	0.078	0.097	0.116	0.135	0.154	0.172	0.191
		Avg	**16.89**	**16.11**	**15.15**	**14.10**	**12.99**	**11.85**	**10.71**	**9.57**	**0.069**	**0.082**	**0.096**	**0.111**	**0.125**	**0.140**	**0.154**	**0.168**
		StdDev	**0.69**	**0.70**	**0.68**	**0.64**	**0.59**	**0.54**	**0.51**	**0.50**	**0.006**	**0.004**	**0.005**	**0.008**	**0.011**	**0.014**	**0.017**	**0.021**
Avg	**6.0**	**---**	**18.27**	**17.42**	**16.39**	**15.26**	**14.07**	**12.85**	**11.62**	**10.42**	**0.069**	**0.082**	**0.096**	**0.110**	**0.124**	**0.138**	**0.152**	**0.166**
StdDev		**---**	**2.85**	**2.71**	**2.55**	**2.37**	**2.19**	**2.01**	**1.84**	**1.68**	**0.007**	**0.007**	**0.008**	**0.010**	**0.013**	**0.016**	**0.019**	**0.022**

Table B.22 *BBR* Mixture Data for *9.5-15/CM-4b* at -12 C

Specimen	V_a		Test Time (sec) and Mixture Stiffness (GPa)								Test Time (sec) and Mixture m-value							
Rep	**(%)**	**Rep**	**8**	**15**	**30**	**60**	**120**	**240**	**480**	**960**	**8**	**15**	**30**	**60**	**120**	**240**	**480**	**960**
1	6.1	1	14.11	13.44	12.60	11.68	10.70	9.69	8.68	7.68	0.070	0.085	0.101	0.118	0.134	0.151	0.168	0.184
		2	9.11	8.64	8.04	7.38	6.68	5.96	5.25	4.56	0.075	0.093	0.114	0.134	0.154	0.174	0.194	0.214
		3	11.40	10.82	10.08	9.28	8.43	7.56	6.70	5.86	0.075	0.092	0.111	0.129	0.148	0.166	0.185	0.203
		4	12.96	12.19	11.30	10.39	9.47	8.57	7.68	6.84	0.092	0.103	0.115	0.127	0.139	0.151	0.163	0.175
		5	9.74	9.25	8.66	8.04	7.39	6.74	6.08	5.45	0.076	0.088	0.101	0.114	0.127	0.141	0.154	0.167
		Avg	**11.46**	**10.87**	**10.14**	**9.35**	**8.53**	**7.70**	**6.88**	**6.08**	**0.078**	**0.092**	**0.108**	**0.124**	**0.140**	**0.156**	**0.173**	**0.189**
		StdDev	**2.11**	**2.00**	**1.87**	**1.74**	**1.61**	**1.47**	**1.34**	**1.22**	**0.009**	**0.007**	**0.007**	**0.008**	**0.010**	**0.013**	**0.016**	**0.020**
2	6.0	1	15.49	14.53	13.39	12.18	10.95	9.72	8.52	7.38	0.093	0.109	0.127	0.145	0.163	0.181	0.199	0.216
		2	14.40	13.61	12.61	11.51	10.34	9.15	7.98	6.85	0.079	0.099	0.121	0.143	0.165	0.187	0.209	0.231
		3	12.57	11.85	10.99	10.10	9.20	8.29	7.40	6.54	0.088	0.101	0.115	0.129	0.143	0.157	0.171	0.185
		4	11.04	10.35	9.55	8.72	7.89	7.06	6.26	5.49	0.096	0.109	0.124	0.138	0.153	0.167	0.182	0.196
		5	15.13	14.26	13.24	12.17	11.08	9.99	8.92	7.88	0.088	0.100	0.114	0.128	0.142	0.157	0.171	0.185
		Avg	**13.72**	**12.92**	**11.96**	**10.94**	**9.89**	**8.84**	**7.81**	**6.83**	**0.089**	**0.104**	**0.120**	**0.137**	**0.153**	**0.170**	**0.186**	**0.203**
		StdDev	**1.87**	**1.78**	**1.65**	**1.50**	**1.34**	**1.19**	**1.04**	**0.91**	**0.006**	**0.005**	**0.006**	**0.008**	**0.011**	**0.014**	**0.017**	**0.021**
3	6.0	1	13.38	12.73	11.93	11.05	10.12	9.17	8.22	7.29	0.072	0.086	0.102	0.118	0.134	0.150	0.166	0.182
		2	12.89	12.13	11.18	10.15	9.08	8.01	6.95	5.95	0.087	0.107	0.128	0.150	0.171	0.193	0.214	0.236
		3	9.98	9.55	9.00	8.41	7.79	7.14	6.49	5.84	0.065	0.078	0.091	0.105	0.118	0.132	0.145	0.159
		4	5.01	4.90	4.76	4.58	4.38	4.15	3.91	3.65	0.028	0.038	0.049	0.060	0.071	0.082	0.093	0.104
		5	10.26	9.70	9.00	8.25	7.47	6.67	5.89	5.13	0.081	0.098	0.117	0.135	0.153	0.172	0.190	0.208
		Avg	**10.31**	**9.80**	**9.17**	**8.49**	**7.77**	**7.03**	**6.29**	**5.57**	**0.067**	**0.081**	**0.097**	**0.113**	**0.130**	**0.146**	**0.162**	**0.178**
		StdDev	**3.33**	**3.09**	**2.79**	**2.48**	**2.17**	**1.87**	**1.59**	**1.33**	**0.023**	**0.027**	**0.031**	**0.034**	**0.038**	**0.042**	**0.046**	**0.050**
Avg	**6.0**	**---**	**11.83**	**11.20**	**10.42**	**9.59**	**8.73**	**7.86**	**7.00**	**6.16**	**0.078**	**0.093**	**0.109**	**0.125**	**0.141**	**0.157**	**0.173**	**0.190**
StdDev		**---**	**2.76**	**2.56**	**2.33**	**2.09**	**1.85**	**1.62**	**1.40**	**1.20**	**0.017**	**0.018**	**0.019**	**0.022**	**0.024**	**0.027**	**0.030**	**0.033**

Table B.23 *BBR* Mixture Data for *9.5-15/CM-4b* at -06 C

Specimen	V_a		Test Time (sec) and Mixture Stiffness (GPa)								Test Time (sec) and Mixture m-value							
Rep	**(%)**	**Rep**	**8**	**15**	**30**	**60**	**120**	**240**	**480**	**960**	**8**	**15**	**30**	**60**	**120**	**240**	**480**	**960**
1	6.1	1	11.05	10.11	9.06	8.02	7.01	6.05	5.16	4.35	0.134	0.150	0.167	0.185	0.203	0.221	0.238	0.256
		2	11.30	10.46	9.48	8.48	7.49	6.52	5.60	4.75	0.114	0.132	0.151	0.170	0.190	0.209	0.228	0.248
		3	13.67	12.56	11.28	9.98	8.70	7.48	6.33	5.28	0.125	0.144	0.166	0.187	0.208	0.229	0.251	0.272
		4	9.48	8.76	7.94	7.11	6.30	5.51	4.77	4.07	0.118	0.133	0.150	0.167	0.184	0.201	0.218	0.235
		5	11.35	10.67	9.85	8.97	8.07	7.16	6.27	5.42	0.089	0.106	0.125	0.144	0.163	0.181	0.200	0.219
		Avg	**11.37**	**10.51**	**9.52**	**8.51**	**7.51**	**6.54**	**5.63**	**4.78**	**0.116**	**0.133**	**0.152**	**0.171**	**0.190**	**0.208**	**0.227**	**0.246**
		StdDev	**1.50**	**1.37**	**1.22**	**1.07**	**0.93**	**0.80**	**0.68**	**0.58**	**0.017**	**0.017**	**0.017**	**0.017**	**0.018**	**0.019**	**0.019**	**0.020**
2	6.0	1	11.20	10.19	9.10	8.04	7.03	6.09	5.23	4.44	0.144	0.157	0.171	0.186	0.200	0.214	0.229	0.243
		2	11.04	10.18	9.18	8.15	7.13	6.14	5.21	4.35	0.118	0.138	0.160	0.182	0.204	0.226	0.248	0.270
		3	11.49	10.55	9.49	8.43	7.39	6.39	5.46	4.60	0.127	0.144	0.162	0.181	0.199	0.218	0.237	0.255
		4	12.05	11.17	10.13	9.05	7.96	6.89	5.88	4.94	0.110	0.130	0.152	0.174	0.196	0.218	0.241	0.263
		5	11.07	10.07	8.97	7.89	6.86	5.89	5.00	4.19	0.143	0.159	0.176	0.194	0.211	0.228	0.246	0.263
		Avg	**11.37**	**10.43**	**9.37**	**8.31**	**7.27**	**6.28**	**5.35**	**4.50**	**0.128**	**0.146**	**0.164**	**0.183**	**0.202**	**0.221**	**0.240**	**0.259**
		StdDev	**0.42**	**0.45**	**0.47**	**0.46**	**0.43**	**0.39**	**0.34**	**0.28**	**0.015**	**0.012**	**0.009**	**0.007**	**0.006**	**0.006**	**0.008**	**0.010**
3	6.0	1	10.39	9.51	8.49	7.45	6.43	5.45	4.55	3.73	0.129	0.151	0.176	0.201	0.225	0.250	0.274	0.299
		2	9.16	8.29	7.33	6.40	5.50	4.67	3.91	3.23	0.149	0.167	0.187	0.207	0.227	0.247	0.267	0.287
		3	9.87	9.02	8.04	7.05	6.08	5.15	4.30	3.52	0.131	0.153	0.178	0.202	0.226	0.250	0.275	0.299
		4	10.67	9.85	8.88	7.87	6.85	5.87	4.95	4.10	0.116	0.138	0.162	0.187	0.211	0.235	0.260	0.284
		5	12.73	11.67	10.44	9.19	7.97	6.80	5.71	4.72	0.128	0.149	0.172	0.195	0.218	0.240	0.263	0.286
		Avg	**10.56**	**9.67**	**8.64**	**7.59**	**6.57**	**5.59**	**4.68**	**3.86**	**0.131**	**0.152**	**0.175**	**0.198**	**0.221**	**0.245**	**0.268**	**0.291**
		StdDev	**1.34**	**1.26**	**1.16**	**1.05**	**0.93**	**0.81**	**0.69**	**0.58**	**0.012**	**0.011**	**0.009**	**0.008**	**0.007**	**0.007**	**0.007**	**0.007**
Avg	**6.0**	**---**	**11.10**	**10.21**	**9.18**	**8.14**	**7.12**	**6.14**	**5.22**	**4.38**	**0.125**	**0.144**	**0.164**	**0.184**	**0.204**	**0.225**	**0.245**	**0.265**
StdDev		**---**	**1.17**	**1.10**	**1.01**	**0.93**	**0.85**	**0.76**	**0.69**	**0.61**	**0.015**	**0.015**	**0.015**	**0.016**	**0.017**	**0.019**	**0.021**	**0.023**

Table B.24 *BBR* Mixture Data for *9.5-15/CM-4c* at -24 C

Specimen	V_a		Test Time (sec) and Mixture Stiffness (GPa)								Test Time (sec) and Mixture m-value							
Rep	**(%)**	**Rep**	**8**	**15**	**30**	**60**	**120**	**240**	**480**	**960**	**8**	**15**	**30**	**60**	**120**	**240**	**480**	**960**
1	5.0	1	22.76	21.93	20.89	19.74	18.50	17.21	15.88	14.53	0.054	0.064	0.076	0.087	0.099	0.111	0.122	0.134
		2	23.98	23.31	22.33	21.13	19.76	18.26	16.66	15.02	0.037	0.053	0.071	0.088	0.106	0.123	0.141	0.158
		3	20.77	19.94	18.88	17.70	16.42	15.08	13.71	12.34	0.058	0.071	0.086	0.101	0.115	0.130	0.145	0.160
		4	16.68	15.99	15.19	14.36	13.50	12.63	11.76	10.89	0.064	0.070	0.078	0.085	0.092	0.100	0.107	0.114
		5	17.27	16.63	15.88	15.11	14.30	13.48	12.65	11.81	0.057	0.063	0.069	0.076	0.082	0.089	0.095	0.102
		Avg	**20.29**	**19.56**	**18.64**	**17.61**	**16.50**	**15.33**	**14.13**	**12.92**	**0.054**	**0.064**	**0.076**	**0.087**	**0.099**	**0.110**	**0.122**	**0.133**
		StdDev	**3.24**	**3.21**	**3.09**	**2.91**	**2.67**	**2.39**	**2.09**	**1.78**	**0.010**	**0.007**	**0.007**	**0.009**	**0.013**	**0.017**	**0.021**	**0.026**
2	5.0	1	24.77	23.63	22.42	21.26	20.14	19.07	18.04	17.06	0.075	0.075	0.076	0.077	0.078	0.079	0.080	0.081
		2	21.55	20.71	19.66	18.52	17.29	16.02	14.72	13.41	0.058	0.069	0.081	0.093	0.105	0.116	0.128	0.140
		3	21.14	20.17	19.06	17.92	16.76	15.60	14.45	13.32	0.072	0.078	0.085	0.093	0.100	0.107	0.114	0.121
		4	30.41	29.13	27.63	26.06	24.43	22.78	21.12	19.46	0.065	0.072	0.080	0.089	0.097	0.105	0.114	0.122
		5	21.95	21.29	20.47	19.57	18.59	17.56	16.48	15.38	0.045	0.052	0.061	0.070	0.078	0.087	0.095	0.104
		Avg	**23.97**	**22.99**	**21.85**	**20.66**	**19.44**	**18.21**	**16.96**	**15.73**	**0.063**	**0.069**	**0.077**	**0.084**	**0.092**	**0.099**	**0.106**	**0.114**
		StdDev	**3.87**	**3.68**	**3.47**	**3.27**	**3.08**	**2.90**	**2.74**	**2.60**	**0.012**	**0.010**	**0.009**	**0.010**	**0.012**	**0.015**	**0.019**	**0.022**
Avg	**5.0**	**---**	**22.13**	**21.27**	**20.24**	**19.14**	**17.97**	**16.77**	**15.55**	**14.32**	**0.058**	**0.067**	**0.076**	**0.086**	**0.095**	**0.105**	**0.114**	**0.124**
StdDev		**---**	**3.89**	**3.72**	**3.53**	**3.33**	**3.13**	**2.93**	**2.74**	**2.57**	**0.011**	**0.009**	**0.008**	**0.009**	**0.012**	**0.016**	**0.021**	**0.025**

Table B.25 *BBR* Mixture Data for *9.5-15/CM-4c* at -18 C

Specimen	V_a		Test Time (sec) and Mixture Stiffness (GPa)								Test Time (sec) and Mixture m-value							
Rep	**(%)**	**Rep**	**8**	**15**	**30**	**60**	**120**	**240**	**480**	**960**	**8**	**15**	**30**	**60**	**120**	**240**	**480**	**960**
1	5.0	1	18.24	17.51	16.63	15.68	14.67	13.63	12.56	11.50	0.059	0.069	0.080	0.091	0.101	0.112	0.123	0.133
		2	18.18	17.06	15.84	14.64	13.47	12.34	11.26	10.22	0.098	0.104	0.111	0.117	0.123	0.129	0.136	0.142
		3	20.67	19.69	18.50	17.21	15.85	14.46	13.06	11.68	0.071	0.083	0.097	0.112	0.126	0.140	0.154	0.168
		4	19.23	18.34	17.25	16.09	14.87	13.62	12.36	11.13	0.070	0.082	0.095	0.107	0.120	0.133	0.146	0.159
		5	20.44	19.39	18.18	16.93	15.67	14.41	13.16	11.95	0.080	0.088	0.098	0.107	0.116	0.126	0.135	0.144
		Avg	**19.35**	**18.40**	**17.28**	**16.11**	**14.91**	**13.69**	**12.48**	**11.29**	**0.076**	**0.085**	**0.096**	**0.107**	**0.117**	**0.128**	**0.139**	**0.149**
		StdDev	**1.18**	**1.14**	**1.09**	**1.03**	**0.95**	**0.86**	**0.76**	**0.67**	**0.015**	**0.013**	**0.011**	**0.010**	**0.010**	**0.010**	**0.012**	**0.014**
2	5.0	1	17.57	17.08	16.40	15.59	14.67	13.67	12.61	11.51	0.038	0.052	0.066	0.080	0.095	0.109	0.124	0.138
		2	17.05	16.09	15.02	13.93	12.85	11.78	10.74	9.74	0.088	0.096	0.104	0.112	0.121	0.129	0.138	0.146
		3	20.28	19.01	17.64	16.30	15.01	13.76	12.57	11.43	0.100	0.105	0.111	0.117	0.122	0.128	0.134	0.139
		4	21.74	20.79	19.64	18.39	17.09	15.74	14.38	13.02	0.065	0.076	0.088	0.100	0.112	0.125	0.137	0.149
		5	16.00	15.41	14.69	13.91	13.08	12.22	11.33	10.43	0.055	0.064	0.074	0.084	0.094	0.104	0.114	0.124
		Avg	**18.53**	**17.68**	**16.68**	**15.63**	**14.54**	**13.43**	**12.32**	**11.23**	**0.069**	**0.079**	**0.089**	**0.099**	**0.109**	**0.119**	**0.129**	**0.139**
		StdDev	**2.39**	**2.21**	**2.03**	**1.87**	**1.71**	**1.56**	**1.40**	**1.24**	**0.025**	**0.022**	**0.019**	**0.016**	**0.014**	**0.012**	**0.010**	**0.010**
Avg	**5.0**	**---**	**18.94**	**18.04**	**16.98**	**15.87**	**14.72**	**13.56**	**12.40**	**11.26**	**0.073**	**0.082**	**0.092**	**0.103**	**0.113**	**0.123**	**0.134**	**0.144**
StdDev		**---**	**1.83**	**1.70**	**1.57**	**1.44**	**1.32**	**1.19**	**1.07**	**0.94**	**0.020**	**0.017**	**0.015**	**0.013**	**0.012**	**0.011**	**0.012**	**0.012**

Table B.26 *BBR* Mixture Data for *9.5-15/CM-4c* at -12 C

Specimen	V_a		Test Time (sec) and Mixture Stiffness (GPa)								Test Time (sec) and Mixture m-value							
Rep	**(%)**	**Rep**	**8**	**15**	**30**	**60**	**120**	**240**	**480**	**960**	**8**	**15**	**30**	**60**	**120**	**240**	**480**	**960**
1	5.0	1	12.34	11.65	10.83	9.98	9.11	8.23	7.37	6.54	0.086	0.098	0.112	0.125	0.139	0.153	0.166	0.180
		2	18.09	17.02	15.71	14.31	12.85	11.39	9.95	8.58	0.088	0.106	0.125	0.145	0.165	0.184	0.204	0.224
		3	13.82	12.86	11.78	10.69	9.62	8.57	7.57	6.63	0.108	0.120	0.133	0.146	0.159	0.173	0.186	0.199
		4	18.18	17.04	15.68	14.24	12.76	11.30	9.87	8.52	0.095	0.111	0.130	0.148	0.167	0.185	0.204	0.222
		5	16.64	15.44	14.06	12.66	11.27	9.92	8.63	7.43	0.112	0.127	0.143	0.160	0.176	0.192	0.209	0.225
		Avg	**15.81**	**14.80**	**13.61**	**12.37**	**11.12**	**9.88**	**8.68**	**7.54**	**0.098**	**0.112**	**0.129**	**0.145**	**0.161**	**0.177**	**0.194**	**0.210**
		StdDev	**2.62**	**2.45**	**2.23**	**1.99**	**1.73**	**1.48**	**1.22**	**0.99**	**0.012**	**0.011**	**0.012**	**0.012**	**0.014**	**0.016**	**0.018**	**0.020**
2	5.0	1	17.56	16.28	14.84	13.40	11.99	10.63	9.34	8.13	0.115	0.127	0.140	0.154	0.167	0.180	0.194	0.207
		2	17.12	15.88	14.51	13.16	11.83	10.55	9.33	8.19	0.114	0.124	0.136	0.148	0.159	0.171	0.183	0.195
		3	18.09	16.82	15.34	13.81	12.28	10.78	9.34	7.99	0.108	0.124	0.142	0.161	0.179	0.197	0.215	0.234
		4	17.82	16.44	14.96	13.52	12.13	10.82	9.59	8.45	0.124	0.132	0.141	0.151	0.160	0.169	0.179	0.188
		5	19.76	18.75	17.49	16.12	14.67	13.20	11.73	10.29	0.075	0.091	0.109	0.127	0.144	0.162	0.179	0.197
		Avg	**18.07**	**16.83**	**15.43**	**14.00**	**12.58**	**11.20**	**9.87**	**8.61**	**0.107**	**0.120**	**0.134**	**0.148**	**0.162**	**0.176**	**0.190**	**0.204**
		StdDev	**1.01**	**1.12**	**1.19**	**1.21**	**1.18**	**1.13**	**1.05**	**0.96**	**0.019**	**0.016**	**0.014**	**0.013**	**0.013**	**0.014**	**0.015**	**0.018**
Avg	**5.0**	**---**	**16.94**	**15.82**	**14.52**	**13.19**	**11.85**	**10.54**	**9.27**	**8.07**	**0.102**	**0.116**	**0.131**	**0.146**	**0.162**	**0.177**	**0.192**	**0.207**
StdDev		**---**	**2.22**	**2.09**	**1.94**	**1.77**	**1.60**	**1.42**	**1.24**	**1.08**	**0.016**	**0.014**	**0.012**	**0.012**	**0.012**	**0.014**	**0.016**	**0.018**

Table B.27 *BBR* Mixture Data for *9.5-15/CM-4c* at -06 C

Specimen	V_a		Test Time (sec) and Mixture Stiffness (GPa)								Test Time (sec) and Mixture m-value							
Rep	**(%)**	**Rep**	**8**	**15**	**30**	**60**	**120**	**240**	**480**	**960**	**8**	**15**	**30**	**60**	**120**	**240**	**480**	**960**
1	5.0	1	13.33	12.34	11.17	9.97	8.77	7.61	6.50	5.48	0.114	0.133	0.154	0.174	0.195	0.216	0.237	0.257
		2	12.03	11.10	10.05	9.01	7.99	7.02	6.10	5.25	0.122	0.135	0.150	0.165	0.180	0.195	0.210	0.225
		3	9.48	8.68	7.79	6.90	6.03	5.21	4.44	3.73	0.131	0.148	0.166	0.185	0.203	0.221	0.240	0.258
		4	13.07	12.09	10.93	9.74	8.54	7.38	6.27	5.26	0.114	0.134	0.156	0.178	0.200	0.222	0.244	0.266
		5	13.95	12.77	11.40	10.02	8.66	7.37	6.17	5.08	0.130	0.151	0.175	0.198	0.222	0.245	0.269	0.292
		Avg	**12.37**	**11.39**	**10.27**	**9.13**	**8.00**	**6.91**	**5.90**	**4.96**	**0.122**	**0.140**	**0.160**	**0.180**	**0.200**	**0.220**	**0.240**	**0.260**
		StdDev	**1.76**	**1.64**	**1.48**	**1.31**	**1.14**	**0.98**	**0.83**	**0.70**	**0.008**	**0.008**	**0.010**	**0.012**	**0.015**	**0.018**	**0.021**	**0.024**
2	5.0	1	10.58	9.74	8.78	7.81	6.86	5.95	5.09	4.30	0.123	0.140	0.159	0.178	0.197	0.216	0.234	0.253
		2	12.55	11.51	10.33	9.16	8.02	6.93	5.92	4.98	0.129	0.146	0.164	0.183	0.201	0.220	0.238	0.257
		3	11.45	10.45	9.35	8.26	7.22	6.24	5.32	4.49	0.137	0.153	0.169	0.186	0.203	0.220	0.237	0.253
		4	14.28	13.06	11.64	10.20	8.79	7.44	6.20	5.07	0.131	0.154	0.178	0.203	0.227	0.252	0.277	0.301
		5	13.16	12.14	10.96	9.75	8.56	7.41	6.33	5.33	0.120	0.138	0.158	0.178	0.198	0.218	0.238	0.258
		Avg	**12.40**	**11.38**	**10.21**	**9.04**	**7.89**	**6.79**	**5.77**	**4.83**	**0.128**	**0.146**	**0.166**	**0.186**	**0.205**	**0.225**	**0.245**	**0.265**
		StdDev	**1.45**	**1.32**	**1.16**	**1.00**	**0.83**	**0.68**	**0.54**	**0.43**	**0.007**	**0.007**	**0.008**	**0.010**	**0.013**	**0.015**	**0.018**	**0.021**
Avg	**5.0**	**---**	**12.39**	**11.39**	**10.24**	**9.08**	**7.94**	**6.85**	**5.83**	**4.90**	**0.125**	**0.143**	**0.163**	**0.183**	**0.203**	**0.223**	**0.242**	**0.262**
StdDev		**---**	**1.52**	**1.40**	**1.25**	**1.10**	**0.94**	**0.80**	**0.66**	**0.55**	**0.008**	**0.008**	**0.009**	**0.011**	**0.013**	**0.016**	**0.019**	**0.021**

Table B.28 *BBR* Mixture Data for *9.5-25/RM-1* at -24 C

Specimen	V_a		Test Time (sec) and Mixture Stiffness (GPa)								Test Time (sec) and Mixture m-value							
Rep	**(%)**	**Rep**	**8**	**15**	**30**	**60**	**120**	**240**	**480**	**960**	**8**	**15**	**30**	**60**	**120**	**240**	**480**	**960**
1	4.0	1	19.41	18.75	17.93	17.03	16.07	15.06	14.02	12.95	0.050	0.059	0.069	0.079	0.089	0.099	0.109	0.119
		2	16.95	16.39	15.68	14.89	14.05	13.16	12.24	11.30	0.049	0.059	0.069	0.079	0.089	0.100	0.110	0.120
		3	19.24	18.85	18.26	17.53	16.67	15.70	14.65	13.55	0.027	0.039	0.052	0.066	0.079	0.093	0.106	0.120
		Avg	**18.53**	**17.99**	**17.29**	**16.49**	**15.60**	**14.64**	**13.64**	**12.60**	**0.042**	**0.052**	**0.063**	**0.075**	**0.086**	**0.097**	**0.108**	**0.119**
		StdDev	**1.37**	**1.39**	**1.41**	**1.40**	**1.37**	**1.32**	**1.25**	**1.17**	**0.013**	**0.012**	**0.010**	**0.008**	**0.006**	**0.004**	**0.002**	**0.001**
2	3.9	1	19.82	19.30	18.64	17.89	17.08	16.20	15.28	14.33	0.038	0.046	0.055	0.063	0.072	0.080	0.089	0.097
		2	21.65	21.02	20.22	19.31	18.31	17.24	16.13	14.98	0.042	0.051	0.061	0.071	0.082	0.092	0.102	0.112
		3*	8.48	8.41	8.32	8.22	8.13	8.02	7.92	7.81	0.014	0.015	0.016	0.017	0.018	0.019	0.020	0.021
		Avg	**20.74**	**20.16**	**19.43**	**18.60**	**17.70**	**16.72**	**15.71**	**14.66**	**0.040**	**0.049**	**0.058**	**0.067**	**0.077**	**0.086**	**0.096**	**0.105**
		StdDev	**1.29**	**1.22**	**1.12**	**1.00**	**0.87**	**0.74**	**0.60**	**0.46**	**0.003**	**0.004**	**0.004**	**0.006**	**0.007**	**0.008**	**0.009**	**0.011**
Avg	**4.0**	**---**	**19.41**	**18.86**	**18.15**	**17.33**	**16.44**	**15.47**	**14.46**	**13.42**	**0.041**	**0.051**	**0.061**	**0.072**	**0.082**	**0.093**	**0.103**	**0.114**
StdDev		**---**	**1.68**	**1.66**	**1.63**	**1.61**	**1.57**	**1.52**	**1.47**	**1.41**	**0.009**	**0.009**	**0.008**	**0.007**	**0.007**	**0.008**	**0.009**	**0.010**

* Outlier that was omitted from analysis.

Table B.29 *BBR* Mixture Data for *9.5-25/RM-1* at -18 C

Specimen	V_a		Test Time (sec) and Mixture Stiffness (GPa)								Test Time (sec) and Mixture m-value							
Rep	**(%)**	**Rep**	**8**	**15**	**30**	**60**	**120**	**240**	**480**	**960**	**8**	**15**	**30**	**60**	**120**	**240**	**480**	**960**
1	4.0	1	19.18	18.38	17.36	16.24	15.05	13.81	12.54	11.29	0.062	0.075	0.089	0.103	0.117	0.131	0.145	0.159
		2	17.68	17.01	16.16	15.21	14.19	13.12	12.02	10.91	0.056	0.067	0.081	0.094	0.107	0.120	0.133	0.146
		3	19.07	18.41	17.58	16.66	15.65	14.59	13.49	12.38	0.050	0.061	0.072	0.084	0.095	0.107	0.119	0.130
		Avg	**18.64**	**17.93**	**17.03**	**16.04**	**14.96**	**13.84**	**12.69**	**11.52**	**0.056**	**0.068**	**0.081**	**0.094**	**0.106**	**0.119**	**0.132**	**0.145**
		StdDev	**0.83**	**0.80**	**0.76**	**0.74**	**0.73**	**0.74**	**0.75**	**0.76**	**0.006**	**0.007**	**0.008**	**0.010**	**0.011**	**0.012**	**0.013**	**0.015**
2	3.9	1	19.61	19.19	18.44	17.42	16.17	14.77	13.25	11.70	0.023	0.045	0.070	0.094	0.119	0.144	0.168	0.193
		2	21.17	20.32	19.32	18.26	17.17	16.04	14.91	13.77	0.061	0.069	0.077	0.085	0.094	0.102	0.110	0.118
		3	15.69	15.23	14.57	13.78	12.88	11.91	10.88	9.83	0.041	0.056	0.072	0.089	0.105	0.122	0.138	0.155
		Avg	**18.82**	**18.25**	**17.44**	**16.49**	**15.41**	**14.24**	**13.01**	**11.76**	**0.042**	**0.057**	**0.073**	**0.090**	**0.106**	**0.122**	**0.139**	**0.155**
		StdDev	**2.82**	**2.68**	**2.53**	**2.38**	**2.24**	**2.12**	**2.02**	**1.97**	**0.019**	**0.012**	**0.004**	**0.005**	**0.013**	**0.021**	**0.029**	**0.037**
Avg	**4.0**	**---**	**18.73**	**18.09**	**17.24**	**16.26**	**15.19**	**14.04**	**12.85**	**11.64**	**0.05**	**0.06**	**0.08**	**0.09**	**0.11**	**0.12**	**0.14**	**0.15**
StdDev		**---**	**1.86**	**1.77**	**1.69**	**1.60**	**1.51**	**1.44**	**1.38**	**1.34**	**0.01**	**0.01**	**0.01**	**0.01**	**0.01**	**0.02**	**0.02**	**0.03**

Table B.30 *BBR* Mixture Data for *9.5-25/RM-1* at -12 C

Specimen	V_a		Test Time (sec) and Mixture Stiffness (GPa)								Test Time (sec) and Mixture m-value							
Rep	**(%)**	**Rep**	**8**	**15**	**30**	**60**	**120**	**240**	**480**	**960**	**8**	**15**	**30**	**60**	**120**	**240**	**480**	**960**
1	4.0	1	19.69	18.85	17.85	16.80	15.70	14.59	13.46	12.34	0.065	0.074	0.083	0.092	0.102	0.111	0.121	0.130
		2	17.68	16.83	15.78	14.62	13.40	12.15	10.89	9.66	0.071	0.086	0.102	0.118	0.134	0.150	0.166	0.182
		3	15.03	14.14	13.11	12.04	10.96	9.88	8.82	7.81	0.090	0.102	0.116	0.129	0.143	0.156	0.170	0.183
		Avg	**17.46**	**16.61**	**15.58**	**14.49**	**13.36**	**12.21**	**11.06**	**9.93**	**0.075**	**0.087**	**0.100**	**0.113**	**0.126**	**0.139**	**0.152**	**0.165**
		StdDev	**2.34**	**2.36**	**2.38**	**2.38**	**2.37**	**2.35**	**2.32**	**2.28**	**0.013**	**0.014**	**0.016**	**0.019**	**0.021**	**0.024**	**0.027**	**0.030**
2	3.9	1	20.53	19.53	18.30	16.99	15.62	14.22	12.82	11.44	0.074	0.086	0.100	0.114	0.128	0.143	0.157	0.171
		2	16.23	15.55	14.66	13.65	12.55	11.40	10.22	9.06	0.060	0.076	0.094	0.112	0.130	0.148	0.166	0.184
		3	18.19	17.30	16.23	15.09	13.91	12.71	11.51	10.34	0.074	0.086	0.099	0.111	0.124	0.136	0.149	0.162
		Avg	**18.32**	**17.46**	**16.40**	**15.24**	**14.02**	**12.77**	**11.52**	**10.28**	**0.069**	**0.083**	**0.098**	**0.113**	**0.127**	**0.142**	**0.157**	**0.172**
		StdDev	**2.16**	**1.99**	**1.83**	**1.68**	**1.54**	**1.41**	**1.30**	**1.19**	**0.008**	**0.006**	**0.003**	**0.002**	**0.003**	**0.006**	**0.008**	**0.011**
Avg	**4.0**	**---**	**17.89**	**17.03**	**15.99**	**14.87**	**13.69**	**12.49**	**11.29**	**10.11**	**0.07**	**0.08**	**0.10**	**0.11**	**0.13**	**0.14**	**0.15**	**0.17**
StdDev		**---**	**2.06**	**2.01**	**1.95**	**1.89**	**1.82**	**1.76**	**1.70**	**1.64**	**0.01**	**0.01**	**0.01**	**0.01**	**0.01**	**0.02**	**0.02**	**0.02**

Table B.31 *BBR* Mixture Data for *9.5-25/RM-1* at -06 C

Specimen	V_a		Test Time (sec) and Mixture Stiffness (GPa)								Test Time (sec) and Mixture m-value							
Rep	**(%)**	**Rep**	**8**	**15**	**30**	**60**	**120**	**240**	**480**	**960**	**8**	**15**	**30**	**60**	**120**	**240**	**480**	**960**
1	4.0	1	14.20	13.24	12.09	10.90	9.70	8.52	7.38	6.31	0.103	0.121	0.140	0.159	0.178	0.197	0.216	0.235
		2	15.10	14.13	12.98	11.76	10.52	9.28	8.08	6.95	0.096	0.114	0.133	0.152	0.171	0.190	0.209	0.228
		3	11.55	10.94	10.12	9.18	8.16	7.12	6.08	5.10	0.073	0.099	0.127	0.155	0.184	0.212	0.240	0.269
		Avg	**13.62**	**12.77**	**11.73**	**10.61**	**9.46**	**8.31**	**7.18**	**6.12**	**0.091**	**0.111**	**0.133**	**0.155**	**0.177**	**0.200**	**0.222**	**0.244**
		StdDev	**1.85**	**1.65**	**1.46**	**1.32**	**1.20**	**1.10**	**1.01**	**0.94**	**0.016**	**0.011**	**0.006**	**0.004**	**0.006**	**0.011**	**0.016**	**0.022**
2	3.9	1	13.99	13.06	11.94	10.78	9.59	8.42	7.29	6.23	0.101	0.119	0.138	0.158	0.178	0.198	0.217	0.237
		2	17.46	16.20	14.73	13.24	11.76	10.32	8.95	7.67	0.112	0.128	0.145	0.162	0.180	0.197	0.214	0.231
		3	12.94	12.25	11.35	10.35	9.29	8.20	7.13	6.10	0.077	0.098	0.121	0.145	0.168	0.191	0.214	0.237
		Avg	**14.80**	**13.83**	**12.68**	**11.46**	**10.22**	**8.98**	**7.79**	**6.67**	**0.097**	**0.115**	**0.135**	**0.155**	**0.175**	**0.195**	**0.215**	**0.235**
		StdDev	**2.37**	**2.08**	**1.81**	**1.56**	**1.35**	**1.17**	**1.01**	**0.87**	**0.018**	**0.015**	**0.012**	**0.009**	**0.006**	**0.004**	**0.002**	**0.003**
Avg	**4.0**	**---**	**14.21**	**13.30**	**12.20**	**11.04**	**9.84**	**8.64**	**7.49**	**6.39**	**0.094**	**0.113**	**0.134**	**0.155**	**0.176**	**0.197**	**0.219**	**0.240**
StdDev		**---**	**2.01**	**1.78**	**1.56**	**1.37**	**1.21**	**1.08**	**0.96**	**0.86**	**0.016**	**0.012**	**0.009**	**0.006**	**0.006**	**0.008**	**0.011**	**0.015**

Table B.32 *BBR* Mixture Data for *9.5-25/RM-2* at -24 C

Specimen	V_a		Test Time (sec) and Mixture Stiffness (GPa)								Test Time (sec) and Mixture m-value							
Rep	**(%)**	**Rep**	**8**	**15**	**30**	**60**	**120**	**240**	**480**	**960**	**8**	**15**	**30**	**60**	**120**	**240**	**480**	**960**
1	4.2	1	23.20	22.54	21.71	20.77	19.74	18.64	17.49	16.30	0.041	0.050	0.059	0.069	0.078	0.087	0.097	0.106
		2	19.66	19.04	18.26	17.38	16.41	15.39	14.32	13.23	0.046	0.055	0.066	0.077	0.088	0.098	0.109	0.120
		3	19.50	18.95	18.22	17.38	16.44	15.42	14.35	13.24	0.040	0.051	0.063	0.074	0.086	0.098	0.110	0.122
		Avg	**20.78**	**20.18**	**19.40**	**18.51**	**17.53**	**16.48**	**15.38**	**14.25**	**0.042**	**0.052**	**0.063**	**0.073**	**0.084**	**0.095**	**0.105**	**0.116**
		StdDev	**2.09**	**2.05**	**2.00**	**1.96**	**1.91**	**1.87**	**1.82**	**1.77**	**0.003**	**0.003**	**0.003**	**0.004**	**0.005**	**0.006**	**0.007**	**0.009**
2	4.7	1	18.37	17.87	17.24	16.54	15.78	14.98	14.14	13.28	0.041	0.048	0.056	0.063	0.071	0.079	0.087	0.095
		2	24.47	23.69	22.64	21.43	20.09	18.65	17.14	15.59	0.045	0.058	0.072	0.086	0.101	0.115	0.129	0.143
		3	22.54	22.03	21.27	20.33	19.24	18.03	16.72	15.34	0.030	0.043	0.058	0.072	0.087	0.102	0.116	0.131
		Avg	**21.79**	**21.19**	**20.38**	**19.44**	**18.37**	**17.22**	**16.00**	**14.74**	**0.038**	**0.050**	**0.062**	**0.074**	**0.086**	**0.099**	**0.111**	**0.123**
		StdDev	**3.12**	**3.00**	**2.81**	**2.57**	**2.28**	**1.96**	**1.62**	**1.27**	**0.008**	**0.008**	**0.009**	**0.012**	**0.015**	**0.018**	**0.021**	**0.025**
Avg	**4.5**	**---**	**21.29**	**20.69**	**19.89**	**18.97**	**17.95**	**16.85**	**15.69**	**14.50**	**0.040**	**0.051**	**0.062**	**0.074**	**0.085**	**0.097**	**0.108**	**0.120**
StdDev		**---**	**2.44**	**2.36**	**2.25**	**2.10**	**1.94**	**1.76**	**1.58**	**1.40**	**0.006**	**0.005**	**0.006**	**0.008**	**0.010**	**0.012**	**0.015**	**0.017**

Table B.33 *BBR* Mixture Data for *9.5-25/RM-2* at -18 C

Specimen	V_a		Test Time (sec) and Mixture Stiffness (GPa)								Test Time (sec) and Mixture m-value							
Rep	**(%)**	**Rep**	**8**	**15**	**30**	**60**	**120**	**240**	**480**	**960**	**8**	**15**	**30**	**60**	**120**	**240**	**480**	**960**
1	4.2	1	11.45	11.33	11.01	10.52	9.88	9.12	8.27	7.38	0.006	0.028	0.053	0.078	0.103	0.128	0.153	0.178
		2	12.97	12.65	12.23	11.73	11.16	10.55	9.90	9.22	0.035	0.044	0.055	0.066	0.076	0.087	0.097	0.108
		3	22.33	21.46	20.41	19.29	18.12	16.91	15.68	14.45	0.059	0.068	0.077	0.086	0.095	0.104	0.113	0.122
		Avg	**15.58**	**15.15**	**14.55**	**13.85**	**13.06**	**12.19**	**11.29**	**10.35**	**0.033**	**0.047**	**0.062**	**0.077**	**0.091**	**0.106**	**0.121**	**0.136**
		StdDev	**5.89**	**5.51**	**5.11**	**4.75**	**4.43**	**4.15**	**3.89**	**3.67**	**0.027**	**0.020**	**0.013**	**0.010**	**0.014**	**0.021**	**0.029**	**0.037**
2	4.7	1	19.83	19.34	18.65	17.82	16.87	15.82	14.71	13.54	0.034	0.046	0.059	0.072	0.086	0.099	0.112	0.125
		2	18.32	17.57	16.71	15.81	14.89	13.95	13.01	12.07	0.063	0.069	0.076	0.083	0.090	0.097	0.104	0.111
		3*	7.20	7.13	7.03	6.90	6.75	6.57	6.37	6.16	0.012	0.017	0.023	0.029	0.035	0.041	0.047	0.053
		Avg	**19.08**	**18.46**	**17.68**	**16.82**	**15.88**	**14.89**	**13.86**	**12.81**	**0.049**	**0.058**	**0.068**	**0.078**	**0.088**	**0.098**	**0.108**	**0.118**
		StdDev	**1.07**	**1.25**	**1.37**	**1.42**	**1.40**	**1.32**	**1.20**	**1.04**	**0.021**	**0.016**	**0.012**	**0.008**	**0.003**	**0.001**	**0.006**	**0.010**
Avg	**4.5**	**---**	**16.98**	**16.47**	**15.80**	**15.03**	**14.18**	**13.27**	**12.31**	**11.33**	**0.039**	**0.051**	**0.064**	**0.077**	**0.090**	**0.103**	**0.116**	**0.129**
StdDev		**---**	**4.62**	**4.34**	**4.06**	**3.80**	**3.57**	**3.35**	**3.15**	**2.97**	**0.023**	**0.017**	**0.012**	**0.008**	**0.010**	**0.015**	**0.022**	**0.028**

* Outlier that was omitted from analysis.

Table B.34 *BBR* Mixture Data for *9.5-25/RM-2* at -12 C

Specimen	V_a		Test Time (sec) and Mixture Stiffness (GPa)								Test Time (sec) and Mixture m-value							
Rep	**(%)**	**Rep**	**8**	**15**	**30**	**60**	**120**	**240**	**480**	**960**	**8**	**15**	**30**	**60**	**120**	**240**	**480**	**960**
1	4.2	1	16.35	15.55	14.57	13.52	12.42	11.29	10.17	9.07	0.073	0.086	0.101	0.115	0.130	0.144	0.159	0.173
		2	21.18	20.26	19.09	17.77	16.35	14.88	13.38	11.89	0.063	0.078	0.095	0.111	0.128	0.145	0.162	0.178
		3	17.36	16.45	15.29	14.00	12.63	11.23	9.85	8.50	0.076	0.095	0.116	0.138	0.159	0.180	0.201	0.222
		Avg	**18.30**	**17.42**	**16.31**	**15.10**	**13.80**	**12.47**	**11.13**	**9.82**	**0.071**	**0.087**	**0.104**	**0.121**	**0.139**	**0.156**	**0.174**	**0.191**
		StdDev	**2.55**	**2.50**	**2.43**	**2.33**	**2.21**	**2.09**	**1.95**	**1.81**	**0.007**	**0.009**	**0.011**	**0.014**	**0.017**	**0.020**	**0.024**	**0.027**
2	4.7	1	17.78	17.14	16.27	15.24	14.10	12.89	11.62	10.35	0.050	0.066	0.085	0.103	0.121	0.140	0.158	0.176
		2	22.09	20.81	19.33	17.81	16.29	14.77	13.29	11.87	0.090	0.101	0.112	0.124	0.135	0.147	0.158	0.170
		3	21.46	20.28	18.90	17.46	15.98	14.50	13.04	11.62	0.084	0.096	0.108	0.121	0.134	0.147	0.160	0.172
		Avg	**20.44**	**19.41**	**18.17**	**16.84**	**15.46**	**14.05**	**12.65**	**11.28**	**0.075**	**0.087**	**0.102**	**0.116**	**0.130**	**0.144**	**0.158**	**0.173**
		StdDev	**2.33**	**1.98**	**1.66**	**1.39**	**1.18**	**1.02**	**0.90**	**0.81**	**0.022**	**0.018**	**0.015**	**0.011**	**0.008**	**0.004**	**0.001**	**0.003**
Avg	**4.5**	**---**	**19.37**	**18.42**	**17.24**	**15.97**	**14.63**	**13.26**	**11.89**	**10.55**	**0.073**	**0.087**	**0.103**	**0.119**	**0.134**	**0.150**	**0.166**	**0.182**
StdDev		**---**	**2.48**	**2.30**	**2.12**	**1.96**	**1.83**	**1.71**	**1.59**	**1.49**	**0.015**	**0.013**	**0.012**	**0.012**	**0.013**	**0.015**	**0.017**	**0.020**

Table B.35 *BBR* Mixture Data for *9.5-25/RM-2* at -06 C

Specimen	V_a		Test Time (sec) and Mixture Stiffness (GPa)								Test Time (sec) and Mixture m-value							
Rep	**(%)**	**Rep**	**8**	**15**	**30**	**60**	**120**	**240**	**480**	**960**	**8**	**15**	**30**	**60**	**120**	**240**	**480**	**960**
1	4.2	1	12.56	11.74	10.79	9.81	8.83	7.87	6.94	6.06	0.101	0.114	0.129	0.144	0.159	0.174	0.189	0.204
		2	14.28	13.45	12.44	11.37	10.27	9.15	8.06	7.02	0.088	0.104	0.121	0.139	0.156	0.174	0.192	0.209
		3	15.17	14.32	13.22	12.00	10.70	9.39	8.09	6.86	0.080	0.103	0.128	0.152	0.177	0.202	0.227	0.251
		Avg	**14.00**	**13.17**	**12.15**	**11.06**	**9.93**	**8.80**	**7.70**	**6.64**	**0.090**	**0.107**	**0.126**	**0.145**	**0.164**	**0.183**	**0.202**	**0.221**
		StdDev	**1.33**	**1.31**	**1.24**	**1.13**	**0.98**	**0.82**	**0.66**	**0.51**	**0.010**	**0.006**	**0.004**	**0.007**	**0.011**	**0.016**	**0.021**	**0.026**
2	4.7	1	16.17	15.11	13.88	12.63	11.37	10.13	8.94	7.81	0.101	0.115	0.129	0.144	0.159	0.174	0.188	0.203
		2	10.95	10.29	9.46	8.58	7.66	6.73	5.83	4.97	0.089	0.109	0.131	0.153	0.175	0.197	0.219	0.241
		3	14.03	13.16	12.07	10.91	9.70	8.50	7.33	6.22	0.092	0.113	0.135	0.158	0.180	0.202	0.225	0.247
		Avg	**13.71**	**12.85**	**11.81**	**10.70**	**9.58**	**8.45**	**7.37**	**6.33**	**0.094**	**0.112**	**0.132**	**0.152**	**0.171**	**0.191**	**0.211**	**0.230**
		StdDev	**2.62**	**2.43**	**2.22**	**2.03**	**1.86**	**1.70**	**1.56**	**1.42**	**0.006**	**0.003**	**0.003**	**0.007**	**0.011**	**0.015**	**0.020**	**0.024**
Avg	**4.5**	**---**	**13.86**	**13.01**	**11.98**	**10.88**	**9.76**	**8.63**	**7.53**	**6.49**	**0.092**	**0.109**	**0.129**	**0.148**	**0.168**	**0.187**	**0.207**	**0.226**
StdDev		**---**	**1.87**	**1.75**	**1.62**	**1.48**	**1.34**	**1.21**	**1.08**	**0.97**	**0.008**	**0.005**	**0.005**	**0.007**	**0.011**	**0.015**	**0.019**	**0.023**

Table B.36 *BBR* Mixture Data for *9.5-50/RM-1* at -24 C

Specimen	V_a		Test Time (sec) and Mixture Stiffness (GPa)								Test Time (sec) and Mixture m-value							
Rep	**(%)**	**Rep**	**8**	**15**	**30**	**60**	**120**	**240**	**480**	**960**	**8**	**15**	**30**	**60**	**120**	**240**	**480**	**960**
1	4.7	1	26.57	25.35	24.07	22.83	21.65	20.51	19.42	18.38	0.074	0.075	0.076	0.076	0.077	0.078	0.079	0.080
		2	26.55	25.68	24.47	23.02	21.38	19.62	17.77	15.90	0.045	0.061	0.079	0.097	0.115	0.133	0.151	0.169
		3	26.27	25.22	24.04	22.84	21.62	20.41	19.20	18.01	0.063	0.067	0.072	0.076	0.081	0.086	0.090	0.095
		Avg	**26.47**	**25.42**	**24.19**	**22.89**	**21.55**	**20.18**	**18.80**	**17.43**	**0.061**	**0.068**	**0.075**	**0.083**	**0.091**	**0.099**	**0.107**	**0.115**
		StdDev	**0.17**	**0.24**	**0.24**	**0.11**	**0.15**	**0.49**	**0.89**	**1.34**	**0.015**	**0.007**	**0.004**	**0.012**	**0.021**	**0.030**	**0.039**	**0.048**
2	4.3	1*	6.81	6.75	6.66	6.57	6.45	6.33	6.19	6.04	0.013	0.016	0.020	0.023	0.027	0.030	0.034	0.037
		2	23.81	22.70	21.43	20.11	18.76	17.40	16.05	14.71	0.072	0.079	0.088	0.096	0.104	0.113	0.121	0.129
		3	22.16	21.54	20.66	19.62	18.43	17.13	15.76	14.35	0.039	0.052	0.067	0.083	0.098	0.113	0.128	0.143
		Avg	**22.99**	**22.12**	**21.05**	**19.87**	**18.60**	**17.27**	**15.91**	**14.53**	**0.056**	**0.066**	**0.078**	**0.090**	**0.101**	**0.113**	**0.125**	**0.136**
		StdDev	**1.17**	**0.82**	**0.54**	**0.35**	**0.23**	**0.19**	**0.21**	**0.25**	**0.023**	**0.019**	**0.015**	**0.009**	**0.004**	**0.000**	**0.005**	**0.010**
Avg	**4.5**	**---**	**25.07**	**24.10**	**22.93**	**21.68**	**20.37**	**19.01**	**17.64**	**16.27**	**0.059**	**0.067**	**0.076**	**0.086**	**0.095**	**0.105**	**0.114**	**0.123**
StdDev		**---**	**2.00**	**1.86**	**1.75**	**1.67**	**1.63**	**1.64**	**1.71**	**1.85**	**0.016**	**0.011**	**0.008**	**0.010**	**0.016**	**0.022**	**0.029**	**0.036**

* Outlier that was omitted from analysis.

Table B.37 *BBR* Mixture Data for *9.5-50/RM-1* at -18 C

Specimen	V_a		Test Time (sec) and Mixture Stiffness (GPa)								Test Time (sec) and Mixture m-value							
Rep	**(%)**	**Rep**	**8**	**15**	**30**	**60**	**120**	**240**	**480**	**960**	**8**	**15**	**30**	**60**	**120**	**240**	**480**	**960**
1	4.7	1	19.90	19.22	18.37	17.43	16.41	15.33	14.22	13.10	0.050	0.060	0.071	0.082	0.092	0.103	0.114	0.124
		2	20.40	19.63	18.64	17.52	16.32	15.05	13.74	12.43	0.055	0.068	0.082	0.096	0.110	0.124	0.138	0.152
		3	18.65	17.99	17.14	16.19	15.16	14.07	12.95	11.81	0.052	0.063	0.076	0.089	0.101	0.114	0.127	0.139
		Avg	**19.65**	**18.95**	**18.05**	**17.05**	**15.96**	**14.82**	**13.64**	**12.44**	**0.052**	**0.064**	**0.076**	**0.089**	**0.101**	**0.114**	**0.126**	**0.139**
		StdDev	**0.90**	**0.85**	**0.80**	**0.74**	**0.69**	**0.66**	**0.64**	**0.65**	**0.002**	**0.004**	**0.005**	**0.007**	**0.009**	**0.010**	**0.012**	**0.014**
2	4.3	1	19.24	18.45	17.59	16.74	15.91	15.09	14.29	13.51	0.065	0.068	0.070	0.073	0.075	0.077	0.080	0.082
		2	14.80	14.25	13.61	12.92	12.20	11.45	10.70	9.93	0.056	0.063	0.071	0.079	0.087	0.095	0.103	0.110
		3	18.90	18.28	17.46	16.52	15.47	14.36	13.20	12.01	0.047	0.059	0.073	0.087	0.101	0.115	0.129	0.142
		Avg	**17.65**	**16.99**	**16.22**	**15.39**	**14.53**	**13.63**	**12.73**	**11.82**	**0.056**	**0.063**	**0.071**	**0.080**	**0.088**	**0.096**	**0.104**	**0.112**
		StdDev	**2.47**	**2.38**	**2.26**	**2.15**	**2.03**	**1.92**	**1.84**	**1.79**	**0.009**	**0.004**	**0.002**	**0.007**	**0.013**	**0.019**	**0.024**	**0.030**
Avg	**4.5**	**---**	**18.65**	**17.97**	**17.13**	**16.22**	**15.24**	**14.23**	**13.18**	**12.13**	**0.054**	**0.064**	**0.074**	**0.084**	**0.094**	**0.105**	**0.115**	**0.125**
StdDev		**---**	**1.99**	**1.92**	**1.82**	**1.70**	**1.57**	**1.44**	**1.33**	**1.25**	**0.006**	**0.004**	**0.004**	**0.008**	**0.012**	**0.017**	**0.021**	**0.026**

Table B.38 *BBR* Mixture Data for *9.5-50/RM-1* at -12 C

Specimen	V_a		Test Time (sec) and Mixture Stiffness (GPa)								Test Time (sec) and Mixture m-value							
Rep	**(%)**	**Rep**	**8**	**15**	**30**	**60**	**120**	**240**	**480**	**960**	**8**	**15**	**30**	**60**	**120**	**240**	**480**	**960**
1	4.7	1	24.28	23.37	22.14	20.73	19.18	17.53	15.84	14.14	0.053	0.069	0.086	0.104	0.121	0.138	0.155	0.173
		2*	8.08	7.96	7.79	7.60	7.39	7.15	6.89	6.62	0.022	0.027	0.033	0.039	0.044	0.050	0.056	0.061
		3	22.14	21.12	19.86	18.51	17.09	15.63	14.17	12.72	0.070	0.082	0.095	0.108	0.122	0.135	0.149	0.162
		Avg	**23.21**	**22.25**	**21.00**	**19.62**	**18.14**	**16.58**	**15.01**	**13.43**	**0.062**	**0.076**	**0.091**	**0.106**	**0.122**	**0.137**	**0.152**	**0.168**
		StdDev	**1.51**	**1.59**	**1.61**	**1.57**	**1.48**	**1.34**	**1.18**	**1.00**	**0.012**	**0.009**	**0.006**	**0.003**	**0.001**	**0.002**	**0.004**	**0.008**
2	4.3	1	22.67	21.81	20.65	19.32	17.85	16.28	14.68	13.07	0.054	0.070	0.088	0.105	0.123	0.141	0.159	0.176
		2	20.26	19.41	18.33	17.11	15.80	14.43	13.03	11.64	0.061	0.075	0.091	0.107	0.123	0.139	0.155	0.171
		3	20.96	20.16	19.19	18.14	17.03	15.89	14.72	13.55	0.057	0.066	0.076	0.086	0.096	0.105	0.115	0.125
		Avg	**21.30**	**20.46**	**19.39**	**18.19**	**16.89**	**15.53**	**14.14**	**12.75**	**0.057**	**0.070**	**0.085**	**0.099**	**0.114**	**0.128**	**0.143**	**0.157**
		StdDev	**1.24**	**1.23**	**1.18**	**1.10**	**1.03**	**0.98**	**0.96**	**0.99**	**0.004**	**0.004**	**0.008**	**0.012**	**0.016**	**0.020**	**0.024**	**0.028**
Avg	**4.5**	**---**	**22.06**	**21.17**	**20.03**	**18.76**	**17.39**	**15.95**	**14.49**	**13.02**	**0.059**	**0.072**	**0.087**	**0.102**	**0.117**	**0.132**	**0.147**	**0.161**
StdDev		**---**	**1.56**	**1.53**	**1.45**	**1.36**	**1.24**	**1.12**	**1.02**	**0.94**	**0.007**	**0.006**	**0.007**	**0.009**	**0.012**	**0.015**	**0.018**	**0.021**

* Outlier that was omitted from analysis.

Table B.39 *BBR* Mixture Data for *9.5-50/RM-1* at -06 C

Specimen	V_a		Test Time (sec) and Mixture Stiffness (GPa)								Test Time (sec) and Mixture m-value							
Rep	**(%)**	**Rep**	**8**	**15**	**30**	**60**	**120**	**240**	**480**	**960**	**8**	**15**	**30**	**60**	**120**	**240**	**480**	**960**
1	4.7	1	18.37	17.66	16.85	16.01	15.14	14.27	13.39	12.51	0.060	0.065	0.071	0.077	0.083	0.089	0.095	0.101
		2	13.95	13.16	12.21	11.20	10.16	9.12	8.10	7.11	0.086	0.100	0.116	0.132	0.148	0.164	0.180	0.196
		3	12.24	11.57	10.77	9.91	9.02	8.12	7.23	6.37	0.082	0.096	0.112	0.128	0.144	0.160	0.176	0.191
		Avg	**14.85**	**14.13**	**13.27**	**12.37**	**11.44**	**10.50**	**9.57**	**8.66**	**0.076**	**0.087**	**0.100**	**0.112**	**0.125**	**0.138**	**0.150**	**0.163**
		StdDev	**3.16**	**3.16**	**3.18**	**3.21**	**3.26**	**3.30**	**3.33**	**3.35**	**0.014**	**0.019**	**0.025**	**0.031**	**0.036**	**0.042**	**0.048**	**0.054**
2	4.3	1	18.41	17.40	16.19	14.91	13.59	12.26	10.95	9.68	0.083	0.097	0.111	0.126	0.141	0.156	0.171	0.185
		2	15.61	14.98	14.14	13.18	12.12	11.01	9.88	8.75	0.057	0.074	0.092	0.111	0.129	0.148	0.166	0.184
		3	15.63	14.75	13.75	12.74	11.72	10.71	9.72	8.76	0.088	0.096	0.106	0.116	0.125	0.135	0.144	0.154
		Avg	**16.55**	**15.71**	**14.69**	**13.61**	**12.48**	**11.33**	**10.18**	**9.06**	**0.076**	**0.089**	**0.103**	**0.118**	**0.132**	**0.146**	**0.160**	**0.175**
		StdDev	**1.61**	**1.47**	**1.31**	**1.15**	**0.98**	**0.82**	**0.67**	**0.53**	**0.016**	**0.013**	**0.010**	**0.008**	**0.008**	**0.011**	**0.014**	**0.018**
Avg	**4.5**	**---**	**15.70**	**14.92**	**13.98**	**12.99**	**11.96**	**10.91**	**9.88**	**8.86**	**0.076**	**0.088**	**0.101**	**0.115**	**0.128**	**0.142**	**0.155**	**0.169**
StdDev		**---**	**2.43**	**2.37**	**2.31**	**2.26**	**2.22**	**2.20**	**2.18**	**2.16**	**0.014**	**0.015**	**0.017**	**0.020**	**0.024**	**0.028**	**0.032**	**0.036**

Table B.40 *BBR* Mixture Data for *9.5-50/RM-2* at -24 C

Specimen	V_a		Test Time (sec) and Mixture Stiffness (GPa)								Test Time (sec) and Mixture m-value							
Rep	**(%)**	**Rep**	**8**	**15**	**30**	**60**	**120**	**240**	**480**	**960**	**8**	**15**	**30**	**60**	**120**	**240**	**480**	**960**
1	4.1	1	19.35	18.78	18.10	17.37	16.61	15.83	15.02	14.19	0.045	0.050	0.056	0.062	0.067	0.073	0.079	0.084
		2	19.76	19.23	18.49	17.61	16.61	15.51	14.35	13.14	0.037	0.049	0.064	0.078	0.092	0.106	0.120	0.134
		3	24.05	23.30	22.37	21.33	20.21	19.03	17.81	16.55	0.046	0.054	0.064	0.073	0.082	0.092	0.101	0.110
		Avg	**21.05**	**20.44**	**19.65**	**18.77**	**17.81**	**16.79**	**15.72**	**14.63**	**0.043**	**0.051**	**0.061**	**0.071**	**0.080**	**0.090**	**0.100**	**0.109**
		StdDev	**2.60**	**2.49**	**2.36**	**2.22**	**2.08**	**1.95**	**1.83**	**1.74**	**0.005**	**0.003**	**0.004**	**0.008**	**0.012**	**0.016**	**0.021**	**0.025**
2	4.5	1	21.34	20.60	19.44	18.00	16.33	14.54	12.69	10.86	0.043	0.069	0.097	0.126	0.154	0.182	0.211	0.239
		2	26.66	25.68	24.46	23.13	21.70	20.20	18.66	17.11	0.054	0.064	0.076	0.087	0.098	0.109	0.120	0.131
		3	23.45	22.61	21.52	20.31	18.99	17.60	16.16	14.71	0.053	0.064	0.077	0.090	0.103	0.116	0.129	0.142
		Avg	**23.82**	**22.96**	**21.81**	**20.48**	**19.01**	**17.44**	**15.84**	**14.22**	**0.050**	**0.066**	**0.083**	**0.101**	**0.118**	**0.136**	**0.153**	**0.171**
		StdDev	**2.68**	**2.56**	**2.52**	**2.57**	**2.68**	**2.83**	**3.00**	**3.15**	**0.006**	**0.003**	**0.012**	**0.022**	**0.031**	**0.040**	**0.050**	**0.059**
Avg	**4.3**	**---**	**22.43**	**21.70**	**20.73**	**19.63**	**18.41**	**17.12**	**15.78**	**14.43**	**0.046**	**0.059**	**0.072**	**0.086**	**0.099**	**0.113**	**0.126**	**0.140**
StdDev		**---**	**2.81**	**2.65**	**2.48**	**2.34**	**2.24**	**2.20**	**2.22**	**2.29**	**0.006**	**0.008**	**0.015**	**0.022**	**0.030**	**0.037**	**0.045**	**0.053**

Table B.41 *BBR* Mixture Data for *9.5-50/RM-2* at -18 C

Specimen	V_a		Test Time (sec) and Mixture Stiffness (GPa)								Test Time (sec) and Mixture m-value							
Rep	**(%)**	**Rep**	**8**	**15**	**30**	**60**	**120**	**240**	**480**	**960**	**8**	**15**	**30**	**60**	**120**	**240**	**480**	**960**
1	4.1	1	18.86	18.27	17.42	16.42	15.27	14.03	12.74	11.42	0.043	0.059	0.077	0.095	0.113	0.131	0.149	0.167
		2	21.76	21.12	20.20	19.09	17.83	16.45	14.99	13.51	0.040	0.055	0.073	0.090	0.107	0.125	0.142	0.159
		3	19.41	18.61	17.65	16.62	15.53	14.41	13.28	12.14	0.062	0.071	0.082	0.092	0.103	0.113	0.124	0.134
		Avg	**20.01**	**19.33**	**18.42**	**17.37**	**16.21**	**14.96**	**13.67**	**12.35**	**0.048**	**0.062**	**0.077**	**0.093**	**0.108**	**0.123**	**0.138**	**0.153**
		StdDev	**1.54**	**1.55**	**1.54**	**1.49**	**1.41**	**1.30**	**1.18**	**1.06**	**0.012**	**0.008**	**0.005**	**0.002**	**0.005**	**0.009**	**0.013**	**0.017**
2	4.5	1	21.22	20.64	19.81	18.83	17.70	16.47	15.17	13.82	0.037	0.051	0.066	0.081	0.096	0.112	0.127	0.142
		2	20.53	19.71	18.69	17.57	16.39	15.15	13.89	12.63	0.060	0.071	0.083	0.095	0.107	0.119	0.131	0.143
		3	27.87	26.97	25.79	24.44	22.96	21.38	19.73	18.05	0.047	0.058	0.071	0.084	0.097	0.109	0.122	0.135
		Avg	**23.21**	**22.44**	**21.43**	**20.28**	**19.02**	**17.67**	**16.26**	**14.83**	**0.048**	**0.060**	**0.073**	**0.087**	**0.100**	**0.113**	**0.127**	**0.140**
		StdDev	**4.05**	**3.95**	**3.81**	**3.66**	**3.48**	**3.28**	**3.07**	**2.85**	**0.011**	**0.010**	**0.009**	**0.007**	**0.006**	**0.005**	**0.005**	**0.005**
Avg	**4.3**	**---**	**21.61**	**20.89**	**19.93**	**18.83**	**17.61**	**16.32**	**14.97**	**13.59**	**0.048**	**0.061**	**0.075**	**0.090**	**0.104**	**0.118**	**0.132**	**0.147**
StdDev		**---**	**3.25**	**3.18**	**3.08**	**2.96**	**2.83**	**2.68**	**2.52**	**2.35**	**0.010**	**0.008**	**0.006**	**0.006**	**0.007**	**0.008**	**0.011**	**0.013**

Table B.42 *BBR* Mixture Data for *9.5-50/RM-2* at -12 C

Specimen	V_a		Test Time (sec) and Mixture Stiffness (GPa)								Test Time (sec) and Mixture m-value							
Rep	**(%)**	**Rep**	**8**	**15**	**30**	**60**	**120**	**240**	**480**	**960**	**8**	**15**	**30**	**60**	**120**	**240**	**480**	**960**
1	4.1	1	20.09	19.53	18.62	17.46	16.09	14.58	12.98	11.36	0.034	0.056	0.081	0.106	0.130	0.155	0.180	0.204
		2	30.81	29.44	27.64	25.60	23.40	21.10	18.77	16.48	0.064	0.081	0.101	0.120	0.139	0.159	0.178	0.198
		3	22.04	20.87	19.57	18.27	16.98	15.72	14.48	13.28	0.084	0.089	0.096	0.102	0.109	0.115	0.122	0.128
		Avg	**24.31**	**23.28**	**21.94**	**20.44**	**18.82**	**17.13**	**15.41**	**13.71**	**0.060**	**0.076**	**0.092**	**0.109**	**0.126**	**0.143**	**0.160**	**0.177**
		StdDev	**5.71**	**5.37**	**4.95**	**4.48**	**3.99**	**3.48**	**3.01**	**2.58**	**0.025**	**0.017**	**0.010**	**0.009**	**0.016**	**0.024**	**0.033**	**0.042**
2	4.5	1	16.08	15.37	14.50	13.57	12.59	11.58	10.56	9.56	0.067	0.078	0.090	0.102	0.114	0.126	0.139	0.151
		2	11.69	11.32	10.87	10.38	9.86	9.31	8.75	8.17	0.047	0.055	0.063	0.071	0.078	0.086	0.094	0.102
		3	13.74	13.17	12.49	11.75	10.98	10.19	9.38	8.58	0.062	0.072	0.082	0.093	0.103	0.114	0.124	0.135
		Avg	**13.84**	**13.29**	**12.62**	**11.90**	**11.14**	**10.36**	**9.56**	**8.77**	**0.059**	**0.068**	**0.078**	**0.088**	**0.099**	**0.109**	**0.119**	**0.129**
		StdDev	**2.19**	**2.02**	**1.82**	**1.60**	**1.37**	**1.14**	**0.92**	**0.71**	**0.010**	**0.012**	**0.014**	**0.016**	**0.018**	**0.020**	**0.023**	**0.025**
Avg	**4.3**	---	**19.07**	**18.28**	**17.28**	**16.17**	**14.98**	**13.74**	**12.49**	**11.24**	**0.060**	**0.072**	**0.085**	**0.099**	**0.112**	**0.126**	**0.139**	**0.153**
StdDev		---	**6.92**	**6.57**	**6.10**	**5.56**	**4.98**	**4.37**	**3.77**	**3.19**	**0.017**	**0.014**	**0.014**	**0.016**	**0.021**	**0.027**	**0.034**	**0.040**

Table B.43 *BBR* Mixture Data for *9.5-50/RM-2* at -06 C

Specimen	V_a		Test Time (sec) and Mixture Stiffness (GPa)								Test Time (sec) and Mixture m-value							
Rep	**(%)**	**Rep**	**8**	**15**	**30**	**60**	**120**	**240**	**480**	**960**	**8**	**15**	**30**	**60**	**120**	**240**	**480**	**960**
1	4.1	1	14.07	13.31	12.39	11.41	10.39	9.36	8.34	7.35	0.081	0.095	0.111	0.127	0.143	0.158	0.174	0.190
		2	17.48	16.39	15.11	13.80	12.48	11.17	9.89	8.68	0.096	0.109	0.124	0.138	0.153	0.167	0.182	0.196
		3	17.70	16.59	15.32	14.03	12.75	11.49	10.26	9.09	0.098	0.109	0.121	0.133	0.145	0.157	0.169	0.180
		Avg	**16.42**	**15.43**	**14.27**	**13.08**	**11.87**	**10.67**	**9.50**	**8.38**	**0.092**	**0.104**	**0.119**	**0.133**	**0.147**	**0.161**	**0.175**	**0.189**
		StdDev	**2.04**	**1.84**	**1.64**	**1.45**	**1.29**	**1.15**	**1.02**	**0.91**	**0.009**	**0.008**	**0.007**	**0.006**	**0.005**	**0.006**	**0.007**	**0.008**
2	4.5	1*	4.22	4.16	4.08	3.99	3.87	3.74	3.59	3.43	0.017	0.024	0.031	0.039	0.046	0.054	0.061	0.069
		2	19.41	18.28	16.94	15.55	14.14	12.73	11.35	10.03	0.090	0.102	0.116	0.130	0.144	0.158	0.172	0.186
		3	15.94	14.79	13.56	12.38	11.27	10.21	9.21	8.28	0.117	0.122	0.128	0.134	0.139	0.145	0.151	0.157
		Avg	**17.68**	**16.54**	**15.25**	**13.97**	**12.71**	**11.47**	**10.28**	**9.16**	**0.104**	**0.112**	**0.122**	**0.132**	**0.142**	**0.152**	**0.162**	**0.172**
		StdDev	**2.45**	**2.47**	**2.39**	**2.24**	**2.03**	**1.78**	**1.51**	**1.24**	**0.019**	**0.014**	**0.008**	**0.003**	**0.004**	**0.009**	**0.015**	**0.021**
Avg	**4.3**	---	**16.92**	**15.87**	**14.66**	**13.43**	**12.21**	**10.99**	**9.81**	**8.69**	**0.096**	**0.107**	**0.120**	**0.132**	**0.145**	**0.157**	**0.170**	**0.182**
StdDev		---	**2.01**	**1.89**	**1.75**	**1.59**	**1.44**	**1.28**	**1.13**	**0.99**	**0.013**	**0.010**	**0.007**	**0.004**	**0.005**	**0.008**	**0.011**	**0.015**

* Outlier that was omitted from analysis.

Table B.44 *BBR* Mixture Data for *R-1* RAP Source, 116 C, None, 50 Gyrations

P_{AC}	Test		Test Time (sec) and Mixture Stiffness (GPa)								Test Time (sec) and Mixture m-value							
(%)	Temp (C)	Rep	8	15	30	60	120	240	480	960	8	15	30	60	120	240	480	960
High	-24	1	17.89	17.38	16.70	15.89	14.99	14.00	12.97	11.89	0.039	0.051	0.065	0.078	0.091	0.105	0.118	0.131
V_a = 2.5%		2	15.03	14.59	14.02	13.38	12.66	11.89	11.09	10.26	0.042	0.052	0.063	0.074	0.085	0.096	0.107	0.118
		3	18.55	17.82	16.95	16.01	15.03	14.02	12.99	11.96	0.060	0.068	0.077	0.087	0.096	0.105	0.114	0.123
		4	24.76	24.09	23.16	22.07	20.84	19.49	18.07	16.59	0.038	0.050	0.063	0.076	0.090	0.103	0.116	0.129
		5*	33.31	31.45	29.46	27.54	25.69	23.91	22.21	20.59	0.090	0.093	0.096	0.099	0.102	0.105	0.108	0.111
		Avg	**19.06**	**18.47**	**17.71**	**16.84**	**15.88**	**14.85**	**13.78**	**12.68**	**0.045**	**0.055**	**0.067**	**0.079**	**0.091**	**0.102**	**0.114**	**0.125**
		StdDev	**4.10**	**4.01**	**3.87**	**3.69**	**3.49**	**3.25**	**3.00**	**2.73**	**0.010**	**0.009**	**0.007**	**0.006**	**0.005**	**0.004**	**0.005**	**0.006**
	-18	1	11.56	11.14	10.63	10.08	9.49	8.88	8.26	7.63	0.055	0.063	0.072	0.082	0.091	0.100	0.110	0.119
		2	18.10	17.37	16.49	15.54	14.56	13.54	12.51	11.48	0.061	0.070	0.080	0.090	0.100	0.109	0.119	0.129
		3	18.89	18.23	17.42	16.53	15.58	14.59	13.56	12.53	0.052	0.061	0.071	0.080	0.090	0.100	0.110	0.119
		4	17.78	17.15	16.35	15.46	14.49	13.46	12.41	11.34	0.052	0.063	0.075	0.087	0.100	0.112	0.124	0.136
		5	18.42	17.73	16.88	15.94	14.93	13.87	12.79	11.71	0.055	0.066	0.077	0.089	0.100	0.111	0.123	0.134
		Avg	**16.95**	**16.33**	**15.55**	**14.71**	**13.81**	**12.87**	**11.91**	**10.94**	**0.055**	**0.065**	**0.075**	**0.086**	**0.096**	**0.107**	**0.117**	**0.128**
		StdDev	**3.04**	**2.93**	**2.78**	**2.62**	**2.45**	**2.27**	**2.09**	**1.90**	**0.004**	**0.004**	**0.004**	**0.004**	**0.005**	**0.006**	**0.007**	**0.008**
Med	-24	1	5.48	5.32	5.15	4.99	4.83	4.67	4.52	4.37	0.046	0.046	0.047	0.047	0.047	0.048	0.048	0.048
V_a = 4.6%		2	9.01	8.90	8.73	8.53	8.28	8.01	7.70	7.37	0.017	0.023	0.031	0.038	0.045	0.053	0.060	0.067
		3	10.95	10.79	10.57	10.31	10.02	9.69	9.33	8.95	0.021	0.026	0.033	0.039	0.045	0.051	0.057	0.064
		4	10.02	9.74	9.40	9.03	8.65	8.24	7.81	7.38	0.042	0.048	0.054	0.060	0.067	0.073	0.079	0.086
		5	7.23	7.15	7.01	6.83	6.61	6.35	6.07	5.76	0.015	0.024	0.033	0.042	0.052	0.061	0.071	0.080
		Avg	**8.54**	**8.38**	**8.17**	**7.94**	**7.68**	**7.39**	**7.09**	**6.77**	**0.028**	**0.034**	**0.039**	**0.045**	**0.051**	**0.057**	**0.063**	**0.069**
		StdDev	**2.20**	**2.17**	**2.13**	**2.07**	**2.00**	**1.93**	**1.84**	**1.75**	**0.015**	**0.012**	**0.010**	**0.009**	**0.009**	**0.010**	**0.012**	**0.015**
	-18	1	6.61	6.56	6.47	6.34	6.19	6.01	5.81	5.59	0.010	0.017	0.024	0.031	0.039	0.046	0.053	0.060
		2	6.37	6.31	6.24	6.14	6.04	5.92	5.79	5.65	0.012	0.016	0.019	0.023	0.027	0.030	0.034	0.038
		3	6.53	6.47	6.39	6.30	6.19	6.06	5.92	5.76	0.012	0.016	0.020	0.024	0.028	0.032	0.036	0.040
		4	7.03	6.97	6.88	6.76	6.61	6.45	6.26	6.06	0.012	0.017	0.022	0.028	0.034	0.039	0.045	0.051
		5*	6.38	6.44	6.51	6.61	6.72	6.86	7.02	7.20	-0.011	-0.015	-0.019	-0.023	-0.027	-0.031	-0.035	-0.039
		Avg	**6.64**	**6.58**	**6.49**	**6.39**	**6.26**	**6.11**	**5.95**	**5.77**	**0.012**	**0.016**	**0.021**	**0.027**	**0.032**	**0.037**	**0.042**	**0.047**
		StdDev	**0.28**	**0.28**	**0.27**	**0.26**	**0.25**	**0.23**	**0.22**	**0.21**	**0.001**	**0.001**	**0.002**	**0.004**	**0.005**	**0.007**	**0.009**	**0.010**

* Outlier that was omitted from analysis.

Table B.45 *BBR* Mixture Data for *R-1* RAP Source, 116 C, None, 65 Gyrations

P_{AC}	Test		Test Time (sec) and Mixture Stiffness (GPa)								Test Time (sec) and Mixture m-value							
(%)	Temp (C)	Rep	8	15	30	60	120	240	480	960	8	15	30	60	120	240	480	960
High	-24	1	17.09	16.53	15.83	15.03	14.17	13.25	12.29	11.32	0.047	0.057	0.069	0.080	0.091	0.102	0.114	0.125
V_a = 1.6%		2	18.18	17.62	16.93	16.17	15.36	14.50	13.61	12.71	0.046	0.054	0.062	0.070	0.079	0.087	0.095	0.104
		3	15.19	14.76	14.18	13.51	12.75	11.93	11.06	10.16	0.040	0.051	0.064	0.077	0.090	0.103	0.115	0.128
		4	18.55	17.97	17.26	16.48	15.65	14.78	13.88	12.96	0.047	0.054	0.062	0.071	0.079	0.087	0.095	0.103
		5*	16.13	15.58	15.01	14.48	13.97	13.50	13.06	12.65	0.056	0.054	0.053	0.052	0.050	0.049	0.047	0.046
		Avg	**17.25**	**16.72**	**16.05**	**15.30**	**14.48**	**13.61**	**12.71**	**11.79**	**0.045**	**0.054**	**0.064**	**0.074**	**0.085**	**0.095**	**0.105**	**0.115**
		StdDev	**1.51**	**1.44**	**1.39**	**1.35**	**1.32**	**1.31**	**1.30**	**1.30**	**0.004**	**0.003**	**0.003**	**0.005**	**0.007**	**0.009**	**0.011**	**0.014**
	-18	1	16.05	15.77	15.30	14.67	13.90	13.01	12.04	11.01	0.020	0.035	0.052	0.069	0.086	0.104	0.121	0.138
		2	20.63	19.82	18.96	18.13	17.32	16.54	15.79	15.06	0.063	0.064	0.064	0.065	0.066	0.067	0.068	0.069
		3	18.55	17.73	16.79	15.82	14.83	13.84	12.84	11.86	0.068	0.075	0.082	0.089	0.097	0.104	0.111	0.119
		4	15.73	15.31	14.78	14.17	13.51	12.80	12.05	11.28	0.039	0.047	0.056	0.065	0.074	0.082	0.091	0.100
		5	20.16	19.46	18.60	17.67	16.69	15.66	14.61	13.54	0.053	0.061	0.069	0.078	0.087	0.096	0.105	0.114
		Avg	**18.22**	**17.62**	**16.89**	**16.09**	**15.25**	**14.37**	**13.47**	**12.55**	**0.048**	**0.056**	**0.065**	**0.073**	**0.082**	**0.091**	**0.099**	**0.108**
		StdDev	**2.27**	**2.06**	**1.89**	**1.76**	**1.69**	**1.66**	**1.67**	**1.72**	**0.020**	**0.015**	**0.012**	**0.010**	**0.012**	**0.016**	**0.021**	**0.026**
Med	-24	1	22.95	22.35	21.63	20.87	20.06	19.22	18.34	17.45	0.040	0.044	0.049	0.054	0.059	0.064	0.069	0.074
V_a = 4.1%		2	19.84	19.30	18.53	17.60	16.55	15.39	14.16	12.90	0.037	0.051	0.066	0.082	0.097	0.112	0.128	0.143
		3	12.80	12.60	12.35	12.05	11.71	11.34	10.95	10.52	0.022	0.027	0.033	0.038	0.043	0.049	0.054	0.060
		4*	12.01	11.81	11.53	11.19	10.81	10.38	9.91	9.42	0.023	0.031	0.039	0.047	0.054	0.062	0.070	0.078
		5	22.54	21.68	20.60	19.44	18.19	16.90	15.58	14.25	0.058	0.068	0.079	0.090	0.101	0.112	0.123	0.134
		Avg	**19.53**	**18.98**	**18.28**	**17.49**	**16.63**	**15.71**	**14.76**	**13.78**	**0.039**	**0.048**	**0.057**	**0.066**	**0.075**	**0.084**	**0.094**	**0.103**
		StdDev	**4.70**	**4.45**	**4.16**	**3.87**	**3.58**	**3.31**	**3.07**	**2.89**	**0.015**	**0.017**	**0.020**	**0.024**	**0.029**	**0.033**	**0.038**	**0.042**
	-18	1	18.21	17.74	17.13	16.42	15.64	14.79	13.89	12.95	0.037	0.046	0.056	0.066	0.076	0.086	0.095	0.105
		2	20.30	19.73	19.00	18.17	17.25	16.26	15.22	14.15	0.040	0.049	0.060	0.070	0.080	0.090	0.100	0.111
		3	14.49	14.16	13.75	13.27	12.75	12.18	11.57	10.94	0.032	0.039	0.047	0.054	0.062	0.070	0.077	0.085
		4	18.29	17.67	16.94	16.17	15.37	14.53	13.69	12.83	0.052	0.058	0.064	0.071	0.077	0.084	0.090	0.097
		5	20.31	19.58	18.65	17.63	16.52	15.36	14.17	12.96	0.053	0.064	0.076	0.087	0.099	0.111	0.123	0.134
		Avg	**18.32**	**17.78**	**17.09**	**16.33**	**15.50**	**14.62**	**13.71**	**12.77**	**0.043**	**0.051**	**0.060**	**0.070**	**0.079**	**0.088**	**0.097**	**0.106**
		StdDev	**2.38**	**2.24**	**2.08**	**1.90**	**1.71**	**1.52**	**1.33**	**1.15**	**0.009**	**0.010**	**0.011**	**0.012**	**0.013**	**0.015**	**0.017**	**0.018**

* Outlier that was omitted from analysis.

Table B.46 *BBR* Mixture Data for *R-1* RAP Source, 116 C, None, 85 Gyrations

P_{AC}	Test		Test Time (sec) and Mixture Stiffness (GPa)								Test Time (sec) and Mixture m-value							
(%)	Temp (C)	Rep	8	15	30	60	120	240	480	960	8	15	30	60	120	240	480	960
High	-24	1	19.06	18.66	18.08	17.37	16.55	15.64	14.66	13.62	0.029	0.040	0.052	0.064	0.076	0.088	0.100	0.112
V_a = 1.2%		2	12.72	12.42	12.01	11.53	10.99	10.40	9.76	9.10	0.033	0.043	0.053	0.064	0.075	0.085	0.096	0.106
		3	20.41	19.75	19.00	18.22	17.43	16.62	15.81	15.00	0.050	0.054	0.058	0.062	0.066	0.070	0.074	0.078
		4	13.42	13.13	12.78	12.39	11.98	11.54	11.08	10.60	0.032	0.037	0.042	0.047	0.052	0.057	0.061	0.066
		5	19.36	18.86	18.16	17.32	16.37	15.32	14.20	13.04	0.035	0.048	0.061	0.075	0.089	0.102	0.116	0.130
		Avg	**16.99**	**16.56**	**16.00**	**15.37**	**14.66**	**13.90**	**13.10**	**12.27**	**0.036**	**0.044**	**0.053**	**0.062**	**0.071**	**0.080**	**0.089**	**0.098**
		StdDev	**3.63**	**3.49**	**3.33**	**3.14**	**2.95**	**2.75**	**2.56**	**2.38**	**0.008**	**0.007**	**0.008**	**0.010**	**0.014**	**0.018**	**0.022**	**0.026**
	-18	1	19.16	18.63	18.02	17.42	16.81	16.20	15.59	14.98	0.045	0.046	0.048	0.050	0.052	0.054	0.056	0.058
		2	19.07	18.45	17.66	16.79	15.84	14.85	13.81	12.76	0.048	0.058	0.068	0.078	0.089	0.099	0.109	0.120
		3	18.40	17.78	16.97	16.04	15.02	13.93	12.80	11.65	0.048	0.061	0.074	0.088	0.102	0.115	0.129	0.143
		4	20.84	20.12	19.21	18.21	17.13	15.99	14.81	13.61	0.051	0.061	0.072	0.083	0.094	0.105	0.116	0.127
		5	19.30	18.71	17.93	17.04	16.07	15.03	13.94	12.82	0.045	0.055	0.067	0.079	0.091	0.103	0.114	0.126
		Avg	**19.36**	**18.74**	**17.96**	**17.10**	**16.17**	**15.20**	**14.19**	**13.16**	**0.047**	**0.056**	**0.066**	**0.076**	**0.086**	**0.095**	**0.105**	**0.115**
		StdDev	**0.90**	**0.85**	**0.81**	**0.80**	**0.83**	**0.92**	**1.06**	**1.23**	**0.003**	**0.006**	**0.010**	**0.015**	**0.019**	**0.024**	**0.028**	**0.033**
Med	-24	1	17.95	17.61	17.15	16.63	16.04	15.41	14.72	14.00	0.028	0.034	0.041	0.048	0.055	0.062	0.069	0.076
V_a = 3.5%		2	22.65	22.11	21.43	20.69	19.90	19.06	18.18	17.27	0.036	0.042	0.048	0.053	0.059	0.065	0.071	0.077
		3	16.37	15.89	15.26	14.57	13.80	12.99	12.14	11.27	0.044	0.053	0.063	0.073	0.083	0.093	0.103	0.113
		4	17.15	16.72	16.21	15.65	15.04	14.41	13.75	13.06	0.037	0.042	0.048	0.054	0.059	0.065	0.071	0.077
		5	20.22	19.57	18.80	17.97	17.10	16.19	15.25	14.30	0.048	0.055	0.062	0.068	0.075	0.082	0.089	0.096
		Avg	**18.87**	**18.38**	**17.77**	**17.10**	**16.38**	**15.61**	**14.81**	**13.98**	**0.039**	**0.045**	**0.052**	**0.059**	**0.066**	**0.073**	**0.081**	**0.088**
		StdDev	**2.56**	**2.49**	**2.43**	**2.37**	**2.32**	**2.27**	**2.23**	**2.19**	**0.008**	**0.008**	**0.009**	**0.011**	**0.012**	**0.013**	**0.015**	**0.016**
	-18	1	15.02	14.57	14.09	13.61	13.15	12.71	12.27	11.85	0.048	0.049	0.049	0.049	0.050	0.050	0.050	0.051
		2	17.27	16.88	16.33	15.67	14.92	14.09	13.20	12.26	0.031	0.042	0.054	0.065	0.077	0.088	0.100	0.112
		3	19.41	19.16	18.70	18.06	17.27	16.33	15.29	14.17	0.014	0.027	0.042	0.058	0.073	0.088	0.103	0.118
		4	15.76	15.26	14.64	13.98	13.28	12.54	11.77	11.00	0.048	0.055	0.063	0.071	0.079	0.087	0.094	0.102
		5	21.51	21.14	20.53	19.72	18.75	17.63	16.40	15.09	0.020	0.034	0.050	0.066	0.081	0.097	0.112	0.128
		Avg	**17.79**	**17.40**	**16.86**	**16.21**	**15.47**	**14.66**	**13.79**	**12.87**	**0.032**	**0.042**	**0.052**	**0.062**	**0.072**	**0.082**	**0.092**	**0.102**
		StdDev	**2.67**	**2.74**	**2.73**	**2.64**	**2.47**	**2.25**	**1.99**	**1.70**	**0.016**	**0.011**	**0.007**	**0.008**	**0.013**	**0.018**	**0.024**	**0.030**

Table B.47 *BBR* Mixture Data for *R-1* RAP Source, 116 C, Sasobit®, 50 Gyrations

P_{AC}	Test		Test Time (sec) and Mixture Stiffness (GPa)								Test Time (sec) and Mixture m-value							
(%)	Temp (C)	Rep	8	15	30	60	120	240	480	960	8	15	30	60	120	240	480	960
High	-24	1	15.95	15.52	15.00	14.44	13.83	13.19	12.53	11.84	0.040	0.046	0.052	0.059	0.065	0.072	0.078	0.084
V_a = 2.4%		2	14.60	14.06	13.40	12.67	11.89	11.08	10.25	9.42	0.055	0.065	0.075	0.086	0.096	0.107	0.117	0.128
		3	17.69	17.19	16.59	15.96	15.30	14.61	13.90	13.18	0.044	0.048	0.053	0.059	0.064	0.069	0.074	0.080
		4	18.01	17.53	16.86	16.07	15.17	14.19	13.14	12.06	0.037	0.049	0.063	0.076	0.090	0.104	0.117	0.131
		5*	31.57	30.61	29.44	28.16	26.80	25.37	23.88	22.37	0.046	0.052	0.060	0.068	0.075	0.083	0.091	0.098
		Avg	**16.56**	**16.08**	**15.46**	**14.79**	**14.05**	**13.27**	**12.46**	**11.63**	**0.044**	**0.052**	**0.061**	**0.070**	**0.079**	**0.088**	**0.097**	**0.106**
		StdDev	**1.59**	**1.61**	**1.60**	**1.59**	**1.58**	**1.58**	**1.57**	**1.58**	**0.008**	**0.009**	**0.011**	**0.013**	**0.017**	**0.020**	**0.024**	**0.028**
	-18	1	20.27	19.71	18.99	18.18	17.29	16.33	15.32	14.29	0.040	0.049	0.058	0.068	0.077	0.087	0.097	0.106
		2	18.28	17.67	16.96	16.21	15.42	14.61	13.79	12.96	0.051	0.057	0.063	0.069	0.075	0.081	0.087	0.093
		3	17.35	16.88	16.27	15.56	14.77	13.92	13.03	12.10	0.039	0.048	0.059	0.070	0.080	0.091	0.101	0.112
		4	18.24	17.72	17.03	16.21	15.30	14.31	13.27	12.19	0.040	0.052	0.064	0.077	0.090	0.103	0.115	0.128
		5	20.12	19.43	18.60	17.71	16.78	15.81	14.82	13.81	0.052	0.059	0.067	0.074	0.082	0.090	0.097	0.105
		Avg	**18.85**	**18.28**	**17.57**	**16.77**	**15.91**	**15.00**	**14.05**	**13.07**	**0.044**	**0.053**	**0.062**	**0.071**	**0.081**	**0.090**	**0.099**	**0.109**
		StdDev	**1.28**	**1.22**	**1.17**	**1.12**	**1.07**	**1.03**	**0.99**	**0.97**	**0.007**	**0.005**	**0.004**	**0.004**	**0.006**	**0.008**	**0.010**	**0.013**
Med	-24	1	15.68	15.34	14.89	14.37	13.77	13.12	12.42	11.68	0.030	0.038	0.047	0.056	0.066	0.075	0.084	0.093
V_a = 4.4%		2	21.59	20.94	20.11	19.18	18.16	17.07	15.94	14.77	0.044	0.053	0.063	0.074	0.084	0.094	0.104	0.115
		3	19.05	18.49	17.75	16.88	15.92	14.88	13.79	12.66	0.041	0.053	0.066	0.078	0.091	0.104	0.116	0.129
		4*	8.06	7.97	7.82	7.64	7.43	7.18	6.91	6.61	0.015	0.022	0.030	0.037	0.045	0.052	0.060	0.067
		5*	15.51	15.04	14.56	14.11	13.71	13.34	13.01	12.70	0.051	0.048	0.046	0.043	0.041	0.038	0.036	0.033
		Avg	**18.77**	**18.26**	**17.58**	**16.81**	**15.95**	**15.02**	**14.05**	**13.04**	**0.038**	**0.048**	**0.059**	**0.069**	**0.080**	**0.091**	**0.101**	**0.112**
		StdDev	**2.96**	**2.81**	**2.61**	**2.41**	**2.20**	**1.98**	**1.77**	**1.58**	**0.007**	**0.009**	**0.010**	**0.012**	**0.013**	**0.015**	**0.016**	**0.018**
	-18	1	22.77	21.94	20.90	19.74	18.49	17.19	15.84	14.48	0.054	0.065	0.076	0.088	0.100	0.112	0.124	0.135
		2	18.54	18.00	17.30	16.48	15.59	14.62	13.60	12.55	0.042	0.052	0.064	0.075	0.087	0.098	0.110	0.121
		3	20.05	19.55	18.82	17.92	16.88	15.72	14.48	13.19	0.033	0.047	0.063	0.079	0.095	0.111	0.126	0.142
		4	16.27	15.56	14.61	13.52	12.34	11.10	9.85	8.61	0.062	0.081	0.101	0.122	0.142	0.163	0.183	0.204
		5*	6.09	6.04	5.97	5.89	5.79	5.67	5.55	5.41	0.011	0.015	0.019	0.023	0.027	0.031	0.034	0.038
		Avg	**19.41**	**18.76**	**17.91**	**16.92**	**15.83**	**14.66**	**13.44**	**12.21**	**0.048**	**0.061**	**0.076**	**0.091**	**0.106**	**0.121**	**0.136**	**0.151**
		StdDev	**2.73**	**2.68**	**2.65**	**2.63**	**2.61**	**2.59**	**2.57**	**2.53**	**0.013**	**0.015**	**0.018**	**0.021**	**0.025**	**0.029**	**0.032**	**0.037**

* Outlier that was omitted from analysis.

Table B.48 *BBR* Mixture Data for *R-1* RAP Source, 116 C, Sasobit®, 65 Gyrations

P_{AC}	Test		Test Time (sec) and Mixture Stiffness (GPa)								Test Time (sec) and Mixture m-value							
(%)	Temp (C)	Rep	8	15	30	60	120	240	480	960	8	15	30	60	120	240	480	960
High	-24	1	18.25	17.79	17.25	16.68	16.07	15.45	14.80	14.14	0.038	0.042	0.047	0.051	0.055	0.059	0.064	0.068
V_a = 1.7%		2	18.68	18.13	17.46	16.71	15.91	15.07	14.19	13.29	0.044	0.051	0.059	0.067	0.075	0.083	0.091	0.099
		3	18.29	17.78	17.14	16.44	15.68	14.88	14.05	13.19	0.042	0.049	0.057	0.064	0.072	0.079	0.087	0.094
		4	19.03	18.41	17.65	16.81	15.90	14.94	13.96	12.95	0.048	0.056	0.066	0.075	0.085	0.094	0.103	0.113
		5	18.42	17.89	17.19	16.41	15.55	14.63	13.67	12.69	0.043	0.052	0.062	0.072	0.083	0.093	0.103	0.113
		Avg	**18.53**	**18.00**	**17.34**	**16.61**	**15.82**	**15.00**	**14.13**	**13.25**	**0.043**	**0.050**	**0.058**	**0.066**	**0.074**	**0.082**	**0.090**	**0.097**
		StdDev	**0.32**	**0.27**	**0.21**	**0.18**	**0.21**	**0.30**	**0.42**	**0.55**	**0.003**	**0.005**	**0.007**	**0.009**	**0.012**	**0.014**	**0.016**	**0.018**
	-18	1	18.48	18.07	17.57	17.03	16.45	15.83	15.19	14.52	0.033	0.038	0.043	0.048	0.053	0.058	0.062	0.067
		2	15.85	15.25	14.54	13.77	12.97	12.14	11.30	10.45	0.057	0.065	0.074	0.082	0.091	0.099	0.108	0.117
		3	20.47	19.68	18.72	17.68	16.58	15.44	14.28	13.11	0.058	0.067	0.077	0.088	0.098	0.108	0.118	0.128
		4	19.78	19.08	18.29	17.48	16.65	15.82	14.98	14.14	0.055	0.059	0.063	0.068	0.072	0.076	0.081	0.085
		5	19.32	18.61	17.80	16.95	16.08	15.20	14.32	13.43	0.057	0.062	0.067	0.073	0.078	0.084	0.090	0.095
		Avg	**18.78**	**18.14**	**17.38**	**16.58**	**15.75**	**14.89**	**14.01**	**13.13**	**0.052**	**0.058**	**0.065**	**0.072**	**0.078**	**0.085**	**0.092**	**0.098**
		StdDev	**1.79**	**1.72**	**1.65**	**1.60**	**1.57**	**1.56**	**1.57**	**1.60**	**0.011**	**0.012**	**0.014**	**0.015**	**0.018**	**0.020**	**0.022**	**0.024**
Med	-24	1	23.31	22.83	22.24	21.60	20.92	20.19	19.43	18.65	0.031	0.035	0.040	0.044	0.049	0.053	0.057	0.062
V_a = 4.3%		2	19.25	18.52	17.69	16.83	15.95	15.06	14.17	13.28	0.059	0.064	0.069	0.075	0.080	0.086	0.091	0.097
		3	14.54	14.22	13.80	13.31	12.77	12.17	11.54	10.88	0.032	0.039	0.048	0.056	0.064	0.073	0.081	0.089
		4*	15.35	14.90	14.31	13.63	12.87	12.04	11.16	10.24	0.053	0.041	0.029	0.019	0.011	0.003	-0.004	-0.009
		5*	18.10	17.23	16.23	15.20	14.14	13.07	12.00	10.93	0.016	0.011	0.006	0.001	-0.003	-0.007	-0.011	-0.014
		Avg	**19.03**	**18.52**	**17.91**	**17.25**	**16.55**	**15.81**	**15.05**	**14.27**	**0.041**	**0.046**	**0.052**	**0.058**	**0.064**	**0.070**	**0.076**	**0.083**
		StdDev	**4.39**	**4.31**	**4.23**	**4.16**	**4.11**	**4.06**	**4.02**	**3.98**	**0.016**	**0.015**	**0.015**	**0.015**	**0.016**	**0.016**	**0.017**	**0.018**
	-18	1	19.28	18.54	17.69	16.80	15.88	14.95	14.00	13.07	0.059	0.065	0.071	0.078	0.084	0.091	0.097	0.103
		2	15.17	14.67	14.09	13.48	12.86	12.22	11.57	10.91	0.051	0.056	0.061	0.066	0.071	0.076	0.081	0.087
		3*	4.17	4.13	4.09	4.04	3.99	3.94	3.89	3.83	0.013	0.014	0.016	0.017	0.018	0.019	0.021	0.022
		4*	4.96	4.92	4.86	4.80	4.72	4.63	4.53	4.42	0.011	0.014	0.018	0.022	0.026	0.029	0.033	0.037
		5*	17.95	17.10	16.25	15.47	14.77	14.13	13.55	13.03	0.079	0.076	0.072	0.069	0.065	0.062	0.059	0.055
		Avg	**17.23**	**16.61**	**15.89**	**15.14**	**14.37**	**13.59**	**12.79**	**11.99**	**0.055**	**0.061**	**0.066**	**0.072**	**0.078**	**0.084**	**0.089**	**0.095**
		StdDev	**2.91**	**2.74**	**2.55**	**2.35**	**2.14**	**1.93**	**1.72**	**1.53**	**0.006**	**0.006**	**0.007**	**0.008**	**0.009**	**0.011**	**0.011**	**0.011**

* Outlier that was omitted from analysis.

Table B.49 *BBR* Mixture Data for *R-1* RAP Source, 116 C, Sasobit®, 85 Gyrations

P_{AC}	Test		Test Time (sec) and Mixture Stiffness (GPa)								Test Time (sec) and Mixture m-value							
(%)	Temp (C)	Rep	8	15	30	60	120	240	480	960	8	15	30	60	120	240	480	960
High	-24	1	25.55	24.66	23.63	22.57	21.49	20.38	19.21	18.11	0.054	0.059	0.064	0.069	0.074	0.078	0.084	0.088
V_a = 1.2%		2	18.32	17.76	17.04	16.24	15.36	14.43	13.40	12.42	0.045	0.054	0.065	0.075	0.085	0.095	0.106	0.116
		3	21.14	20.52	19.74	18.85	17.89	16.85	15.70	14.60	0.042	0.051	0.061	0.071	0.081	0.091	0.101	0.111
		4	18.66	18.10	17.42	16.66	15.85	15.00	14.06	13.16	0.044	0.052	0.060	0.068	0.076	0.084	0.093	0.100
		5*	16.95	16.49	16.00	15.53	15.09	14.67	14.24	13.86	0.044	0.044	0.043	0.042	0.042	0.041	0.040	0.039
		Avg	**20.92**	**20.26**	**19.46**	**18.58**	**17.65**	**16.66**	**15.59**	**14.57**	**0.047**	**0.054**	**0.062**	**0.071**	**0.079**	**0.087**	**0.096**	**0.104**
		StdDev	**3.34**	**3.18**	**3.03**	**2.90**	**2.78**	**2.69**	**2.60**	**2.53**	**0.005**	**0.003**	**0.002**	**0.003**	**0.005**	**0.007**	**0.010**	**0.012**
	-18	1	14.17	13.52	12.80	12.08	11.36	10.65	9.91	9.23	0.072	0.077	0.081	0.086	0.091	0.096	0.101	0.105
		2	19.49	18.82	17.96	17.00	15.97	14.88	13.68	12.55	0.051	0.061	0.073	0.085	0.096	0.108	0.121	0.132
		3	15.41	14.92	14.27	13.52	12.69	11.80	10.82	9.88	0.045	0.057	0.071	0.084	0.098	0.112	0.126	0.139
		4	20.51	19.66	18.74	17.85	16.98	16.13	15.26	14.48	0.067	0.068	0.070	0.071	0.073	0.075	0.076	0.078
		5	19.78	19.20	18.44	17.57	16.61	15.59	14.46	13.37	0.043	0.053	0.064	0.075	0.086	0.097	0.109	0.120
		Avg	**17.87**	**17.22**	**16.44**	**15.60**	**14.72**	**13.81**	**12.83**	**11.90**	**0.056**	**0.063**	**0.072**	**0.080**	**0.089**	**0.097**	**0.106**	**0.115**
		StdDev	**2.88**	**2.80**	**2.72**	**2.63**	**2.53**	**2.44**	**2.34**	**2.26**	**0.013**	**0.009**	**0.006**	**0.007**	**0.010**	**0.014**	**0.020**	**0.024**
Med	-24	1	17.63	16.99	16.20	15.34	14.41	13.43	12.43	11.42	0.054	0.063	0.074	0.085	0.096	0.106	0.117	0.128
V_a = 3.5%		2	16.92	16.51	15.93	15.23	14.43	13.54	12.60	11.61	0.033	0.045	0.058	0.071	0.085	0.098	0.111	0.125
		3	21.87	21.38	20.67	19.81	18.81	17.71	16.52	15.28	0.030	0.042	0.055	0.068	0.081	0.094	0.107	0.119
		4	17.01	16.54	15.90	15.16	14.34	13.44	12.50	11.52	0.040	0.050	0.063	0.075	0.087	0.099	0.111	0.123
		5	10.82	10.64	10.42	10.18	9.91	9.62	9.31	8.99	0.024	0.028	0.032	0.036	0.041	0.045	0.049	0.053
		Avg	**16.85**	**16.41**	**15.83**	**15.14**	**14.38**	**13.55**	**12.67**	**11.76**	**0.036**	**0.046**	**0.056**	**0.067**	**0.078**	**0.088**	**0.099**	**0.110**
		StdDev	**3.95**	**3.82**	**3.63**	**3.41**	**3.15**	**2.86**	**2.56**	**2.25**	**0.011**	**0.013**	**0.015**	**0.018**	**0.021**	**0.025**	**0.028**	**0.032**
	-18	1	17.11	16.60	16.02	15.43	14.81	14.19	13.56	12.93	0.046	0.049	0.053	0.057	0.060	0.064	0.067	0.071
		2	24.50	23.69	22.77	21.83	20.87	19.90	18.92	17.93	0.051	0.055	0.059	0.063	0.067	0.071	0.075	0.079
		3	16.51	15.86	14.96	13.92	12.76	11.54	10.29	9.05	0.055	0.074	0.094	0.115	0.135	0.155	0.176	0.196
		4	17.06	16.53	15.86	15.11	14.30	13.44	12.55	11.64	0.046	0.055	0.065	0.075	0.084	0.094	0.104	0.114
		5	21.64	21.11	20.38	19.52	18.54	17.46	16.32	15.12	0.034	0.045	0.057	0.068	0.080	0.092	0.104	0.116
		Avg	**19.36**	**18.76**	**18.00**	**17.16**	**16.26**	**15.31**	**14.33**	**13.33**	**0.047**	**0.056**	**0.065**	**0.075**	**0.085**	**0.095**	**0.105**	**0.115**
		StdDev	**3.54**	**3.46**	**3.40**	**3.36**	**3.34**	**3.34**	**3.36**	**3.38**	**0.008**	**0.011**	**0.017**	**0.023**	**0.029**	**0.036**	**0.043**	**0.050**

* Outlier that was omitted from analysis.

Table B.50 *BBR* Mixture Data for *R-1* RAP Source, 116, Evotherm™, 50 Gyrations

P_{AC}	Test		Test Time (sec) and Mixture Stiffness (GPa)								Test Time (sec) and Mixture m-value							
(%)	Temp (C)	Rep	8	15	30	60	120	240	480	960	8	15	30	60	120	240	480	960
High	-24	1	21.04	20.56	19.93	19.19	18.37	17.47	16.52	15.52	0.032	0.041	0.050	0.059	0.068	0.077	0.086	0.095
V_a = 2.1%		2	20.50	19.85	19.02	18.09	17.08	16.02	14.91	13.77	0.047	0.056	0.067	0.077	0.088	0.098	0.109	0.119
		3	19.24	18.76	18.11	17.34	16.46	15.51	14.49	13.44	0.035	0.045	0.057	0.069	0.080	0.092	0.104	0.115
		4	18.58	18.03	17.31	16.48	15.55	14.55	13.50	12.42	0.042	0.053	0.065	0.077	0.090	0.102	0.114	0.127
		5	21.88	21.20	20.37	19.46	18.49	17.46	16.39	15.30	0.046	0.053	0.062	0.070	0.079	0.087	0.095	0.104
		Avg	**20.25**	**19.68**	**18.95**	**18.11**	**17.19**	**16.20**	**15.16**	**14.09**	**0.040**	**0.050**	**0.060**	**0.070**	**0.081**	**0.091**	**0.102**	**0.112**
		StdDev	**1.34**	**1.29**	**1.26**	**1.25**	**1.26**	**1.27**	**1.29**	**1.31**	**0.006**	**0.007**	**0.007**	**0.008**	**0.009**	**0.010**	**0.011**	**0.013**
	-18	1	19.22	18.31	17.20	16.01	14.77	13.50	12.14	10.90	0.071	0.083	0.097	0.110	0.123	0.137	0.151	0.164
		2	26.32	25.88	25.18	24.25	23.14	21.87	20.39	18.92	0.020	0.033	0.047	0.061	0.075	0.088	0.103	0.117
		3	20.52	19.79	18.83	17.75	16.56	15.31	13.94	12.65	0.052	0.064	0.079	0.093	0.107	0.121	0.135	0.149
		4	28.32	27.20	25.74	24.06	22.24	20.31	18.22	16.27	0.056	0.072	0.089	0.105	0.122	0.139	0.157	0.174
		5	22.21	21.30	20.21	19.06	17.85	16.61	15.28	14.05	0.062	0.071	0.080	0.090	0.099	0.109	0.119	0.128
		Avg	**23.32**	**22.50**	**21.43**	**20.23**	**18.91**	**17.52**	**15.99**	**14.56**	**0.052**	**0.065**	**0.078**	**0.092**	**0.105**	**0.119**	**0.133**	**0.146**
		StdDev	**3.87**	**3.87**	**3.83**	**3.75**	**3.63**	**3.49**	**3.31**	**3.13**	**0.019**	**0.019**	**0.019**	**0.019**	**0.020**	**0.021**	**0.022**	**0.024**
Med	-24	1*	14.20	13.71	13.07	12.36	11.58	10.76	9.90	9.04	0.050	0.062	0.075	0.087	0.100	0.113	0.126	0.139
V_a = 4.8%		2	26.30	25.74	24.85	23.69	22.32	20.77	19.09	17.34	0.026	0.042	0.060	0.077	0.095	0.113	0.130	0.148
		3	16.62	16.24	15.63	14.85	13.92	12.88	11.75	10.59	0.028	0.045	0.065	0.084	0.103	0.122	0.141	0.160
		4	23.06	22.32	21.30	20.08	18.71	17.24	15.69	14.12	0.044	0.060	0.076	0.093	0.110	0.127	0.144	0.161
		5	23.42	23.11	22.52	21.70	20.67	19.47	18.13	16.69	0.014	0.029	0.045	0.062	0.078	0.095	0.111	0.128
		Avg	**22.35**	**21.85**	**21.08**	**20.08**	**18.91**	**17.59**	**16.17**	**14.69**	**0.028**	**0.044**	**0.062**	**0.079**	**0.097**	**0.114**	**0.132**	**0.149**
		StdDev	**4.09**	**4.02**	**3.92**	**3.79**	**3.64**	**3.46**	**3.27**	**3.06**	**0.012**	**0.013**	**0.013**	**0.013**	**0.014**	**0.014**	**0.015**	**0.015**
	-18	1	21.28	20.69	19.94	19.07	18.12	17.09	16.01	14.89	0.040	0.049	0.059	0.069	0.079	0.089	0.099	0.109
		2	16.75	16.33	15.70	14.91	14.00	12.98	11.89	10.76	0.033	0.048	0.066	0.083	0.100	0.118	0.135	0.152
		3*	4.81	4.73	4.62	4.50	4.37	4.23	4.08	3.92	0.027	0.031	0.035	0.040	0.045	0.049	0.054	0.059
		4	17.56	17.12	16.52	15.82	15.02	14.15	13.22	12.25	0.035	0.045	0.057	0.069	0.080	0.092	0.104	0.115
		5	23.99	23.03	21.86	20.60	19.27	17.89	16.49	15.09	0.060	0.070	0.080	0.091	0.102	0.112	0.123	0.133
		Avg	**19.90**	**19.29**	**18.51**	**17.60**	**16.60**	**15.53**	**14.40**	**13.25**	**0.042**	**0.053**	**0.066**	**0.078**	**0.090**	**0.103**	**0.115**	**0.127**
		StdDev	**3.37**	**3.13**	**2.89**	**2.68**	**2.50**	**2.34**	**2.21**	**2.10**	**0.012**	**0.011**	**0.010**	**0.011**	**0.012**	**0.014**	**0.017**	**0.019**

* Outlier that was omitted from analysis.

Table B.51 *BBR* Mixture Data for *R-1* RAP Source, 116 C, Evotherm™, 65 Gyrations

P_{AC}	Test		Test Time (sec) and Mixture Stiffness (GPa)								Test Time (sec) and Mixture m-value							
(%)	Temp (C)	Rep	8	15	30	60	120	240	480	960	8	15	30	60	120	240	480	960
High	-24	1	14.28	13.95	13.55	13.12	12.66	12.18	11.68	11.16	0.035	0.039	0.044	0.049	0.054	0.059	0.063	0.068
V_a = 1.9%		2	13.72	13.28	12.73	12.13	11.50	10.83	10.14	9.44	0.049	0.056	0.065	0.073	0.082	0.090	0.099	0.107
		3	16.13	15.70	15.09	14.36	13.52	12.60	11.62	10.60	0.036	0.050	0.065	0.079	0.094	0.109	0.124	0.139
		4	23.72	22.62	21.45	20.32	19.22	18.16	17.15	16.17	0.074	0.076	0.078	0.079	0.081	0.082	0.084	0.086
		5*	17.91	17.67	17.52	17.49	17.58	17.80	18.14	18.61	0.026	0.017	0.007	-0.003	-0.012	-0.022	-0.032	-0.042
		Avg	**16.96**	**16.39**	**15.71**	**14.98**	**14.22**	**13.44**	**12.65**	**11.84**	**0.049**	**0.055**	**0.063**	**0.070**	**0.078**	**0.085**	**0.093**	**0.100**
		StdDev	**4.62**	**4.28**	**3.95**	**3.67**	**3.43**	**3.24**	**3.08**	**2.97**	**0.018**	**0.015**	**0.014**	**0.014**	**0.017**	**0.021**	**0.026**	**0.031**
	-18	1	16.80	16.18	15.47	14.73	13.97	13.20	12.43	11.66	0.058	0.062	0.068	0.073	0.079	0.084	0.090	0.095
		2	17.79	17.26	16.61	15.90	15.13	14.33	13.49	12.64	0.045	0.052	0.059	0.067	0.075	0.083	0.090	0.098
		3	18.03	17.50	16.82	16.04	15.19	14.28	13.33	12.35	0.042	0.052	0.063	0.073	0.084	0.094	0.105	0.116
		4	18.32	17.61	16.85	16.13	15.43	14.77	14.14	13.53	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.064
		5	17.75	17.24	16.56	15.77	14.89	13.94	12.95	11.92	0.041	0.052	0.064	0.077	0.089	0.101	0.113	0.125
		Avg	**17.74**	**17.16**	**16.46**	**15.71**	**14.92**	**14.11**	**13.27**	**12.42**	**0.050**	**0.056**	**0.064**	**0.071**	**0.078**	**0.085**	**0.092**	**0.100**
		StdDev	**0.57**	**0.57**	**0.57**	**0.57**	**0.57**	**0.58**	**0.63**	**0.73**	**0.010**	**0.006**	**0.003**	**0.005**	**0.010**	**0.014**	**0.019**	**0.024**
Med	-24	1	11.60	11.39	11.11	10.79	10.44	10.05	9.64	9.20	0.027	0.032	0.039	0.045	0.051	0.058	0.064	0.070
V_a = 4.3%		2	14.61	14.28	13.84	13.33	12.74	12.10	11.41	10.69	0.032	0.040	0.050	0.060	0.070	0.079	0.089	0.099
		3	10.64	9.96	9.19	8.41	7.63	6.86	6.12	5.42	0.099	0.110	0.122	0.134	0.146	0.159	0.171	0.183
		4	19.31	18.56	17.63	16.60	15.50	14.35	13.17	11.98	0.057	0.068	0.080	0.093	0.105	0.118	0.130	0.143
		5	20.16	19.72	18.99	18.02	16.87	15.56	14.15	12.69	0.026	0.044	0.065	0.085	0.106	0.127	0.147	0.168
		Avg	**15.26**	**14.78**	**14.15**	**13.43**	**12.63**	**11.78**	**10.90**	**9.99**	**0.048**	**0.059**	**0.071**	**0.084**	**0.096**	**0.108**	**0.120**	**0.132**
		StdDev	**4.35**	**4.29**	**4.17**	**3.98**	**3.74**	**3.47**	**3.18**	**2.88**	**0.031**	**0.031**	**0.033**	**0.034**	**0.037**	**0.040**	**0.043**	**0.047**
	-18	1	19.88	19.47	18.89	18.21	17.42	16.54	15.60	14.60	0.028	0.038	0.048	0.059	0.069	0.080	0.090	0.100
		2	20.20	19.83	19.35	18.79	18.16	17.47	16.72	15.94	0.026	0.032	0.039	0.046	0.053	0.059	0.066	0.073
		3*	8.96	8.52	7.98	7.40	6.80	6.18	5.57	4.96	0.074	0.087	0.101	0.116	0.130	0.144	0.159	0.173
		4	16.66	16.20	15.66	15.06	14.42	13.76	13.06	12.35	0.041	0.047	0.053	0.059	0.065	0.072	0.078	0.084
		5	22.05	20.95	19.68	18.37	17.03	15.69	14.36	13.05	0.077	0.085	0.095	0.104	0.114	0.123	0.133	0.142
		Avg	**19.70**	**19.11**	**18.40**	**17.61**	**16.76**	**15.87**	**14.94**	**13.99**	**0.043**	**0.051**	**0.059**	**0.067**	**0.075**	**0.084**	**0.092**	**0.100**
		StdDev	**2.24**	**2.04**	**1.85**	**1.72**	**1.63**	**1.58**	**1.58**	**1.61**	**0.024**	**0.024**	**0.025**	**0.025**	**0.027**	**0.028**	**0.029**	**0.030**

* Outlier that was omitted from analysis.

Table B.52 *BBR* Mixture Data for *R-1* RAP Source, 116 C, Evotherm™, 85 Gyrations

P_{AC}	Test		Test Time (sec) and Mixture Stiffness (GPa)								Test Time (sec) and Mixture m-value							
(%)	Temp (C)	Rep	8	15	30	60	120	240	480	960	8	15	30	60	120	240	480	960
High	-24	1	15.78	15.20	14.57	13.96	13.35	12.77	12.20	11.64	0.059	0.060	0.062	0.063	0.064	0.065	0.067	0.068
V_a = 1.3%		2	22.65	22.43	22.12	21.74	21.29	20.77	20.21	19.58	0.013	0.018	0.023	0.028	0.033	0.038	0.043	0.048
		3	21.63	20.92	20.06	19.14	18.17	17.16	16.13	15.08	0.050	0.057	0.064	0.071	0.079	0.086	0.094	0.101
		4	18.71	18.42	17.93	17.29	16.51	15.61	14.62	13.56	0.019	0.032	0.046	0.060	0.074	0.088	0.102	0.116
		5	20.43	20.10	19.48	18.64	17.59	16.38	15.05	13.65	0.018	0.035	0.054	0.074	0.093	0.112	0.132	0.151
		Avg	**19.84**	**19.41**	**18.83**	**18.15**	**17.38**	**16.54**	**15.64**	**14.70**	**0.032**	**0.040**	**0.050**	**0.059**	**0.068**	**0.078**	**0.087**	**0.097**
		StdDev	**2.70**	**2.76**	**2.82**	**2.85**	**2.87**	**2.89**	**2.93**	**2.99**	**0.021**	**0.018**	**0.017**	**0.019**	**0.023**	**0.028**	**0.034**	**0.041**
	-18	1	22.50	21.85	21.04	20.14	19.18	18.15	17.09	15.99	0.043	0.050	0.059	0.067	0.075	0.083	0.091	0.100
		2	21.81	21.09	20.21	19.24	18.21	17.11	15.98	14.84	0.049	0.057	0.066	0.075	0.085	0.094	0.103	0.112
		3	21.60	20.88	20.01	19.07	18.08	17.06	16.01	14.94	0.051	0.058	0.065	0.073	0.080	0.088	0.096	0.103
		4	20.14	19.44	18.58	17.66	16.69	15.68	14.64	13.59	0.053	0.060	0.069	0.077	0.086	0.095	0.103	0.112
		5	20.66	20.09	19.37	18.56	17.69	16.75	15.77	14.76	0.041	0.048	0.057	0.066	0.074	0.083	0.091	0.100
		Avg	**21.34**	**20.67**	**19.84**	**18.94**	**17.97**	**16.95**	**15.90**	**14.82**	**0.047**	**0.055**	**0.063**	**0.072**	**0.080**	**0.088**	**0.097**	**0.105**
		StdDev	**0.94**	**0.93**	**0.92**	**0.91**	**0.90**	**0.89**	**0.87**	**0.85**	**0.005**	**0.005**	**0.005**	**0.005**	**0.005**	**0.006**	**0.006**	**0.006**
Med	-24	1	24.24	23.57	22.73	21.80	20.79	19.72	18.59	17.43	0.041	0.048	0.056	0.064	0.073	0.081	0.089	0.097
V_a = 3.7%		2	17.30	16.74	16.04	15.28	14.46	13.59	12.71	11.80	0.049	0.057	0.066	0.075	0.084	0.093	0.102	0.111
		3	21.44	21.01	20.40	19.64	18.77	17.79	16.73	15.61	0.027	0.037	0.049	0.060	0.072	0.083	0.094	0.106
		4	14.10	13.73	13.31	12.87	12.42	11.94	11.46	10.97	0.040	0.043	0.047	0.050	0.054	0.058	0.061	0.065
		5*	19.63	19.34	19.07	18.84	18.66	18.52	18.42	18.36	0.025	0.022	0.019	0.016	0.013	0.009	0.006	0.003
		Avg	**19.27**	**18.76**	**18.12**	**17.40**	**16.61**	**15.76**	**14.87**	**13.95**	**0.039**	**0.046**	**0.054**	**0.062**	**0.071**	**0.079**	**0.087**	**0.095**
		StdDev	**4.47**	**4.38**	**4.24**	**4.06**	**3.85**	**3.61**	**3.35**	**3.07**	**0.009**	**0.008**	**0.009**	**0.010**	**0.012**	**0.015**	**0.018**	**0.021**
	-18	1	18.20	17.70	17.10	16.45	15.77	15.06	14.32	13.57	0.042	0.047	0.053	0.058	0.064	0.069	0.075	0.081
		2	16.56	16.10	15.50	14.80	14.03	13.19	12.31	11.40	0.040	0.050	0.061	0.072	0.083	0.094	0.105	0.116
		3	22.90	22.11	21.21	20.26	19.29	18.29	17.27	16.26	0.053	0.058	0.063	0.069	0.074	0.079	0.085	0.090
		4	16.98	16.34	15.59	14.79	13.95	13.08	12.20	11.31	0.057	0.064	0.072	0.080	0.088	0.097	0.105	0.113
		5	23.31	22.62	21.71	20.67	19.52	18.28	16.98	15.65	0.043	0.053	0.065	0.077	0.089	0.100	0.112	0.124
		Avg	**19.59**	**18.98**	**18.22**	**17.39**	**16.51**	**15.58**	**14.62**	**13.64**	**0.047**	**0.054**	**0.063**	**0.071**	**0.080**	**0.088**	**0.096**	**0.105**
		StdDev	**3.27**	**3.16**	**3.03**	**2.89**	**2.74**	**2.59**	**2.44**	**2.31**	**0.008**	**0.007**	**0.007**	**0.009**	**0.011**	**0.013**	**0.016**	**0.018**

Table B.53 *BBR* Mixture Data for *R-1* RAP Source, 138 C, None, 50 Gyrations

P_{AC}	Test		Test Time (sec) and Mixture Stiffness (GPa)								Test Time (sec) and Mixture m-value							
(%)	Temp (C)	Rep	8	15	30	60	120	240	480	960	8	15	30	60	120	240	480	960
High	-24	1	21.56	20.96	20.12	19.14	18.02	16.81	15.53	14.20	0.039	0.052	0.066	0.080	0.094	0.108	0.121	0.135
V_a = 1.0%		2	19.47	18.83	18.02	17.14	16.18	15.17	14.12	13.06	0.049	0.058	0.068	0.078	0.088	0.098	0.108	0.118
		3	20.78	20.13	19.35	18.50	17.60	16.66	15.69	14.70	0.047	0.054	0.061	0.068	0.076	0.083	0.090	0.098
		4	20.19	19.53	18.66	17.67	16.57	15.41	14.19	12.95	0.047	0.059	0.072	0.086	0.099	0.112	0.125	0.138
		5	20.38	19.77	19.03	18.23	17.38	16.49	15.57	14.62	0.045	0.051	0.058	0.065	0.073	0.080	0.087	0.094
		Avg	**20.48**	**19.84**	**19.04**	**18.13**	**17.15**	**16.11**	**15.02**	**13.91**	**0.045**	**0.055**	**0.065**	**0.075**	**0.086**	**0.096**	**0.106**	**0.117**
		StdDev	**0.77**	**0.78**	**0.78**	**0.77**	**0.76**	**0.76**	**0.79**	**0.84**	**0.004**	**0.004**	**0.006**	**0.008**	**0.011**	**0.014**	**0.017**	**0.021**
	-18	1	18.36	17.70	16.95	16.19	15.42	14.65	13.88	13.12	0.057	0.060	0.064	0.068	0.072	0.076	0.080	0.084
		2	15.59	15.08	14.41	13.66	12.85	11.98	11.07	10.15	0.048	0.059	0.071	0.083	0.095	0.107	0.119	0.131
		3	17.80	16.99	16.10	15.21	14.34	13.48	12.63	11.80	0.072	0.076	0.080	0.084	0.088	0.092	0.095	0.099
		4	20.15	19.29	18.34	17.38	16.43	15.49	14.57	13.66	0.068	0.071	0.075	0.079	0.083	0.087	0.091	0.095
		5	16.66	16.06	15.34	14.56	13.75	12.91	12.06	11.19	0.055	0.062	0.070	0.079	0.087	0.095	0.103	0.111
		Avg	**17.71**	**17.02**	**16.23**	**15.40**	**14.56**	**13.70**	**12.84**	**11.99**	**0.060**	**0.066**	**0.072**	**0.078**	**0.085**	**0.091**	**0.098**	**0.104**
		StdDev	**1.73**	**1.61**	**1.51**	**1.44**	**1.40**	**1.39**	**1.40**	**1.42**	**0.010**	**0.007**	**0.006**	**0.006**	**0.008**	**0.011**	**0.015**	**0.018**
Med	-24	1	18.55	18.19	17.70	17.11	16.44	15.69	14.88	14.02	0.027	0.035	0.044	0.053	0.063	0.072	0.081	0.090
V_a = 3.4%		2	19.64	19.08	18.38	17.60	16.75	15.86	14.92	13.96	0.042	0.050	0.058	0.067	0.075	0.084	0.092	0.101
		3	19.76	19.31	18.76	18.16	17.52	16.84	16.13	15.40	0.034	0.039	0.044	0.049	0.055	0.060	0.065	0.070
		4	21.77	21.25	20.51	19.62	18.61	17.49	16.29	15.04	0.033	0.044	0.057	0.070	0.083	0.096	0.109	0.122
		5	15.37	14.92	14.34	13.68	12.96	12.18	11.36	10.53	0.042	0.052	0.062	0.073	0.084	0.095	0.105	0.116
		Avg	**19.02**	**18.55**	**17.94**	**17.24**	**16.46**	**15.61**	**14.72**	**13.79**	**0.036**	**0.044**	**0.053**	**0.063**	**0.072**	**0.081**	**0.090**	**0.100**
		StdDev	**2.35**	**2.32**	**2.26**	**2.20**	**2.13**	**2.05**	**1.99**	**1.93**	**0.007**	**0.007**	**0.009**	**0.011**	**0.013**	**0.015**	**0.018**	**0.021**
	-18	1	17.60	17.12	16.57	16.00	15.41	14.82	14.22	13.61	0.043	0.046	0.049	0.052	0.055	0.058	0.062	0.065
		2	21.82	21.15	20.34	19.45	18.49	17.50	16.47	15.41	0.046	0.053	0.061	0.068	0.076	0.084	0.092	0.099
		3	17.16	16.62	15.93	15.14	14.28	13.36	12.41	11.43	0.045	0.056	0.067	0.079	0.090	0.102	0.113	0.124
		4	22.31	21.61	20.77	19.84	18.86	17.83	16.76	15.67	0.047	0.054	0.062	0.069	0.077	0.085	0.093	0.101
		5	19.81	19.31	18.61	17.77	16.81	15.76	14.64	13.47	0.035	0.047	0.060	0.073	0.087	0.100	0.113	0.126
		Avg	**19.74**	**19.16**	**18.44**	**17.64**	**16.77**	**15.85**	**14.90**	**13.92**	**0.043**	**0.051**	**0.060**	**0.068**	**0.077**	**0.086**	**0.094**	**0.103**
		StdDev	**2.35**	**2.27**	**2.17**	**2.07**	**1.96**	**1.86**	**1.78**	**1.72**	**0.005**	**0.005**	**0.007**	**0.010**	**0.014**	**0.017**	**0.021**	**0.025**

Table B.54 *BBR* Mixture Data for *R-1* RAP Source, 138 C, None, 65 Gyrations

P_{AC}	Test		Test Time (sec) and Mixture Stiffness (GPa)								Test Time (sec) and Mixture m-value							
(%)	Temp (C)	Rep	8	15	30	60	120	240	480	960	8	15	30	60	120	240	480	960
High	-24	1	24.64	23.83	22.81	21.67	20.42	19.11	17.74	16.35	0.048	0.058	0.069	0.080	0.091	0.102	0.113	0.124
V_a = 1.0%		2	21.29	20.61	19.79	18.89	17.93	16.93	15.89	14.83	0.047	0.055	0.063	0.071	0.079	0.087	0.095	0.104
		3	19.88	19.27	18.53	17.72	16.86	15.96	15.03	14.08	0.046	0.053	0.060	0.068	0.075	0.083	0.090	0.098
		4	18.31	17.73	17.01	16.19	15.31	14.37	13.39	12.38	0.046	0.055	0.066	0.076	0.086	0.097	0.107	0.117
		5*	24.19	23.45	22.67	21.92	21.21	20.53	19.89	19.28	0.050	0.049	0.049	0.048	0.047	0.046	0.046	0.045
		Avg	**21.66**	**20.98**	**20.16**	**19.28**	**18.35**	**17.38**	**16.39**	**15.38**	**0.048**	**0.054**	**0.061**	**0.069**	**0.076**	**0.083**	**0.090**	**0.097**
		StdDev	**2.73**	**2.64**	**2.55**	**2.49**	**2.46**	**2.46**	**2.51**	**2.60**	**0.002**	**0.003**	**0.008**	**0.012**	**0.017**	**0.022**	**0.026**	**0.031**
	-18	1	13.77	13.36	12.87	12.35	11.79	11.21	10.60	9.99	0.044	0.050	0.057	0.063	0.070	0.077	0.083	0.090
		2	20.40	19.56	18.60	17.62	16.63	15.63	14.63	13.64	0.064	0.070	0.075	0.081	0.087	0.093	0.098	0.104
		3	22.53	21.79	20.86	19.80	18.66	17.44	16.17	14.88	0.047	0.058	0.069	0.080	0.092	0.103	0.115	0.126
		4	18.66	17.75	16.71	15.65	14.58	13.51	12.46	11.43	0.077	0.083	0.091	0.098	0.106	0.113	0.121	0.128
		5*	3.93	3.90	3.87	3.83	3.78	3.73	3.67	3.61	0.010	0.012	0.014	0.017	0.019	0.021	0.024	0.026
		Avg	**18.84**	**18.12**	**17.26**	**16.36**	**15.42**	**14.45**	**13.47**	**12.49**	**0.058**	**0.065**	**0.073**	**0.081**	**0.089**	**0.097**	**0.104**	**0.112**
		StdDev	**3.73**	**3.57**	**3.38**	**3.16**	**2.94**	**2.69**	**2.44**	**2.19**	**0.015**	**0.014**	**0.014**	**0.014**	**0.015**	**0.015**	**0.017**	**0.018**
Med	-24	1	23.57	22.88	22.03	21.08	20.06	18.97	17.85	16.69	0.043	0.051	0.059	0.068	0.076	0.084	0.093	0.101
V_a = 3.5%		2	19.90	19.38	18.71	17.95	17.11	16.20	15.24	14.25	0.038	0.046	0.055	0.065	0.074	0.083	0.093	0.102
		3	17.56	16.93	16.16	15.31	14.42	13.48	12.52	11.55	0.054	0.063	0.072	0.082	0.092	0.102	0.111	0.121
		4	19.03	18.61	18.08	17.48	16.83	16.13	15.38	14.61	0.033	0.039	0.045	0.052	0.058	0.065	0.071	0.078
		5*	21.18	20.85	20.81	21.11	21.77	22.81	24.29	26.29	0.036	0.015	-0.009	-0.032	-0.056	-0.079	-0.103	-0.126
		Avg	**20.01**	**19.45**	**18.74**	**17.96**	**17.10**	**16.20**	**15.25**	**14.27**	**0.042**	**0.050**	**0.058**	**0.067**	**0.075**	**0.084**	**0.092**	**0.101**
		StdDev	**2.56**	**2.51**	**2.44**	**2.38**	**2.31**	**2.24**	**2.18**	**2.11**	**0.009**	**0.010**	**0.011**	**0.013**	**0.014**	**0.015**	**0.016**	**0.018**
	-18	1	15.43	14.94	14.33	13.66	12.95	12.20	11.42	10.63	0.048	0.056	0.064	0.073	0.082	0.090	0.099	0.108
		2	16.86	16.38	15.77	15.07	14.30	13.47	12.61	11.71	0.041	0.050	0.060	0.071	0.081	0.091	0.101	0.111
		3*	6.11	6.06	5.99	5.89	5.79	5.66	5.52	5.37	0.011	0.015	0.020	0.025	0.029	0.034	0.038	0.043
		4	21.28	20.59	19.76	18.85	17.88	16.86	15.81	14.74	0.048	0.056	0.064	0.072	0.080	0.089	0.097	0.105
		5	16.25	15.91	15.42	14.81	14.11	13.33	12.49	11.61	0.028	0.039	0.052	0.064	0.076	0.088	0.100	0.112
		Avg	**17.46**	**16.96**	**16.32**	**15.60**	**14.81**	**13.97**	**13.08**	**12.17**	**0.041**	**0.050**	**0.060**	**0.070**	**0.080**	**0.090**	**0.099**	**0.109**
		StdDev	**2.62**	**2.50**	**2.37**	**2.25**	**2.13**	**2.01**	**1.90**	**1.78**	**0.009**	**0.008**	**0.006**	**0.004**	**0.003**	**0.001**	**0.002**	**0.003**

* Outlier that was omitted from analysis.

Table B.55 *BBR* Mixture Data for *R-1* RAP Source, 138 C, None, 85 Gyrations

P_{AC}	Test		Test Time (sec) and Mixture Stiffness (GPa)								Test Time (sec) and Mixture m-value							
(%)	Temp (C)	Rep	8	15	30	60	120	240	480	960	8	15	30	60	120	240	480	960
High	-24	1	25.10	24.51	23.84	23.15	22.45	21.74	21.01	20.28	0.037	0.039	0.041	0.043	0.045	0.048	0.050	0.052
V_a = 0.6%		2	17.08	16.66	16.11	15.46	14.74	13.96	13.12	12.25	0.035	0.044	0.054	0.064	0.074	0.084	0.094	0.104
		3	22.99	22.28	21.38	20.38	19.30	18.15	16.96	15.74	0.046	0.055	0.064	0.074	0.084	0.093	0.103	0.112
		4	17.65	17.04	16.17	15.11	13.92	12.63	11.30	9.96	0.046	0.066	0.087	0.108	0.129	0.150	0.172	0.193
		5	21.04	20.39	19.57	18.65	17.65	16.59	15.48	14.35	0.045	0.054	0.064	0.074	0.085	0.095	0.105	0.115
		Avg	**20.77**	**20.18**	**19.41**	**18.55**	**17.61**	**16.61**	**15.58**	**14.52**	**0.042**	**0.051**	**0.062**	**0.073**	**0.083**	**0.094**	**0.105**	**0.115**
		StdDev	**3.43**	**3.37**	**3.35**	**3.39**	**3.47**	**3.59**	**3.74**	**3.90**	**0.006**	**0.010**	**0.017**	**0.023**	**0.030**	**0.037**	**0.044**	**0.050**
	-18	1	18.43	17.75	16.89	15.96	14.96	13.91	12.77	11.71	0.055	0.065	0.077	0.088	0.099	0.110	0.122	0.133
		2	18.04	17.61	17.07	16.47	15.82	15.13	14.36	13.62	0.036	0.042	0.048	0.055	0.061	0.068	0.074	0.081
		3	18.92	18.31	17.49	16.56	15.52	14.41	13.19	12.02	0.046	0.059	0.073	0.086	0.100	0.114	0.128	0.142
		4*	6.56	6.51	6.43	6.33	6.22	6.08	5.92	5.75	0.011	0.015	0.020	0.025	0.030	0.034	0.040	0.044
		5*	15.83	15.09	14.43	13.93	13.55	13.31	13.17	13.16	0.082	0.070	0.058	0.045	0.033	0.020	0.007	-0.005
		Avg	**18.46**	**17.89**	**17.15**	**16.33**	**15.43**	**14.48**	**13.44**	**12.45**	**0.046**	**0.055**	**0.066**	**0.076**	**0.087**	**0.097**	**0.108**	**0.119**
		StdDev	**0.44**	**0.37**	**0.31**	**0.32**	**0.44**	**0.61**	**0.82**	**1.03**	**0.010**	**0.012**	**0.016**	**0.019**	**0.022**	**0.025**	**0.030**	**0.033**
Med	-24	1	16.84	16.58	16.25	15.87	15.44	14.97	14.47	13.93	0.022	0.027	0.032	0.037	0.042	0.047	0.052	0.057
V_a = 2.3%		2	17.11	16.76	16.31	15.78	15.20	14.56	13.88	13.16	0.029	0.036	0.043	0.051	0.058	0.066	0.073	0.080
		3	20.44	20.10	19.53	18.80	17.92	16.91	15.80	14.62	0.021	0.034	0.048	0.062	0.077	0.091	0.105	0.119
		4	20.47	19.80	19.01	18.19	17.34	16.46	15.58	14.69	0.051	0.056	0.061	0.066	0.072	0.077	0.082	0.088
		5	25.44	25.23	24.67	23.77	22.58	21.14	19.50	17.73	0.003	0.022	0.043	0.064	0.085	0.106	0.127	0.147
		Avg	**20.06**	**19.69**	**19.15**	**18.48**	**17.69**	**16.81**	**15.84**	**14.83**	**0.025**	**0.035**	**0.046**	**0.056**	**0.067**	**0.077**	**0.088**	**0.098**
		StdDev	**3.47**	**3.50**	**3.43**	**3.25**	**2.97**	**2.61**	**2.19**	**1.74**	**0.017**	**0.013**	**0.011**	**0.012**	**0.017**	**0.023**	**0.029**	**0.035**
	-18	1	18.33	17.91	17.41	16.88	16.33	15.75	15.16	14.55	0.035	0.039	0.042	0.046	0.050	0.054	0.057	0.061
		2	17.50	16.90	16.19	15.43	14.62	13.79	12.95	12.09	0.052	0.059	0.066	0.073	0.081	0.088	0.095	0.103
		3	21.72	21.11	20.33	19.44	18.46	17.41	16.30	15.16	0.041	0.050	0.060	0.070	0.080	0.090	0.100	0.110
		4	24.28	23.55	22.70	21.80	20.86	19.90	18.91	17.91	0.046	0.051	0.056	0.061	0.066	0.071	0.076	0.081
		5	23.87	23.51	22.85	21.95	20.84	19.56	18.13	16.62	0.017	0.032	0.049	0.066	0.083	0.100	0.117	0.134
		Avg	**21.14**	**20.60**	**19.90**	**19.10**	**18.22**	**17.28**	**16.29**	**15.27**	**0.038**	**0.046**	**0.055**	**0.063**	**0.072**	**0.081**	**0.089**	**0.098**
		StdDev	**3.11**	**3.10**	**3.03**	**2.91**	**2.76**	**2.58**	**2.38**	**2.21**	**0.013**	**0.010**	**0.009**	**0.011**	**0.014**	**0.018**	**0.023**	**0.028**

* Outlier that was omitted from analysis.

Table B.56 *BBR* Mixture Data for *R-1* RAP Source, 138 C, Sasobit®, 50 Gyrations

P_{AC}	Test		Test Time (sec) and Mixture Stiffness (GPa)								Test Time (sec) and Mixture m-value							
(%)	Temp (C)	Rep	8	15	30	60	120	240	480	960	8	15	30	60	120	240	480	960
High	-24	1	18.68	18.04	17.22	16.30	15.30	14.24	13.14	12.02	0.050	0.061	0.073	0.085	0.097	0.110	0.122	0.134
V_a = 1.2%		2	18.24	17.45	16.59	15.73	14.90	14.08	13.28	12.50	0.069	0.072	0.075	0.078	0.080	0.083	0.086	0.089
		3	15.77	15.46	15.10	14.71	14.30	13.87	13.43	12.96	0.030	0.033	0.036	0.039	0.042	0.046	0.049	0.052
		4*	9.64	9.24	8.74	8.18	7.58	6.96	6.33	5.70	0.061	0.074	0.088	0.102	0.116	0.130	0.145	0.159
		5	21.54	20.81	19.93	18.98	17.99	16.96	15.91	14.84	0.052	0.059	0.066	0.074	0.081	0.089	0.096	0.104
		Avg	**18.56**	**17.94**	**17.21**	**16.43**	**15.62**	**14.79**	**13.94**	**13.08**	**0.050**	**0.056**	**0.063**	**0.069**	**0.075**	**0.082**	**0.088**	**0.095**
		StdDev	**2.37**	**2.21**	**2.02**	**1.82**	**1.63**	**1.46**	**1.32**	**1.23**	**0.016**	**0.017**	**0.018**	**0.021**	**0.023**	**0.027**	**0.030**	**0.034**
	-18	1*	5.09	5.07	5.03	4.98	4.92	4.86	4.78	4.70	0.007	0.010	0.013	0.015	0.018	0.021	0.023	0.026
		2	17.77	17.36	16.70	15.85	14.85	13.73	12.53	11.28	0.029	0.046	0.065	0.085	0.104	0.123	0.142	0.161
		3	17.61	17.15	16.51	15.75	14.88	13.93	12.92	11.88	0.036	0.048	0.062	0.075	0.088	0.102	0.115	0.129
		4	13.42	12.90	12.33	11.76	11.20	10.64	10.10	9.56	0.062	0.064	0.067	0.069	0.072	0.075	0.077	0.080
		5	16.65	16.10	15.47	14.80	14.11	13.41	12.69	11.97	0.051	0.055	0.061	0.066	0.071	0.077	0.082	0.087
		Avg	**16.36**	**15.88**	**15.25**	**14.54**	**13.76**	**12.93**	**12.06**	**11.17**	**0.045**	**0.053**	**0.064**	**0.074**	**0.084**	**0.094**	**0.104**	**0.114**
		StdDev	**2.02**	**2.06**	**2.02**	**1.91**	**1.74**	**1.54**	**1.32**	**1.12**	**0.015**	**0.008**	**0.003**	**0.008**	**0.016**	**0.023**	**0.030**	**0.038**
Med	-24	1	22.95	22.41	21.62	20.65	19.54	18.30	16.97	15.58	0.032	0.045	0.059	0.073	0.087	0.102	0.116	0.130
V_a = 3.4%		2	15.89	15.42	14.79	14.05	13.23	12.33	11.39	10.42	0.041	0.054	0.067	0.081	0.094	0.108	0.121	0.135
		3	18.55	18.01	17.35	16.65	15.90	15.12	14.31	13.49	0.045	0.050	0.057	0.063	0.069	0.076	0.082	0.089
		4	21.40	20.88	20.14	19.23	18.19	17.03	15.79	14.49	0.032	0.045	0.059	0.074	0.088	0.102	0.116	0.131
		5*	25.59	24.62	23.65	22.77	21.97	21.26	20.61	20.04	0.063	0.060	0.057	0.053	0.049	0.046	0.042	0.039
		Avg	**19.70**	**19.18**	**18.48**	**17.65**	**16.71**	**15.69**	**14.61**	**13.50**	**0.037**	**0.048**	**0.060**	**0.073**	**0.085**	**0.097**	**0.109**	**0.121**
		StdDev	**3.12**	**3.10**	**3.03**	**2.91**	**2.77**	**2.59**	**2.41**	**2.22**	**0.007**	**0.004**	**0.005**	**0.007**	**0.011**	**0.014**	**0.018**	**0.022**
	-18	1*	6.33	6.27	6.21	6.13	6.05	5.96	5.87	5.77	0.013	0.014	0.016	0.018	0.020	0.022	0.024	0.026
		2	19.76	19.33	18.69	17.88	16.93	15.86	14.71	13.49	0.027	0.041	0.056	0.071	0.086	0.102	0.117	0.132
		3	20.53	20.11	19.49	18.74	17.85	16.87	15.80	14.67	0.027	0.038	0.051	0.063	0.076	0.088	0.101	0.113
		4	20.28	19.58	18.79	17.97	17.14	16.29	15.44	14.60	0.054	0.058	0.062	0.066	0.071	0.075	0.079	0.084
		5	21.50	20.92	20.15	19.25	18.23	17.12	15.95	14.74	0.037	0.048	0.060	0.072	0.084	0.096	0.108	0.120
		Avg	**20.52**	**19.99**	**19.28**	**18.46**	**17.54**	**16.54**	**15.48**	**14.38**	**0.036**	**0.046**	**0.057**	**0.068**	**0.079**	**0.090**	**0.101**	**0.112**
		StdDev	**0.73**	**0.70**	**0.68**	**0.65**	**0.61**	**0.57**	**0.55**	**0.59**	**0.013**	**0.009**	**0.005**	**0.004**	**0.007**	**0.012**	**0.016**	**0.020**

* Outlier that was omitted from analysis.

Table B.57 *BBR* Mixture Data for *R-1* RAP Source, 138 C, Sasobit®, 65 Gyrations

P_{AC}	Test		Test Time (sec) and Mixture Stiffness (GPa)								Test Time (sec) and Mixture m-value							
(%)	Temp (C)	Rep	8	15	30	60	120	240	480	960	8	15	30	60	120	240	480	960
High	-24	1	15.47	15.20	14.88	14.53	14.17	13.79	13.40	12.99	0.027	0.029	0.032	0.035	0.038	0.040	0.043	0.046
V_a = 0.6%		2	18.15	17.79	17.27	16.66	15.95	15.16	14.31	13.41	0.028	0.037	0.047	0.058	0.068	0.078	0.089	0.099
		3	18.65	18.20	17.54	16.73	15.79	14.75	13.64	12.49	0.033	0.046	0.061	0.076	0.091	0.105	0.120	0.135
		4	19.84	19.27	18.59	17.86	17.09	16.30	15.48	14.65	0.044	0.049	0.055	0.060	0.066	0.072	0.077	0.083
		5	20.07	19.52	18.79	17.92	16.95	15.90	14.78	13.63	0.038	0.049	0.062	0.074	0.086	0.099	0.111	0.124
		Avg	**18.44**	**17.99**	**17.41**	**16.74**	**15.99**	**15.18**	**14.32**	**13.43**	**0.034**	**0.042**	**0.051**	**0.061**	**0.070**	**0.079**	**0.088**	**0.097**
		StdDev	**1.84**	**1.72**	**1.56**	**1.37**	**1.17**	**0.98**	**0.85**	**0.81**	**0.007**	**0.009**	**0.012**	**0.016**	**0.021**	**0.026**	**0.030**	**0.035**
	-18	1	17.10	16.60	15.98	15.29	14.54	13.75	12.92	12.06	0.043	0.051	0.059	0.068	0.077	0.085	0.094	0.103
		2	21.74	21.03	20.16	19.21	18.21	17.15	16.06	14.96	0.049	0.057	0.065	0.073	0.082	0.090	0.099	0.107
		3	21.90	21.17	20.34	19.47	18.58	17.66	16.74	15.81	0.051	0.056	0.060	0.065	0.070	0.075	0.080	0.085
		4	22.06	21.40	20.57	19.64	18.63	17.56	16.43	15.28	0.044	0.052	0.062	0.071	0.081	0.091	0.100	0.110
		5	15.45	14.86	14.17	13.43	12.66	11.87	11.06	10.25	0.058	0.065	0.073	0.081	0.089	0.097	0.105	0.113
		Avg	**19.65**	**19.01**	**18.24**	**17.41**	**16.52**	**15.60**	**14.64**	**13.67**	**0.049**	**0.056**	**0.064**	**0.072**	**0.080**	**0.088**	**0.096**	**0.104**
		StdDev	**3.14**	**3.06**	**2.97**	**2.86**	**2.75**	**2.64**	**2.52**	**2.40**	**0.006**	**0.006**	**0.006**	**0.006**	**0.007**	**0.008**	**0.010**	**0.011**
Med	-24	1	21.88	21.55	21.03	20.35	19.53	18.59	17.54	16.41	0.018	0.029	0.041	0.053	0.065	0.078	0.090	0.102
V_a = 3.0%		2	19.30	18.77	18.11	17.36	16.55	15.69	14.78	13.84	0.040	0.048	0.056	0.065	0.073	0.082	0.090	0.099
		3	19.24	18.70	18.08	17.45	16.80	16.14	15.47	14.80	0.044	0.047	0.050	0.053	0.056	0.059	0.062	0.066
		4	19.96	19.62	19.14	18.56	17.89	17.14	16.32	15.46	0.024	0.032	0.040	0.049	0.057	0.066	0.075	0.083
		5	15.62	15.24	14.78	14.29	13.76	13.20	12.62	12.02	0.037	0.042	0.047	0.052	0.057	0.062	0.068	0.073
		Avg	**19.20**	**18.78**	**18.23**	**17.60**	**16.91**	**16.15**	**15.35**	**14.50**	**0.033**	**0.039**	**0.047**	**0.054**	**0.062**	**0.069**	**0.077**	**0.084**
		StdDev	**2.27**	**2.29**	**2.27**	**2.21**	**2.12**	**1.99**	**1.84**	**1.68**	**0.011**	**0.009**	**0.007**	**0.006**	**0.007**	**0.010**	**0.013**	**0.016**
	-18	1	18.23	17.74	17.15	16.51	15.84	15.13	14.39	13.64	0.041	0.046	0.052	0.057	0.063	0.069	0.075	0.080
		2	20.09	19.41	18.61	17.75	16.85	15.93	14.98	14.02	0.051	0.058	0.064	0.071	0.078	0.085	0.092	0.099
		3	15.73	15.33	14.83	14.27	13.66	13.01	12.33	11.62	0.037	0.044	0.052	0.059	0.067	0.074	0.082	0.089
		4	11.24	10.95	10.62	10.28	9.91	9.53	9.15	8.75	0.039	0.042	0.046	0.050	0.054	0.058	0.062	0.066
		5	17.63	16.97	16.21	15.42	14.60	13.77	12.93	12.09	0.058	0.063	0.069	0.075	0.082	0.088	0.094	0.100
		Avg	**16.58**	**16.08**	**15.48**	**14.85**	**14.17**	**13.47**	**12.76**	**12.02**	**0.045**	**0.051**	**0.057**	**0.063**	**0.069**	**0.075**	**0.081**	**0.087**
		StdDev	**3.37**	**3.22**	**3.04**	**2.86**	**2.67**	**2.48**	**2.28**	**2.09**	**0.009**	**0.009**	**0.010**	**0.010**	**0.011**	**0.012**	**0.013**	**0.014**

Table B.58 *BBR* Mixture Data for *R-1* RAP Source, 138 C, Sasobit®, 85 Gyrations

P_{AC}	Test		Test Time (sec) and Mixture Stiffness (GPa)								Test Time (sec) and Mixture m-value							
(%)	Temp (C)	Rep	8	15	30	60	120	240	480	960	8	15	30	60	120	240	480	960
High	-24	1	20.41	19.78	19.01	18.16	17.25	16.28	15.29	14.27	0.046	0.053	0.062	0.070	0.079	0.087	0.095	0.104
V_a = 0.3%		2	18.76	18.27	17.67	17.02	16.32	15.59	14.82	14.03	0.039	0.045	0.051	0.057	0.064	0.070	0.076	0.082
		3	18.90	18.47	17.96	17.40	16.80	16.16	15.49	14.80	0.034	0.038	0.043	0.048	0.053	0.058	0.063	0.068
		4	18.92	18.32	17.53	16.63	15.62	14.54	13.42	12.27	0.045	0.057	0.070	0.083	0.096	0.110	0.123	0.136
		5	22.81	22.28	21.55	20.66	19.65	18.53	17.33	16.07	0.031	0.042	0.054	0.067	0.079	0.091	0.103	0.115
		Avg	**19.96**	**19.43**	**18.75**	**17.97**	**17.13**	**16.22**	**15.27**	**14.29**	**0.039**	**0.047**	**0.056**	**0.065**	**0.074**	**0.083**	**0.092**	**0.101**
		StdDev	**1.73**	**1.71**	**1.67**	**1.61**	**1.53**	**1.46**	**1.41**	**1.38**	**0.007**	**0.008**	**0.010**	**0.013**	**0.016**	**0.020**	**0.023**	**0.027**
	-18	1	22.13	21.57	20.88	20.12	19.30	18.43	17.52	16.58	0.038	0.044	0.050	0.057	0.063	0.070	0.076	0.083
		2	23.16	22.38	21.44	20.43	19.36	18.24	17.10	15.95	0.051	0.058	0.066	0.074	0.081	0.089	0.097	0.105
		3	20.97	20.31	19.48	18.54	17.54	16.47	15.35	14.22	0.046	0.056	0.066	0.076	0.086	0.096	0.106	0.116
		4	15.80	15.26	14.65	14.02	13.37	12.72	12.05	11.39	0.053	0.057	0.061	0.066	0.070	0.075	0.079	0.084
		5	22.02	21.40	20.63	19.79	18.88	17.91	16.91	15.87	0.042	0.049	0.056	0.064	0.072	0.080	0.087	0.095
		Avg	**20.81**	**20.18**	**19.42**	**18.58**	**17.69**	**16.76**	**15.79**	**14.80**	**0.046**	**0.053**	**0.060**	**0.067**	**0.075**	**0.082**	**0.089**	**0.097**
		StdDev	**2.91**	**2.85**	**2.76**	**2.65**	**2.52**	**2.39**	**2.24**	**2.10**	**0.006**	**0.006**	**0.007**	**0.008**	**0.009**	**0.011**	**0.012**	**0.014**
Med	-24	1	18.20	17.84	17.33	16.71	15.99	15.19	14.32	13.40	0.027	0.037	0.047	0.058	0.069	0.080	0.090	0.101
V_a = 2.7%		2	18.76	18.14	17.48	16.84	16.21	15.61	15.01	14.44	0.053	0.053	0.054	0.054	0.055	0.055	0.056	0.057
		3	12.55	12.07	11.50	10.90	10.26	9.61	8.95	8.29	0.058	0.066	0.074	0.082	0.090	0.099	0.107	0.115
		4	22.29	21.82	21.08	20.14	19.02	17.76	16.40	14.97	0.027	0.041	0.058	0.074	0.091	0.107	0.123	0.140
		5*	23.67	22.77	21.90	21.15	20.51	19.96	19.51	19.14	0.064	0.059	0.053	0.048	0.042	0.036	0.030	0.025
		Avg	**17.95**	**17.47**	**16.85**	**16.15**	**15.37**	**14.54**	**13.67**	**12.77**	**0.041**	**0.049**	**0.058**	**0.067**	**0.076**	**0.085**	**0.094**	**0.103**
		StdDev	**4.03**	**4.03**	**3.96**	**3.84**	**3.67**	**3.47**	**3.26**	**3.06**	**0.017**	**0.013**	**0.011**	**0.013**	**0.017**	**0.023**	**0.029**	**0.035**
	-18	1	20.70	19.71	18.63	17.57	16.52	15.49	14.49	13.53	0.076	0.080	0.083	0.087	0.091	0.094	0.098	0.102
		2	17.34	16.89	16.31	15.65	14.92	14.13	13.30	12.44	0.037	0.046	0.055	0.064	0.074	0.083	0.092	0.102
		3	21.29	20.58	19.70	18.74	17.70	16.62	15.49	14.35	0.050	0.058	0.068	0.077	0.087	0.096	0.106	0.115
		4	16.16	15.79	15.32	14.81	14.24	13.64	13.00	12.33	0.034	0.040	0.046	0.053	0.059	0.066	0.073	0.079
		5	17.76	17.23	16.64	16.06	15.48	14.90	14.33	13.76	0.047	0.049	0.051	0.052	0.054	0.056	0.057	0.059
		Avg	**18.65**	**18.04**	**17.32**	**16.56**	**15.77**	**14.96**	**14.12**	**13.28**	**0.049**	**0.054**	**0.061**	**0.067**	**0.073**	**0.079**	**0.085**	**0.091**
		StdDev	**2.23**	**2.02**	**1.79**	**1.57**	**1.36**	**1.17**	**1.00**	**0.87**	**0.017**	**0.016**	**0.015**	**0.015**	**0.016**	**0.018**	**0.020**	**0.022**

* Outlier that was omitted from analysis.

Table B.59 *BBR* Mixture Data for *R-1* RAP Source, 138 C, Evotherm™, 50 Gyrations

P_{AC}	Test		Test Time (sec) and Mixture Stiffness (GPa)								Test Time (sec) and Mixture m-value							
(%)	Temp (C)	Rep	8	15	30	60	120	240	480	960	8	15	30	60	120	240	480	960
High	-24	1	20.78	20.21	19.48	18.65	17.73	16.75	15.71	14.64	0.039	0.048	0.058	0.068	0.078	0.087	0.097	0.107
V_a = 0.7%		2	16.86	16.32	15.61	14.80	13.89	12.93	11.92	10.89	0.046	0.058	0.071	0.084	0.097	0.111	0.124	0.137
		3	15.43	15.04	14.54	13.97	13.35	12.67	11.96	11.23	0.037	0.045	0.053	0.062	0.070	0.079	0.087	0.096
		4	19.09	18.55	17.90	17.19	16.43	15.63	14.81	13.96	0.042	0.048	0.055	0.062	0.068	0.075	0.082	0.089
		5	19.23	18.60	17.85	17.06	16.23	15.37	14.49	13.59	0.050	0.056	0.062	0.069	0.075	0.082	0.089	0.095
		Avg	**18.28**	**17.74**	**17.08**	**16.33**	**15.53**	**14.67**	**13.78**	**12.86**	**0.043**	**0.051**	**0.060**	**0.069**	**0.078**	**0.087**	**0.096**	**0.105**
		StdDev	**2.12**	**2.05**	**1.98**	**1.91**	**1.84**	**1.79**	**1.73**	**1.69**	**0.005**	**0.005**	**0.007**	**0.009**	**0.012**	**0.014**	**0.017**	**0.019**
	-18	1	19.66	18.82	17.90	16.98	16.08	15.18	14.30	13.44	0.068	0.071	0.074	0.078	0.081	0.084	0.088	0.091
		2	19.88	19.26	18.50	17.67	16.79	15.87	14.91	13.94	0.047	0.054	0.062	0.070	0.078	0.086	0.093	0.101
		3	17.10	16.49	15.75	14.96	14.12	13.25	12.36	11.46	0.054	0.062	0.070	0.079	0.088	0.096	0.105	0.113
		4	17.41	16.81	16.04	15.18	14.25	13.26	12.24	11.20	0.050	0.061	0.073	0.086	0.098	0.110	0.122	0.134
		5	20.45	19.77	18.92	17.97	16.94	15.85	14.73	13.58	0.049	0.058	0.069	0.080	0.090	0.101	0.112	0.123
		Avg	**18.90**	**18.23**	**17.42**	**16.55**	**15.64**	**14.68**	**13.71**	**12.72**	**0.053**	**0.061**	**0.070**	**0.078**	**0.087**	**0.095**	**0.104**	**0.112**
		StdDev	**1.53**	**1.49**	**1.44**	**1.40**	**1.37**	**1.33**	**1.31**	**1.29**	**0.008**	**0.006**	**0.005**	**0.006**	**0.008**	**0.011**	**0.014**	**0.017**
Med	-24	1	21.62	21.29	20.78	20.15	19.41	18.56	17.63	16.63	0.021	0.030	0.039	0.049	0.059	0.069	0.079	0.089
V_a = 3.6%		2	21.60	21.14	20.45	19.58	18.57	17.43	16.20	14.91	0.028	0.041	0.055	0.070	0.084	0.098	0.113	0.127
		3	21.32	20.56	19.68	18.76	17.80	16.82	15.83	14.84	0.055	0.060	0.066	0.072	0.078	0.085	0.091	0.097
		4*	10.84	10.55	10.14	9.65	9.10	8.50	7.86	7.19	0.037	0.050	0.064	0.078	0.092	0.106	0.120	0.134
		5*	21.80	21.52	21.33	21.25	21.28	21.43	21.69	22.06	0.024	0.017	0.009	0.002	-0.006	-0.014	-0.021	-0.029
		Avg	**21.51**	**21.00**	**20.30**	**19.50**	**18.59**	**17.60**	**16.55**	**15.46**	**0.035**	**0.044**	**0.053**	**0.064**	**0.074**	**0.084**	**0.094**	**0.104**
		StdDev	**0.17**	**0.39**	**0.56**	**0.70**	**0.81**	**0.88**	**0.95**	**1.01**	**0.018**	**0.015**	**0.014**	**0.013**	**0.013**	**0.015**	**0.017**	**0.020**
	-18	1	23.92	23.17	22.34	21.50	20.65	19.81	18.96	18.12	0.049	0.052	0.054	0.057	0.059	0.062	0.064	0.067
		2	23.84	22.83	21.69	20.53	19.36	18.20	17.04	15.89	0.066	0.071	0.076	0.082	0.087	0.092	0.098	0.103
		3	21.35	20.57	19.58	18.47	17.26	16.00	14.69	13.37	0.053	0.065	0.078	0.091	0.104	0.116	0.129	0.142
		4	23.30	22.50	21.52	20.43	19.28	18.06	16.81	15.54	0.051	0.060	0.069	0.079	0.089	0.099	0.108	0.118
		5	23.66	22.76	21.74	20.69	19.62	18.54	17.46	16.38	0.059	0.064	0.069	0.074	0.079	0.084	0.090	0.095
		Avg	**23.21**	**22.37**	**21.37**	**20.32**	**19.24**	**18.12**	**16.99**	**15.86**	**0.056**	**0.062**	**0.069**	**0.076**	**0.084**	**0.091**	**0.098**	**0.105**
		StdDev	**1.07**	**1.03**	**1.05**	**1.12**	**1.23**	**1.37**	**1.54**	**1.71**	**0.007**	**0.007**	**0.009**	**0.013**	**0.016**	**0.020**	**0.024**	**0.028**

* Outlier that was omitted from analysis.

Table B.60 *BBR* Mixture Data for *R-1* RAP Source, 138 C, Evotherm™, 65 Gyrations

P_{AC}	Test		Test Time (sec) and Mixture Stiffness (GPa)								Test Time (sec) and Mixture m-value							
(%)	Temp (C)	Rep	8	15	30	60	120	240	480	960	8	15	30	60	120	240	480	960
High	-24	1	19.82	19.25	18.52	17.67	16.74	15.75	14.64	13.57	0.041	0.051	0.062	0.073	0.083	0.094	0.105	0.116
V_a = 0.7%		2	26.98	26.43	25.63	24.64	23.50	22.23	20.77	19.34	0.028	0.039	0.050	0.062	0.074	0.086	0.099	0.111
		3	25.44	24.74	23.83	22.82	21.71	20.52	19.20	17.94	0.041	0.049	0.058	0.067	0.077	0.086	0.095	0.104
		4	23.20	22.69	21.99	21.16	20.22	19.19	18.02	16.87	0.031	0.040	0.050	0.060	0.070	0.080	0.091	0.101
		5	22.28	21.57	20.71	19.78	18.78	17.73	16.59	15.51	0.048	0.055	0.063	0.071	0.079	0.087	0.095	0.103
		Avg	**23.55**	**22.94**	**22.13**	**21.21**	**20.19**	**19.09**	**17.85**	**16.65**	**0.038**	**0.047**	**0.057**	**0.067**	**0.077**	**0.087**	**0.097**	**0.107**
		StdDev	**2.78**	**2.78**	**2.75**	**2.69**	**2.61**	**2.50**	**2.36**	**2.22**	**0.008**	**0.007**	**0.006**	**0.005**	**0.005**	**0.005**	**0.005**	**0.006**
	-18	1	19.26	18.66	17.88	17.00	16.04	15.01	13.87	12.79	0.045	0.056	0.067	0.078	0.090	0.101	0.113	0.125
		2	18.93	18.31	17.57	16.75	15.89	14.99	14.00	13.06	0.049	0.056	0.064	0.072	0.080	0.089	0.097	0.105
		3	17.35	16.81	16.16	15.45	14.69	13.89	13.01	12.18	0.046	0.053	0.061	0.069	0.077	0.085	0.093	0.101
		4	20.58	19.83	18.90	17.90	16.84	15.73	14.53	13.41	0.055	0.064	0.074	0.083	0.093	0.103	0.113	0.123
		5	19.99	19.27	18.39	17.46	16.49	15.48	14.39	13.37	0.055	0.063	0.071	0.079	0.087	0.095	0.104	0.111
		Avg	**19.22**	**18.58**	**17.78**	**16.91**	**15.99**	**15.02**	**13.96**	**12.96**	**0.050**	**0.058**	**0.067**	**0.076**	**0.085**	**0.094**	**0.104**	**0.113**
		StdDev	**1.23**	**1.14**	**1.04**	**0.93**	**0.82**	**0.71**	**0.60**	**0.51**	**0.005**	**0.005**	**0.005**	**0.006**	**0.007**	**0.008**	**0.009**	**0.011**
Med	-24	1	24.02	23.49	22.73	21.80	20.72	19.53	18.24	16.88	0.030	0.041	0.054	0.067	0.079	0.092	0.105	0.118
V_a = 2.5%		2	20.67	19.99	19.24	18.49	17.74	17.00	16.27	15.54	0.052	0.054	0.056	0.058	0.061	0.063	0.065	0.067
		3	24.00	23.07	22.03	20.98	19.93	18.88	17.83	16.80	0.061	0.065	0.068	0.072	0.076	0.080	0.084	0.088
		4*	22.15	21.24	20.31	19.45	18.66	17.93	17.25	16.63	0.068	0.066	0.064	0.061	0.059	0.056	0.054	0.052
		5*	20.68	20.20	19.69	19.19	18.70	18.23	17.78	17.34	0.038	0.037	0.037	0.037	0.037	0.037	0.036	0.036
		Avg	**22.90**	**22.18**	**21.33**	**20.42**	**19.46**	**18.47**	**17.44**	**16.41**	**0.048**	**0.053**	**0.060**	**0.066**	**0.072**	**0.078**	**0.085**	**0.091**
		StdDev	**1.93**	**1.91**	**1.85**	**1.73**	**1.54**	**1.31**	**1.04**	**0.75**	**0.016**	**0.012**	**0.008**	**0.007**	**0.010**	**0.015**	**0.020**	**0.026**
	-18	1	22.07	21.18	20.14	19.05	17.92	16.78	15.63	14.48	0.062	0.069	0.077	0.084	0.091	0.099	0.106	0.114
		2	23.13	22.24	21.29	20.38	19.50	18.65	17.83	17.04	0.062	0.063	0.063	0.064	0.064	0.064	0.065	0.065
		3	21.64	20.99	20.14	19.17	18.11	16.98	15.80	14.58	0.044	0.054	0.065	0.076	0.088	0.099	0.110	0.121
		4	18.61	17.81	16.96	16.14	15.35	14.58	13.84	13.12	0.069	0.070	0.071	0.072	0.073	0.075	0.076	0.077
		5	23.53	23.16	22.47	21.51	20.31	18.92	17.39	15.78	0.016	0.034	0.053	0.073	0.092	0.112	0.131	0.151
		Avg	**21.80**	**21.08**	**20.20**	**19.25**	**18.24**	**17.18**	**16.10**	**15.00**	**0.051**	**0.058**	**0.066**	**0.074**	**0.082**	**0.090**	**0.098**	**0.106**
		StdDev	**1.94**	**2.02**	**2.05**	**2.00**	**1.89**	**1.74**	**1.59**	**1.48**	**0.021**	**0.015**	**0.009**	**0.007**	**0.012**	**0.019**	**0.027**	**0.035**

* Outlier that was omitted from analysis.

Table B.61 *BBR* Mixture Data for *R-1* RAP Source, 138 C, Evotherm™, 85 Gyrations

P_{AC}	Test		Test Time (sec) and Mixture Stiffness (GPa)								Test Time (sec) and Mixture m-value							
(%)	Temp (C)	Rep	8	15	30	60	120	240	480	960	8	15	30	60	120	240	480	960
High	-24	1	24.14	23.56	22.86	22.11	21.31	20.48	19.62	18.73	0.037	0.041	0.046	0.050	0.055	0.060	0.064	0.069
V_a = 0.5%		2	18.40	17.88	17.23	16.50	15.70	14.85	13.96	13.04	0.041	0.049	0.058	0.067	0.076	0.085	0.094	0.102
		3	22.03	21.39	20.59	19.70	18.73	17.71	16.64	15.54	0.043	0.051	0.059	0.068	0.077	0.085	0.094	0.103
		4	18.95	18.42	17.81	17.16	16.48	15.78	15.06	14.33	0.043	0.047	0.051	0.056	0.060	0.065	0.069	0.074
		5	21.64	20.97	20.16	19.30	18.40	17.46	16.50	15.52	0.048	0.053	0.060	0.066	0.072	0.079	0.085	0.091
		Avg	**21.03**	**20.44**	**19.73**	**18.95**	**18.12**	**17.26**	**16.36**	**15.44**	**0.042**	**0.048**	**0.055**	**0.061**	**0.068**	**0.075**	**0.081**	**0.088**
		StdDev	**2.36**	**2.32**	**2.27**	**2.23**	**2.19**	**2.16**	**2.13**	**2.11**	**0.004**	**0.005**	**0.006**	**0.008**	**0.010**	**0.012**	**0.014**	**0.016**
	-18	1	23.67	22.79	21.71	20.53	19.27	17.96	16.62	15.26	0.055	0.065	0.075	0.086	0.096	0.107	0.117	0.128
		2	20.59	19.96	19.14	18.22	17.21	16.14	15.02	13.88	0.045	0.055	0.066	0.077	0.087	0.098	0.109	0.120
		3	21.97	21.40	20.63	19.74	18.74	17.65	16.50	15.30	0.037	0.047	0.058	0.069	0.081	0.092	0.103	0.114
		4	20.92	20.15	19.24	18.27	17.25	16.20	15.13	14.05	0.056	0.063	0.071	0.079	0.087	0.095	0.103	0.111
		5	20.91	20.07	19.13	18.18	17.21	16.24	15.27	14.31	0.062	0.067	0.072	0.076	0.081	0.086	0.091	0.096
		Avg	**21.61**	**20.87**	**19.97**	**18.99**	**17.94**	**16.84**	**15.71**	**14.56**	**0.051**	**0.059**	**0.068**	**0.077**	**0.086**	**0.096**	**0.105**	**0.114**
		StdDev	**1.26**	**1.22**	**1.16**	**1.08**	**0.99**	**0.89**	**0.78**	**0.68**	**0.010**	**0.008**	**0.007**	**0.006**	**0.006**	**0.008**	**0.010**	**0.012**
Med	-24	1*	5.93	5.87	5.78	5.68	5.57	5.44	5.29	5.13	0.015	0.019	0.023	0.028	0.032	0.037	0.041	0.046
V_a = 2.2%		2	19.98	19.43	18.77	18.05	17.29	16.49	15.67	14.82	0.042	0.047	0.053	0.059	0.065	0.071	0.077	0.083
		3	20.77	20.28	19.59	18.76	17.82	16.78	15.66	14.50	0.032	0.044	0.056	0.068	0.081	0.093	0.105	0.118
		4	15.32	14.87	14.33	13.76	13.17	12.56	11.93	11.30	0.046	0.051	0.056	0.061	0.066	0.071	0.076	0.081
		5*	9.50	9.40	9.25	9.05	8.81	8.53	8.22	7.87	0.014	0.020	0.028	0.035	0.043	0.050	0.058	0.065
		Avg	**18.69**	**18.19**	**17.56**	**16.86**	**16.09**	**15.28**	**14.42**	**13.54**	**0.040**	**0.047**	**0.055**	**0.063**	**0.071**	**0.078**	**0.086**	**0.094**
		StdDev	**2.95**	**2.91**	**2.83**	**2.71**	**2.55**	**2.36**	**2.16**	**1.95**	**0.007**	**0.004**	**0.002**	**0.005**	**0.009**	**0.013**	**0.016**	**0.021**
	-18	1	16.84	16.57	16.26	15.96	15.67	15.37	15.08	14.80	0.026	0.027	0.027	0.027	0.027	0.027	0.028	0.028
		2	14.22	13.78	13.26	12.72	12.16	11.58	10.99	10.40	0.048	0.053	0.058	0.063	0.068	0.073	0.078	0.083
		3	17.53	17.19	16.68	16.04	15.29	14.45	13.53	12.56	0.026	0.037	0.050	0.063	0.075	0.088	0.101	0.114
		4	16.74	16.35	15.83	15.22	14.53	13.77	12.97	12.13	0.033	0.042	0.052	0.062	0.072	0.082	0.092	0.102
		5	15.08	14.65	14.08	13.44	12.72	11.94	11.13	10.29	0.041	0.051	0.062	0.074	0.085	0.096	0.107	0.119
		Avg	**16.08**	**15.71**	**15.22**	**14.67**	**14.07**	**13.42**	**12.74**	**12.03**	**0.035**	**0.042**	**0.050**	**0.058**	**0.065**	**0.073**	**0.081**	**0.089**
		StdDev	**1.38**	**1.43**	**1.48**	**1.51**	**1.56**	**1.62**	**1.72**	**1.85**	**0.010**	**0.011**	**0.014**	**0.018**	**0.022**	**0.027**	**0.032**	**0.037**

* Outlier that was omitted from analysis.

Table B.62 *BBR* Mixture Data for *R-1* RAP Source, 154 C, None, 65 Gyrations

P_{AC}	Test		Test Time (sec) and Mixture Stiffness (GPa)								Test Time (sec) and Mixture m-value							
(%)	Temp (C)	Rep	8	15	30	60	120	240	480	960	8	15	30	60	120	240	480	960
High	-24	1	21.32	20.78	20.08	19.28	18.41	17.47	16.47	15.44	0.037	0.045	0.054	0.063	0.071	0.080	0.089	0.098
V_a = 0.5%		2	21.56	20.94	20.16	19.29	18.34	17.33	16.28	15.20	0.042	0.050	0.059	0.068	0.077	0.086	0.095	0.104
		3	22.29	21.59	20.73	19.80	18.81	17.76	16.69	15.59	0.047	0.054	0.062	0.070	0.078	0.086	0.094	0.102
		4	18.99	18.41	17.70	16.93	16.11	15.25	14.36	13.45	0.046	0.053	0.060	0.068	0.075	0.083	0.091	0.098
		5	22.50	21.84	21.03	20.13	19.16	18.13	17.06	15.96	0.043	0.051	0.059	0.067	0.075	0.084	0.092	0.100
		Avg	**21.33**	**20.71**	**19.94**	**19.09**	**18.16**	**17.19**	**16.17**	**15.13**	**0.043**	**0.051**	**0.059**	**0.067**	**0.076**	**0.084**	**0.092**	**0.100**
		StdDev	**1.40**	**1.36**	**1.31**	**1.26**	**1.19**	**1.13**	**1.05**	**0.98**	**0.004**	**0.004**	**0.003**	**0.003**	**0.003**	**0.002**	**0.002**	**0.002**
	-18	1	20.87	20.41	19.82	19.16	18.43	17.65	16.83	15.96	0.033	0.039	0.046	0.052	0.059	0.066	0.073	0.079
		2	19.15	18.57	17.84	17.03	16.15	15.23	14.26	13.27	0.045	0.053	0.062	0.072	0.081	0.090	0.099	0.108
		3	17.93	17.43	16.74	15.92	15.00	14.00	12.94	11.84	0.039	0.051	0.065	0.079	0.093	0.107	0.121	0.135
		4	17.53	17.02	16.37	15.66	14.88	14.05	13.18	12.29	0.043	0.051	0.060	0.069	0.078	0.087	0.096	0.106
		5	18.16	17.54	16.77	15.92	15.01	14.04	13.05	12.03	0.050	0.059	0.070	0.080	0.091	0.101	0.111	0.122
		Avg	**18.73**	**18.19**	**17.51**	**16.74**	**15.89**	**14.99**	**14.05**	**13.08**	**0.042**	**0.051**	**0.061**	**0.070**	**0.080**	**0.090**	**0.100**	**0.110**
		StdDev	**1.34**	**1.36**	**1.40**	**1.45**	**1.51**	**1.57**	**1.64**	**1.70**	**0.006**	**0.007**	**0.009**	**0.011**	**0.013**	**0.016**	**0.018**	**0.021**
Med	-24	1	18.61	17.81	16.90	15.95	14.98	14.01	13.03	12.06	0.066	0.073	0.080	0.087	0.094	0.101	0.108	0.115
V_a = 2.0%		2	14.68	14.40	14.03	13.60	13.11	12.57	11.98	11.36	0.026	0.034	0.041	0.049	0.057	0.065	0.073	0.081
		3	16.82	16.45	16.02	15.56	15.07	14.55	14.02	13.46	0.033	0.036	0.040	0.044	0.048	0.052	0.056	0.060
		4	13.99	13.78	13.50	13.18	12.83	12.44	12.03	11.59	0.023	0.027	0.032	0.037	0.042	0.046	0.051	0.056
		5	10.95	10.78	10.56	10.29	9.98	9.64	9.26	8.86	0.021	0.027	0.034	0.041	0.047	0.054	0.060	0.067
		Avg	**15.01**	**14.65**	**14.20**	**13.72**	**13.19**	**12.64**	**12.06**	**11.47**	**0.034**	**0.039**	**0.045**	**0.052**	**0.058**	**0.064**	**0.070**	**0.076**
		StdDev	**2.91**	**2.69**	**2.47**	**2.26**	**2.07**	**1.91**	**1.77**	**1.67**	**0.019**	**0.019**	**0.020**	**0.020**	**0.021**	**0.022**	**0.023**	**0.024**
	-18	1	19.01	18.57	18.08	17.58	17.08	16.58	16.07	15.57	0.037	0.038	0.039	0.041	0.042	0.044	0.045	0.047
		2	15.56	15.07	14.50	13.91	13.30	12.67	12.04	11.40	0.049	0.053	0.058	0.062	0.067	0.072	0.076	0.081
		3	19.12	18.51	17.80	17.06	16.30	15.53	14.74	13.95	0.050	0.054	0.059	0.063	0.068	0.073	0.077	0.082
		4	19.30	18.75	18.04	17.24	16.37	15.43	14.46	13.45	0.042	0.051	0.060	0.070	0.080	0.090	0.099	0.109
		5	16.89	16.44	15.93	15.39	14.83	14.26	13.68	13.09	0.041	0.044	0.048	0.051	0.055	0.058	0.062	0.065
		Avg	**17.98**	**17.47**	**16.87**	**16.24**	**15.58**	**14.89**	**14.20**	**13.49**	**0.044**	**0.048**	**0.053**	**0.058**	**0.062**	**0.067**	**0.072**	**0.077**
		StdDev	**1.67**	**1.64**	**1.60**	**1.55**	**1.51**	**1.49**	**1.48**	**1.51**	**0.006**	**0.007**	**0.009**	**0.012**	**0.014**	**0.017**	**0.020**	**0.023**

Table B.63 *BBR* Mixture Data for *R-1* RAP Source, 154 C, None, 65 Gyrations Continued

P_{AC}	Test		Test Time (sec) and Mixture Stiffness (GPa)								Test Time (sec) and Mixture m-value							
(%)	Temp (C)	Rep	8	15	30	60	120	240	480	960	8	15	30	60	120	240	480	960
Low	-24	1	23.10	22.65	22.15	21.64	21.13	20.61	20.09	19.56	0.031	0.032	0.033	0.034	0.035	0.036	0.038	0.039
V_a = 4.2%		2	18.35	18.05	17.61	17.06	16.42	15.69	14.89	14.04	0.022	0.031	0.041	0.051	0.060	0.070	0.080	0.090
		3	21.42	20.90	20.29	19.66	18.99	18.31	17.60	16.89	0.038	0.041	0.044	0.048	0.051	0.055	0.058	0.062
		4*	30.92	30.21	29.07	27.61	25.87	23.93	21.83	19.66	0.028	0.046	0.065	0.084	0.103	0.122	0.142	0.161
		5*	22.52	22.13	21.72	21.34	20.98	20.64	20.33	20.04	0.029	0.027	0.026	0.025	0.024	0.023	0.021	0.020
		Avg	**20.96**	**20.53**	**20.02**	**19.45**	**18.85**	**18.20**	**17.53**	**16.83**	**0.030**	**0.035**	**0.039**	**0.044**	**0.049**	**0.054**	**0.059**	**0.064**
		StdDev	**2.41**	**2.32**	**2.28**	**2.30**	**2.36**	**2.46**	**2.60**	**2.76**	**0.008**	**0.006**	**0.006**	**0.009**	**0.013**	**0.017**	**0.021**	**0.026**
	-18	1	18.37	17.99	17.54	17.07	16.59	16.09	15.58	15.05	0.033	0.035	0.038	0.040	0.043	0.045	0.048	0.051
		2	21.75	21.38	20.79	20.04	19.15	18.14	17.03	15.84	0.022	0.034	0.046	0.059	0.072	0.085	0.098	0.111
		3	21.42	20.76	20.01	19.24	18.45	17.66	16.86	16.05	0.048	0.052	0.055	0.058	0.062	0.065	0.069	0.072
		4	16.48	16.15	15.74	15.31	14.84	14.35	13.85	13.32	0.031	0.035	0.039	0.042	0.046	0.050	0.054	0.058
		5	15.41	15.19	14.83	14.38	13.83	13.21	12.51	11.77	0.019	0.029	0.039	0.050	0.061	0.072	0.083	0.094
		Avg	**18.69**	**18.29**	**17.78**	**17.21**	**16.57**	**15.89**	**15.16**	**14.41**	**0.031**	**0.037**	**0.043**	**0.050**	**0.057**	**0.064**	**0.070**	**0.077**
		StdDev	**2.85**	**2.74**	**2.60**	**2.44**	**2.27**	**2.11**	**1.95**	**1.83**	**0.012**	**0.009**	**0.007**	**0.009**	**0.012**	**0.016**	**0.020**	**0.025**

* Outlier that was omitted from analysis.

Table B.64 *BBR* Mixture Data for *R-1* RAP Source, 154 C, Sasobit®, 65 Gyrations

P_{AC}	Test		Test Time (sec) and Mixture Stiffness (GPa)								Test Time (sec) and Mixture m-value							
(%)	Temp (C)	Rep	8	15	30	60	120	240	480	960	8	15	30	60	120	240	480	960
High	-24	1	20.07	19.49	18.85	18.19	17.53	16.86	16.19	15.52	0.045	0.047	0.050	0.052	0.055	0.057	0.060	0.062
V_a = 0.7%		2	17.51	16.88	16.12	15.30	14.43	13.53	12.60	11.67	0.054	0.062	0.071	0.080	0.089	0.098	0.107	0.116
		3	20.83	20.42	19.84	19.14	18.34	17.46	16.50	15.48	0.027	0.037	0.047	0.057	0.067	0.077	0.087	0.097
		4	18.42	18.00	17.41	16.73	15.95	15.09	14.18	13.22	0.032	0.042	0.053	0.063	0.074	0.085	0.096	0.106
		5	19.01	18.43	17.72	16.94	16.11	15.23	14.33	13.41	0.046	0.053	0.061	0.069	0.077	0.084	0.092	0.100
		Avg	**19.17**	**18.64**	**17.99**	**17.26**	**16.47**	**15.63**	**14.76**	**13.86**	**0.041**	**0.048**	**0.056**	**0.064**	**0.072**	**0.080**	**0.088**	**0.096**
		StdDev	**1.31**	**1.36**	**1.42**	**1.47**	**1.52**	**1.56**	**1.60**	**1.64**	**0.011**	**0.010**	**0.010**	**0.011**	**0.013**	**0.015**	**0.018**	**0.020**
	-18	1	16.50	16.09	15.64	15.19	14.72	14.26	13.79	13.33	0.039	0.040	0.042	0.044	0.045	0.047	0.049	0.050
		2	18.30	17.85	17.26	16.57	15.80	14.96	14.07	13.14	0.035	0.044	0.054	0.064	0.074	0.084	0.094	0.104
		3	17.88	17.39	16.79	16.12	15.41	14.66	13.88	13.07	0.041	0.048	0.055	0.062	0.069	0.076	0.083	0.090
		4	20.31	19.84	19.19	18.41	17.52	16.53	15.47	14.36	0.031	0.042	0.054	0.066	0.078	0.090	0.101	0.113
		5	20.81	20.10	19.28	18.44	17.57	16.69	15.81	14.92	0.053	0.058	0.062	0.067	0.072	0.076	0.081	0.086
		Avg	**18.76**	**18.26**	**17.63**	**16.95**	**16.21**	**15.42**	**14.60**	**13.76**	**0.040**	**0.046**	**0.053**	**0.060**	**0.067**	**0.074**	**0.082**	**0.089**
		StdDev	**1.78**	**1.70**	**1.58**	**1.44**	**1.28**	**1.12**	**0.96**	**0.83**	**0.008**	**0.007**	**0.007**	**0.010**	**0.013**	**0.016**	**0.020**	**0.024**
Med	-24	1	17.68	17.37	16.90	16.29	15.57	14.75	13.85	12.88	0.022	0.034	0.046	0.059	0.072	0.085	0.097	0.110
V_a = 1.7%		2	21.39	20.88	20.22	19.47	18.63	17.72	16.76	15.76	0.035	0.042	0.051	0.059	0.068	0.076	0.085	0.093
		3	14.85	14.60	14.23	13.77	13.25	12.65	12.01	11.32	0.023	0.032	0.042	0.052	0.061	0.071	0.080	0.090
		4	13.86	13.69	13.45	13.16	12.83	12.46	12.05	11.62	0.018	0.023	0.028	0.034	0.039	0.045	0.051	0.056
		5	16.61	16.13	15.50	14.77	13.95	13.06	12.13	11.16	0.040	0.052	0.064	0.076	0.089	0.101	0.113	0.126
		Avg	**16.88**	**16.53**	**16.06**	**15.49**	**14.84**	**14.13**	**13.36**	**12.55**	**0.028**	**0.036**	**0.046**	**0.056**	**0.066**	**0.076**	**0.085**	**0.095**
		StdDev	**2.93**	**2.81**	**2.67**	**2.52**	**2.36**	**2.20**	**2.05**	**1.92**	**0.009**	**0.011**	**0.013**	**0.015**	**0.018**	**0.020**	**0.023**	**0.026**
	-18	1	13.89	13.71	13.52	13.31	13.11	12.90	12.69	12.48	0.020	0.021	0.021	0.022	0.023	0.023	0.024	0.025
		2	16.66	16.26	15.79	15.30	14.79	14.25	13.70	13.14	0.037	0.040	0.044	0.048	0.051	0.055	0.059	0.062
		3	17.25	16.95	16.49	15.90	15.20	14.41	13.54	12.62	0.022	0.034	0.046	0.059	0.071	0.083	0.096	0.108
		4	15.58	15.26	14.85	14.38	13.85	13.28	12.67	12.03	0.030	0.036	0.043	0.050	0.057	0.064	0.071	0.078
		5	21.49	21.06	20.42	19.65	18.74	17.72	16.62	15.45	0.027	0.038	0.050	0.062	0.074	0.087	0.099	0.111
		Avg	**16.97**	**16.65**	**16.21**	**15.71**	**15.14**	**14.51**	**13.85**	**13.14**	**0.027**	**0.034**	**0.041**	**0.048**	**0.055**	**0.063**	**0.070**	**0.077**
		StdDev	**2.83**	**2.75**	**2.60**	**2.41**	**2.17**	**1.90**	**1.62**	**1.35**	**0.007**	**0.008**	**0.011**	**0.016**	**0.021**	**0.026**	**0.031**	**0.036**

Table B.65 *BBR* Mixture Data for *R-1* RAP Source, 154 C, Sasobit®, 65 Gyrations Continued

P_{AC}	Test		Test Time (sec) and Mixture Stiffness (GPa)								Test Time (sec) and Mixture m-value							
(%)	Temp (C)	Rep	8	15	30	60	120	240	480	960	8	15	30	60	120	240	480	960
Low	-24	1	18.73	18.32	17.87	17.39	16.91	16.42	15.91	15.41	0.034	0.035	0.038	0.040	0.042	0.044	0.046	0.048
V_a = 4.1%		2	26.22	25.36	24.38	23.37	22.35	21.31	20.27	19.23	0.052	0.055	0.059	0.063	0.067	0.070	0.074	0.078
		3	21.13	20.68	20.07	19.37	18.57	17.70	16.76	15.78	0.030	0.038	0.047	0.056	0.065	0.074	0.083	0.092
		4	22.24	21.82	21.25	20.57	19.80	18.96	18.04	17.08	0.027	0.034	0.042	0.051	0.059	0.067	0.075	0.084
		5*	21.07	20.74	20.41	20.11	19.85	19.61	19.41	19.23	0.026	0.024	0.022	0.020	0.018	0.016	0.014	0.012
		Avg	**22.08**	**21.54**	**20.89**	**20.18**	**19.41**	**18.60**	**17.75**	**16.87**	**0.035**	**0.041**	**0.046**	**0.052**	**0.058**	**0.064**	**0.070**	**0.075**
		StdDev	**3.13**	**2.93**	**2.71**	**2.50**	**2.29**	**2.09**	**1.90**	**1.73**	**0.011**	**0.010**	**0.009**	**0.010**	**0.011**	**0.014**	**0.016**	**0.019**
	-18	1	18.53	18.21	17.84	17.45	17.06	16.65	16.23	15.80	0.027	0.029	0.031	0.032	0.034	0.036	0.038	0.039
		2	15.46	14.96	14.33	13.65	12.91	12.14	11.33	10.52	0.048	0.057	0.066	0.075	0.085	0.094	0.103	0.113
		3*	9.88	9.55	9.12	8.62	8.08	7.50	6.90	6.29	0.048	0.060	0.074	0.087	0.101	0.114	0.127	0.141
		4*	10.68	10.37	9.89	9.28	8.57	7.79	6.97	6.13	0.036	0.057	0.080	0.103	0.126	0.150	0.173	0.196
		5*	16.16	15.84	15.69	15.74	16.00	16.47	17.18	18.15	0.040	0.023	0.005	-0.014	-0.033	-0.051	-0.070	-0.089
		Avg	**17.00**	**16.59**	**16.09**	**15.55**	**14.99**	**14.40**	**13.78**	**13.16**	**0.038**	**0.043**	**0.049**	**0.054**	**0.060**	**0.065**	**0.071**	**0.076**
		StdDev	**2.17**	**2.30**	**2.48**	**2.69**	**2.93**	**3.19**	**3.46**	**3.73**	**0.015**	**0.020**	**0.025**	**0.030**	**0.036**	**0.041**	**0.046**	**0.052**

* Outlier that was omitted from analysis.

Table B.66 *BBR* Mixture Data for *R-1* RAP Source, 154 C, Evotherm™, 65 Gyrations

P_{AC}	Test		Test Time (sec) and Mixture Stiffness (GPa)								Test Time (sec) and Mixture m-value							
(%)	Temp (C)	Rep	8	15	30	60	120	240	480	960	8	15	30	60	120	240	480	960
High	-24	1	13.33	13.17	12.96	12.69	12.37	12.01	11.60	11.17	0.015	0.021	0.027	0.033	0.040	0.046	0.052	0.059
V_a = 0.5%		2	14.06	13.75	13.36	12.93	12.46	11.96	11.44	10.89	0.033	0.038	0.044	0.050	0.056	0.062	0.068	0.074
		3	15.94	15.50	14.96	14.37	13.73	13.05	12.34	11.62	0.041	0.048	0.055	0.062	0.069	0.077	0.084	0.091
		4	20.21	19.69	19.02	18.28	17.48	16.61	15.71	14.78	0.039	0.046	0.053	0.061	0.069	0.077	0.084	0.092
		5	12.17	11.96	11.68	11.36	11.00	10.61	10.18	9.74	0.025	0.031	0.037	0.043	0.049	0.056	0.062	0.068
		Avg	**15.14**	**14.81**	**14.40**	**13.92**	**13.41**	**12.85**	**12.26**	**11.64**	**0.031**	**0.037**	**0.043**	**0.050**	**0.057**	**0.063**	**0.070**	**0.077**
		StdDev	**3.15**	**3.01**	**2.84**	**2.66**	**2.47**	**2.28**	**2.08**	**1.89**	**0.011**	**0.011**	**0.012**	**0.012**	**0.013**	**0.013**	**0.014**	**0.015**
	-18	1	15.49	15.08	14.54	13.92	13.23	12.49	11.70	10.88	0.038	0.047	0.058	0.068	0.078	0.089	0.099	0.110
		2	15.54	15.12	14.56	13.90	13.16	12.36	11.52	10.64	0.038	0.049	0.061	0.073	0.085	0.096	0.108	0.120
		3	12.72	12.35	11.93	11.49	11.05	10.59	10.13	9.66	0.045	0.048	0.052	0.055	0.059	0.063	0.066	0.070
		4	15.77	15.37	14.85	14.26	13.61	12.91	12.18	11.42	0.038	0.045	0.054	0.063	0.071	0.080	0.089	0.097
		5	18.07	17.58	16.95	16.24	15.46	14.63	13.75	12.84	0.039	0.048	0.057	0.066	0.075	0.085	0.094	0.103
		Avg	**15.52**	**15.10**	**14.57**	**13.96**	**13.30**	**12.60**	**11.86**	**11.09**	**0.040**	**0.047**	**0.056**	**0.065**	**0.074**	**0.083**	**0.091**	**0.100**
		StdDev	**1.90**	**1.86**	**1.78**	**1.69**	**1.57**	**1.44**	**1.31**	**1.17**	**0.003**	**0.001**	**0.003**	**0.006**	**0.010**	**0.013**	**0.016**	**0.019**
Med	-24	1	20.75	19.95	19.08	18.22	17.38	16.56	15.75	14.97	0.062	0.063	0.065	0.067	0.069	0.071	0.073	0.075
V_a = 2.0%		2	21.65	21.29	20.74	20.06	19.25	18.33	17.32	16.24	0.022	0.032	0.043	0.054	0.065	0.076	0.087	0.098
		3	19.45	19.07	18.53	17.88	17.14	16.32	15.43	14.49	0.027	0.036	0.046	0.056	0.066	0.076	0.086	0.096
		4	17.93	17.51	17.03	16.51	15.96	15.39	14.80	14.20	0.035	0.039	0.043	0.047	0.050	0.054	0.058	0.062
		5	18.86	18.39	17.81	17.16	16.46	15.72	14.93	14.12	0.037	0.043	0.050	0.057	0.063	0.070	0.077	0.084
		Avg	**19.73**	**19.24**	**18.64**	**17.97**	**17.24**	**16.46**	**15.65**	**14.80**	**0.037**	**0.043**	**0.049**	**0.056**	**0.063**	**0.070**	**0.076**	**0.083**
		StdDev	**1.48**	**1.45**	**1.41**	**1.34**	**1.26**	**1.14**	**1.01**	**0.87**	**0.015**	**0.012**	**0.009**	**0.007**	**0.007**	**0.009**	**0.012**	**0.015**
	-18	1	19.13	18.77	18.32	17.81	17.26	16.66	16.03	15.36	0.028	0.033	0.038	0.043	0.048	0.053	0.059	0.064
		2	21.37	21.14	20.70	20.06	19.25	18.29	17.21	16.03	0.011	0.024	0.038	0.052	0.067	0.081	0.095	0.110
		3	18.07	17.48	16.76	15.97	15.14	14.26	13.36	12.44	0.049	0.057	0.065	0.073	0.082	0.090	0.099	0.107
		4	9.75	9.30	8.78	8.23	7.66	7.09	6.52	5.96	0.071	0.079	0.088	0.098	0.107	0.116	0.126	0.135
		5	13.97	13.81	13.53	13.15	12.68	12.12	11.49	10.80	0.012	0.023	0.035	0.047	0.059	0.071	0.083	0.095
		Avg	**18.14**	**17.80**	**17.33**	**16.75**	**16.08**	**15.33**	**14.52**	**13.66**	**0.025**	**0.034**	**0.044**	**0.054**	**0.064**	**0.074**	**0.084**	**0.094**
		StdDev	**3.10**	**3.06**	**3.01**	**2.92**	**2.82**	**2.71**	**2.58**	**2.46**	**0.018**	**0.016**	**0.014**	**0.013**	**0.014**	**0.016**	**0.018**	**0.021**

* Outlier that was omitted from analysis.

Table B.67 *BBR* Mixture Data for *R-1* RAP Source, 154 C, Evotherm™, 65 Gyrations Continued

P_{AC}	Test		Test Time (sec) and Mixture Stiffness (GPa)								Test Time (sec) and Mixture m-value							
(%)	Temp (C)	Rep	8	15	30	60	120	240	480	960	8	15	30	60	120	240	480	960
Low	-24	1	16.54	16.34	16.08	15.79	15.47	15.11	14.73	14.33	0.018	0.021	0.025	0.028	0.031	0.035	0.038	0.042
V_a = 4.0%		2	18.07	17.71	17.21	16.63	15.96	15.22	14.42	13.58	0.028	0.036	0.046	0.055	0.064	0.073	0.082	0.091
		3	17.71	17.32	16.90	16.49	16.09	15.69	15.31	14.93	0.035	0.035	0.036	0.036	0.036	0.036	0.036	0.036
		4	22.05	21.56	20.91	20.16	19.32	18.40	17.42	16.39	0.032	0.040	0.048	0.057	0.066	0.075	0.084	0.092
		5*	25.59	25.14	24.72	24.36	24.07	23.85	23.69	23.58	0.030	0.026	0.023	0.019	0.015	0.012	0.008	0.004
		Avg	**18.59**	**18.23**	**17.78**	**17.27**	**16.71**	**16.11**	**15.47**	**14.81**	**0.028**	**0.033**	**0.038**	**0.044**	**0.049**	**0.055**	**0.060**	**0.065**
		StdDev	**2.40**	**2.29**	**2.15**	**1.97**	**1.76**	**1.55**	**1.35**	**1.19**	**0.007**	**0.008**	**0.011**	**0.014**	**0.018**	**0.022**	**0.026**	**0.031**
	-18	1	22.45	21.82	21.07	20.25	19.37	18.45	17.49	16.51	0.042	0.048	0.054	0.061	0.067	0.074	0.080	0.087
		2	12.14	11.98	11.74	11.46	11.12	10.73	10.31	9.84	0.018	0.025	0.032	0.040	0.047	0.055	0.062	0.070
		3	14.69	14.54	14.31	14.01	13.66	13.25	12.79	12.29	0.014	0.020	0.027	0.034	0.040	0.047	0.054	0.061
		4	16.67	16.29	15.84	15.37	14.88	14.38	13.86	13.33	0.036	0.039	0.042	0.045	0.048	0.051	0.055	0.058
		5	19.71	19.49	19.10	18.57	17.91	17.13	16.25	15.30	0.012	0.023	0.035	0.047	0.058	0.070	0.082	0.094
		Avg	**17.13**	**16.82**	**16.41**	**15.93**	**15.39**	**14.79**	**14.14**	**13.45**	**0.024**	**0.031**	**0.038**	**0.045**	**0.052**	**0.059**	**0.067**	**0.074**
		StdDev	**4.06**	**3.91**	**3.72**	**3.52**	**3.31**	**3.08**	**2.84**	**2.60**	**0.014**	**0.012**	**0.011**	**0.010**	**0.011**	**0.012**	**0.014**	**0.016**

* Outlier that was omitted from analysis.

Table B.68 *BBR* Mixture Data for *R-2* RAP Source, 116 C, None, 65 Gyrations

P_{AC}	Test		Test Time (sec) and Mixture Stiffness (GPa)								Test Time (sec) and Mixture m-value							
(%)	Temp (C)	Rep	8	15	30	60	120	240	480	960	8	15	30	60	120	240	480	960
High	-24	1	13.22	12.97	12.61	12.17	11.67	11.10	10.49	9.83	0.026	0.035	0.046	0.056	0.066	0.077	0.087	0.098
V_a = 1.2%		2	22.24	21.62	20.75	19.70	18.50	17.19	15.80	14.37	0.038	0.052	0.067	0.083	0.098	0.114	0.129	0.145
		3	19.75	19.17	18.49	17.78	17.04	16.28	15.51	14.72	0.045	0.049	0.054	0.059	0.064	0.068	0.073	0.078
		4	18.19	17.70	17.10	16.46	15.78	15.07	14.33	13.58	0.042	0.047	0.052	0.058	0.064	0.069	0.075	0.080
		5	21.02	20.49	19.71	18.74	17.62	16.38	15.06	13.68	0.033	0.048	0.064	0.081	0.097	0.114	0.130	0.146
		Avg	**18.88**	**18.39**	**17.73**	**16.97**	**16.12**	**15.21**	**14.24**	**13.24**	**0.037**	**0.046**	**0.057**	**0.067**	**0.078**	**0.088**	**0.099**	**0.109**
		StdDev	**3.51**	**3.37**	**3.17**	**2.94**	**2.68**	**2.42**	**2.17**	**1.96**	**0.008**	**0.006**	**0.009**	**0.013**	**0.018**	**0.023**	**0.029**	**0.034**
	-18	1	20.69	20.11	19.44	18.75	18.03	17.30	16.55	15.80	0.044	0.047	0.051	0.054	0.058	0.062	0.065	0.069
		2	17.44	16.87	16.14	15.33	14.44	13.51	12.53	11.54	0.048	0.058	0.069	0.080	0.091	0.102	0.113	0.125
		3	22.34	21.48	20.45	19.35	18.20	17.02	15.82	14.61	0.058	0.066	0.075	0.084	0.093	0.101	0.110	0.119
		4	22.38	21.64	20.70	19.66	18.54	17.36	16.13	14.89	0.049	0.059	0.069	0.079	0.090	0.100	0.111	0.121
		5	23.05	22.27	21.26	20.13	18.89	17.57	16.20	14.82	0.049	0.060	0.073	0.085	0.098	0.111	0.123	0.136
		Avg	**21.18**	**20.47**	**19.60**	**18.64**	**17.62**	**16.55**	**15.45**	**14.33**	**0.050**	**0.058**	**0.067**	**0.077**	**0.086**	**0.095**	**0.105**	**0.114**
		StdDev	**2.26**	**2.16**	**2.04**	**1.92**	**1.81**	**1.71**	**1.65**	**1.63**	**0.005**	**0.007**	**0.010**	**0.013**	**0.016**	**0.019**	**0.023**	**0.026**
Med	-24	1	27.15	26.30	25.12	23.72	22.13	20.41	18.62	16.78	0.043	0.058	0.075	0.091	0.108	0.125	0.141	0.158
V_a = 2.7%		2	19.41	18.97	18.35	17.61	16.76	15.83	14.82	13.76	0.031	0.042	0.054	0.065	0.077	0.089	0.101	0.113
		3	25.62	24.82	23.75	22.51	21.14	19.66	18.12	16.54	0.044	0.057	0.070	0.084	0.098	0.111	0.125	0.139
		4	22.57	21.94	21.15	20.28	19.33	18.33	17.29	16.21	0.041	0.049	0.057	0.065	0.073	0.081	0.089	0.097
		5*	23.44	22.60	21.79	21.06	20.43	19.88	19.41	19.01	0.060	0.055	0.051	0.046	0.042	0.037	0.032	0.028
		Avg	**23.64**	**22.93**	**22.03**	**21.04**	**19.96**	**18.82**	**17.65**	**16.46**	**0.044**	**0.052**	**0.061**	**0.070**	**0.079**	**0.089**	**0.098**	**0.107**
		StdDev	**2.97**	**2.82**	**2.59**	**2.33**	**2.06**	**1.84**	**1.76**	**1.87**	**0.010**	**0.007**	**0.011**	**0.018**	**0.026**	**0.034**	**0.042**	**0.050**
	-18	1	26.29	25.82	25.24	24.63	23.97	23.27	22.54	21.78	0.027	0.031	0.034	0.037	0.041	0.044	0.048	0.051
		2	21.31	20.76	19.99	19.05	17.97	16.79	15.52	14.21	0.034	0.048	0.062	0.077	0.091	0.106	0.120	0.135
		3	18.09	17.52	16.82	16.07	15.27	14.43	13.56	12.68	0.048	0.055	0.062	0.070	0.078	0.085	0.093	0.101
		4*	6.39	6.34	6.27	6.19	6.09	5.97	5.85	5.71	0.011	0.014	0.018	0.022	0.026	0.029	0.033	0.037
		5	21.56	20.84	19.85	18.66	17.33	15.89	14.39	12.87	0.045	0.062	0.080	0.098	0.116	0.134	0.152	0.170
		Avg	**21.81**	**21.24**	**20.48**	**19.60**	**18.64**	**17.60**	**16.50**	**15.39**	**0.039**	**0.049**	**0.060**	**0.071**	**0.082**	**0.092**	**0.103**	**0.114**
		StdDev	**3.38**	**3.43**	**3.50**	**3.60**	**3.74**	**3.91**	**4.10**	**4.32**	**0.010**	**0.013**	**0.019**	**0.025**	**0.031**	**0.038**	**0.044**	**0.051**

* Outlier that was omitted from analysis.

Table B.69 *BBR* Mixture Data for *R-2* RAP Source, 138 C, None, 65 Gyrations

P_{AC}	Test		Test Time (sec) and Mixture Stiffness (GPa)								Test Time (sec) and Mixture m-value							
(%)	Temp (C)	Rep	8	15	30	60	120	240	480	960	8	15	30	60	120	240	480	960
High	-24	1	23.11	22.31	21.27	20.08	18.78	17.39	15.96	14.50	0.050	0.062	0.076	0.090	0.104	0.117	0.131	0.145
V_a = 1.6%		2	25.80	24.89	23.72	22.40	20.96	19.44	17.86	16.26	0.051	0.063	0.076	0.089	0.102	0.115	0.129	0.142
		3	21.32	20.70	19.96	19.16	18.31	17.42	16.50	15.56	0.044	0.050	0.056	0.062	0.069	0.075	0.081	0.088
		4	16.96	16.53	16.02	15.49	14.94	14.37	13.78	13.19	0.040	0.043	0.047	0.050	0.054	0.058	0.062	0.066
		5*	8.13	8.06	7.98	7.89	7.79	7.69	7.58	7.46	0.013	0.014	0.016	0.017	0.018	0.020	0.021	0.023
		Avg	**21.80**	**21.11**	**20.24**	**19.28**	**18.25**	**17.16**	**16.03**	**14.88**	**0.046**	**0.055**	**0.064**	**0.073**	**0.082**	**0.091**	**0.101**	**0.110**
		StdDev	**3.71**	**3.51**	**3.22**	**2.87**	**2.49**	**2.09**	**1.70**	**1.34**	**0.005**	**0.010**	**0.015**	**0.020**	**0.025**	**0.029**	**0.035**	**0.039**
	-18	1	23.06	22.39	21.62	20.84	20.05	19.25	18.43	17.62	0.046	0.048	0.051	0.055	0.058	0.061	0.064	0.067
		2	19.01	18.50	17.84	17.07	16.23	15.31	14.35	13.35	0.039	0.048	0.058	0.068	0.079	0.089	0.099	0.109
		3	15.90	15.45	14.90	14.30	13.66	12.99	12.29	11.57	0.042	0.049	0.056	0.063	0.070	0.077	0.084	0.090
		4	14.02	13.68	13.24	12.75	12.22	11.64	11.04	10.42	0.037	0.043	0.051	0.058	0.065	0.073	0.080	0.087
		5	16.00	15.67	15.16	14.53	13.79	12.96	12.07	11.13	0.027	0.040	0.054	0.068	0.082	0.096	0.110	0.124
		Avg	**17.60**	**17.14**	**16.55**	**15.90**	**15.19**	**14.43**	**13.64**	**12.82**	**0.038**	**0.046**	**0.054**	**0.062**	**0.071**	**0.079**	**0.087**	**0.096**
		StdDev	**3.54**	**3.41**	**3.28**	**3.17**	**3.08**	**3.00**	**2.94**	**2.89**	**0.007**	**0.004**	**0.003**	**0.006**	**0.010**	**0.014**	**0.018**	**0.022**
Med	-24	1	21.27	21.04	20.69	20.23	19.68	19.04	18.33	17.55	0.014	0.021	0.028	0.036	0.044	0.051	0.059	0.067
V_a = 2.3%		2	20.68	20.30	19.73	19.01	18.15	17.19	16.13	15.01	0.024	0.035	0.048	0.060	0.073	0.085	0.098	0.110
		3	18.50	18.08	17.50	16.80	16.01	15.13	14.19	13.21	0.031	0.042	0.053	0.064	0.076	0.087	0.098	0.109
		4	23.16	22.74	22.10	21.30	20.35	19.29	18.13	16.89	0.024	0.035	0.047	0.059	0.071	0.084	0.096	0.108
		5	21.34	20.85	20.22	19.51	18.73	17.89	17.00	16.08	0.034	0.041	0.048	0.055	0.062	0.070	0.077	0.084
		Avg	**20.99**	**20.60**	**20.05**	**19.37**	**18.58**	**17.71**	**16.76**	**15.75**	**0.025**	**0.035**	**0.045**	**0.055**	**0.065**	**0.075**	**0.086**	**0.096**
		StdDev	**1.68**	**1.68**	**1.68**	**1.67**	**1.67**	**1.68**	**1.69**	**1.71**	**0.008**	**0.008**	**0.009**	**0.011**	**0.013**	**0.015**	**0.017**	**0.020**
	-18	1	24.43	24.05	23.48	22.73	21.84	20.82	19.70	18.49	0.019	0.029	0.041	0.052	0.063	0.075	0.086	0.097
		2*	5.49	5.46	5.40	5.33	5.24	5.14	5.03	4.90	0.008	0.012	0.017	0.021	0.026	0.031	0.035	0.040
		3	30.04	29.04	27.70	26.15	24.43	22.59	20.67	18.71	0.047	0.061	0.076	0.091	0.106	0.121	0.136	0.151
		4	28.11	27.12	25.99	24.80	23.58	22.33	21.07	19.80	0.054	0.059	0.065	0.070	0.076	0.081	0.087	0.092
		5	29.72	28.50	27.06	25.57	24.03	22.46	20.88	19.31	0.064	0.071	0.078	0.086	0.094	0.101	0.109	0.117
		Avg	**28.08**	**27.18**	**26.06**	**24.81**	**23.47**	**22.05**	**20.58**	**19.08**	**0.046**	**0.055**	**0.065**	**0.075**	**0.085**	**0.095**	**0.105**	**0.114**
		StdDev	**2.57**	**2.24**	**1.86**	**1.49**	**1.14**	**0.83**	**0.61**	**0.59**	**0.019**	**0.018**	**0.017**	**0.018**	**0.019**	**0.021**	**0.024**	**0.027**

* Outlier that was omitted from analysis.

Table B.70 *BBR* Mixture Data for *R-2* RAP Source, 138 C, None, 65 Gyrations Continued

P_{AC}	Test		Test Time (sec) and Mixture Stiffness (GPa)								Test Time (sec) and Mixture m-value							
(%)	Temp (C)	Rep	8	15	30	60	120	240	480	960	8	15	30	60	120	240	480	960
Low	-24	1	28.60	28.29	27.52	26.33	24.78	22.95	20.90	18.72	0.006	0.028	0.052	0.076	0.099	0.123	0.147	0.171
V_a = 4.0%		2	25.47	24.80	23.95	23.00	21.96	20.86	19.69	18.49	0.039	0.046	0.054	0.062	0.071	0.079	0.087	0.095
		3	19.78	19.33	18.78	18.18	17.54	16.85	16.13	15.39	0.034	0.039	0.044	0.050	0.055	0.060	0.065	0.071
		4	22.66	22.23	21.58	20.76	19.80	18.71	17.53	16.27	0.025	0.036	0.049	0.062	0.075	0.088	0.101	0.114
		5	22.20	21.59	20.89	20.15	19.40	18.62	17.83	17.03	0.043	0.046	0.050	0.053	0.057	0.061	0.064	0.068
		Avg	**23.74**	**23.25**	**22.54**	**21.69**	**20.70**	**19.60**	**18.42**	**17.18**	**0.029**	**0.039**	**0.050**	**0.061**	**0.071**	**0.082**	**0.093**	**0.104**
		StdDev	**3.38**	**3.43**	**3.34**	**3.11**	**2.77**	**2.35**	**1.88**	**1.43**	**0.014**	**0.008**	**0.004**	**0.010**	**0.018**	**0.026**	**0.034**	**0.042**
	-18	1	23.58	22.98	22.26	21.49	20.66	19.80	18.90	17.98	0.038	0.043	0.048	0.054	0.059	0.064	0.069	0.075
		2*	5.14	5.12	5.08	5.04	4.98	4.91	4.83	4.74	0.005	0.008	0.011	0.015	0.018	0.022	0.025	0.029
		3	24.77	24.16	23.33	22.37	21.27	20.08	18.81	17.48	0.034	0.045	0.056	0.067	0.078	0.089	0.100	0.111
		4	26.20	25.52	24.63	23.63	22.52	21.33	20.08	18.77	0.038	0.046	0.055	0.065	0.074	0.083	0.092	0.101
		5	25.07	24.18	23.21	22.28	21.36	20.48	19.62	18.78	0.057	0.058	0.059	0.060	0.061	0.062	0.062	0.063
		Avg	**24.91**	**24.21**	**23.36**	**22.44**	**21.45**	**20.42**	**19.35**	**18.25**	**0.042**	**0.048**	**0.055**	**0.062**	**0.068**	**0.075**	**0.081**	**0.088**
		StdDev	**1.08**	**1.04**	**0.97**	**0.88**	**0.78**	**0.67**	**0.61**	**0.64**	**0.010**	**0.007**	**0.005**	**0.006**	**0.009**	**0.014**	**0.018**	**0.022**

* Outlier that was omitted from analysis.

Table B.71 *BBR* Mixture Data for *R-2* RAP Source, 138 C, Sasobit®, 65 Gyrations

P_{AC}	Test		Test Time (sec) and Mixture Stiffness (GPa)								Test Time (sec) and Mixture m-value							
(%)	Temp (C)	Rep	8	15	30	60	120	240	480	960	8	15	30	60	120	240	480	960
High	-24	1	23.25	22.42	21.48	20.50	19.51	18.51	17.49	16.48	0.055	0.060	0.064	0.069	0.074	0.079	0.083	0.088
V_a = 1.9%		2	17.08	16.72	16.18	15.52	14.74	13.88	12.94	11.96	0.028	0.040	0.054	0.067	0.081	0.094	0.107	0.121
		3	18.53	18.04	17.41	16.69	15.89	15.04	14.13	13.20	0.038	0.047	0.056	0.066	0.075	0.085	0.094	0.103
		4	17.63	17.22	16.66	15.99	15.23	14.40	13.50	12.56	0.032	0.042	0.053	0.065	0.076	0.087	0.098	0.109
		5	17.78	17.39	16.84	16.16	15.38	14.51	13.58	12.60	0.030	0.041	0.053	0.065	0.078	0.090	0.102	0.114
		Avg	**18.85**	**18.36**	**17.71**	**16.97**	**16.15**	**15.27**	**14.33**	**13.36**	**0.037**	**0.046**	**0.056**	**0.066**	**0.077**	**0.087**	**0.097**	**0.107**
		StdDev	**2.51**	**2.32**	**2.15**	**2.02**	**1.92**	**1.86**	**1.82**	**1.80**	**0.011**	**0.008**	**0.005**	**0.002**	**0.003**	**0.006**	**0.009**	**0.012**
	-18	1	18.23	17.66	17.02	16.35	15.67	14.98	14.29	13.59	0.049	0.052	0.056	0.059	0.063	0.067	0.070	0.074
		2	17.97	17.52	16.91	16.19	15.37	14.48	13.53	12.54	0.035	0.045	0.057	0.069	0.080	0.092	0.104	0.115
		3	20.16	19.31	18.38	17.45	16.52	15.61	14.72	13.84	0.067	0.070	0.073	0.077	0.080	0.083	0.087	0.090
		4	20.57	19.84	18.96	18.02	17.02	15.99	14.93	13.86	0.053	0.061	0.069	0.078	0.086	0.095	0.103	0.112
		5	17.11	16.63	15.98	15.20	14.33	13.38	12.38	11.34	0.039	0.051	0.065	0.078	0.092	0.106	0.119	0.133
		Avg	**18.81**	**18.19**	**17.45**	**16.64**	**15.79**	**14.89**	**13.97**	**13.04**	**0.048**	**0.056**	**0.064**	**0.072**	**0.080**	**0.089**	**0.097**	**0.105**
		StdDev	**1.49**	**1.34**	**1.20**	**1.11**	**1.05**	**1.02**	**1.04**	**1.09**	**0.013**	**0.010**	**0.008**	**0.008**	**0.011**	**0.015**	**0.019**	**0.023**
Med	-24	1	24.70	24.28	23.67	22.91	22.02	21.02	19.93	18.76	0.023	0.032	0.042	0.052	0.062	0.072	0.082	0.092
V_a = 2.2%		2	20.57	20.07	19.40	18.61	17.73	16.76	15.73	14.66	0.034	0.044	0.054	0.065	0.076	0.086	0.097	0.107
		3	21.74	21.33	20.77	20.12	19.36	18.54	17.64	16.69	0.027	0.034	0.042	0.051	0.059	0.067	0.076	0.084
		4	22.32	21.64	20.82	19.93	18.99	17.99	16.97	15.92	0.046	0.052	0.059	0.067	0.074	0.081	0.088	0.095
		5	21.11	20.65	20.10	19.53	18.92	18.29	17.63	16.96	0.034	0.037	0.040	0.044	0.047	0.051	0.054	0.058
		Avg	**22.09**	**21.59**	**20.95**	**20.22**	**19.40**	**18.52**	**17.58**	**16.60**	**0.033**	**0.040**	**0.048**	**0.056**	**0.064**	**0.071**	**0.079**	**0.087**
		StdDev	**1.60**	**1.62**	**1.62**	**1.61**	**1.59**	**1.55**	**1.52**	**1.50**	**0.009**	**0.008**	**0.009**	**0.010**	**0.012**	**0.014**	**0.016**	**0.018**
	-18	1	20.37	19.94	19.46	19.00	18.54	18.10	17.66	17.23	0.034	0.035	0.035	0.035	0.035	0.035	0.035	0.036
		2	17.31	16.89	16.36	15.76	15.10	14.39	13.64	12.87	0.036	0.042	0.050	0.058	0.065	0.073	0.081	0.088
		3	22.17	21.47	20.64	19.76	18.82	17.85	16.86	15.84	0.048	0.054	0.060	0.067	0.073	0.080	0.086	0.093
		4	21.58	21.03	20.35	19.60	18.79	17.94	17.05	16.13	0.038	0.044	0.051	0.057	0.064	0.070	0.077	0.083
		5	20.91	20.36	19.69	18.98	18.23	17.45	16.64	15.81	0.041	0.045	0.050	0.056	0.061	0.066	0.071	0.076
		Avg	**20.47**	**19.94**	**19.30**	**18.62**	**17.90**	**17.15**	**16.37**	**15.58**	**0.039**	**0.044**	**0.049**	**0.054**	**0.060**	**0.065**	**0.070**	**0.075**
		StdDev	**1.89**	**1.80**	**1.71**	**1.64**	**1.58**	**1.56**	**1.57**	**1.62**	**0.005**	**0.007**	**0.009**	**0.012**	**0.014**	**0.017**	**0.020**	**0.023**

Table B.72 *BBR* Mixture Data for *R-2* RAP Source, 138 C, Sasobit®, 65 Gyrations Continued

P_{AC}	Test		Test Time (sec) and Mixture Stiffness (GPa)								Test Time (sec) and Mixture m-value							
(%)	Temp (C)	Rep	8	15	30	60	120	240	480	960	8	15	30	60	120	240	480	960
Low	-24	1	24.74	23.92	22.95	21.92	20.84	19.72	18.57	17.41	0.050	0.056	0.063	0.070	0.076	0.083	0.090	0.096
V_a = 4.0%		2	23.22	22.75	22.10	21.35	20.49	19.55	18.54	17.47	0.029	0.037	0.046	0.055	0.063	0.072	0.081	0.090
		3	23.71	23.10	22.33	21.48	20.56	19.58	18.55	17.49	0.039	0.045	0.052	0.060	0.067	0.074	0.081	0.088
		4*	6.08	6.05	6.01	5.96	5.91	5.86	5.81	5.75	0.008	0.009	0.010	0.011	0.012	0.013	0.014	0.015
		5	22.01	21.47	20.83	20.14	19.41	18.65	17.86	17.05	0.037	0.042	0.046	0.051	0.055	0.060	0.065	0.069
		Avg	**23.42**	**22.81**	**22.05**	**21.22**	**20.33**	**19.38**	**18.38**	**17.36**	**0.039**	**0.045**	**0.052**	**0.059**	**0.065**	**0.072**	**0.079**	**0.086**
		StdDev	**1.13**	**1.02**	**0.89**	**0.76**	**0.63**	**0.49**	**0.35**	**0.21**	**0.009**	**0.008**	**0.008**	**0.008**	**0.009**	**0.009**	**0.010**	**0.012**
	-18	1	20.36	20.03	19.60	19.08	18.49	17.84	17.13	16.37	0.022	0.029	0.035	0.042	0.049	0.055	0.062	0.069
		2	18.10	17.62	17.07	16.48	15.88	15.27	14.64	14.00	0.041	0.044	0.048	0.052	0.055	0.059	0.063	0.066
		3	20.35	19.78	19.03	18.17	17.21	16.18	15.10	13.98	0.040	0.050	0.061	0.072	0.084	0.095	0.106	0.117
		4	20.55	20.37	19.97	19.39	18.63	17.72	16.69	15.55	0.008	0.021	0.036	0.050	0.065	0.079	0.094	0.109
		5	21.87	21.46	20.87	20.16	19.35	18.44	17.45	16.40	0.026	0.035	0.045	0.055	0.065	0.074	0.084	0.094
		Avg	**20.25**	**19.85**	**19.31**	**18.66**	**17.91**	**17.09**	**16.20**	**15.26**	**0.028**	**0.036**	**0.045**	**0.054**	**0.063**	**0.073**	**0.082**	**0.091**
		StdDev	**1.36**	**1.40**	**1.42**	**1.41**	**1.37**	**1.31**	**1.26**	**1.21**	**0.014**	**0.012**	**0.011**	**0.011**	**0.013**	**0.016**	**0.019**	**0.023**

* Outlier that was omitted from analysis.

Table B.73 *BBR* Mixture Data for *R-2* RAP Source, 138 C, Evotherm™, 65 Gyrations

P_{AC}	Test		Test Time (sec) and Mixture Stiffness (GPa)								Test Time (sec) and Mixture m-value							
(%)	Temp (C)	Rep	8	15	30	60	120	240	480	960	8	15	30	60	120	240	480	960
High	-24	1	20.29	19.82	19.18	18.41	17.53	16.56	15.52	14.43	0.031	0.042	0.053	0.065	0.076	0.088	0.099	0.111
V_a = 1.6%		2	20.00	19.40	18.73	18.04	17.34	16.64	15.94	15.24	0.047	0.050	0.053	0.055	0.058	0.061	0.064	0.066
		3	16.53	16.13	15.62	15.05	14.42	13.74	13.03	12.29	0.036	0.042	0.050	0.058	0.065	0.073	0.081	0.088
		4	21.15	20.58	19.87	19.07	18.20	17.27	16.30	15.30	0.040	0.047	0.055	0.063	0.071	0.079	0.088	0.096
		5*	20.74	20.36	19.99	19.67	19.40	19.18	19.01	18.89	0.031	0.028	0.025	0.021	0.018	0.015	0.011	0.008
		Avg	**19.74**	**19.26**	**18.68**	**18.05**	**17.38**	**16.68**	**15.96**	**15.23**	**0.037**	**0.042**	**0.047**	**0.053**	**0.058**	**0.063**	**0.068**	**0.074**
		StdDev	**1.85**	**1.81**	**1.78**	**1.79**	**1.84**	**1.95**	**2.13**	**2.38**	**0.007**	**0.008**	**0.013**	**0.018**	**0.023**	**0.029**	**0.035**	**0.040**
	-18	1	18.74	18.25	17.65	17.00	16.31	15.58	14.82	14.04	0.039	0.045	0.051	0.057	0.063	0.069	0.075	0.081
		2	18.34	17.61	16.77	15.88	14.98	14.06	13.14	12.22	0.062	0.068	0.074	0.081	0.088	0.095	0.101	0.108
		3	20.15	19.60	18.86	17.98	16.98	15.90	14.74	13.55	0.037	0.049	0.062	0.076	0.089	0.102	0.115	0.128
		4	18.92	18.41	17.74	16.99	16.17	15.28	14.35	13.39	0.040	0.048	0.058	0.067	0.077	0.086	0.095	0.105
		5	19.36	18.81	18.09	17.28	16.37	15.41	14.39	13.35	0.041	0.051	0.061	0.072	0.082	0.093	0.104	0.114
		Avg	**19.10**	**18.54**	**17.82**	**17.03**	**16.16**	**15.25**	**14.29**	**13.31**	**0.044**	**0.052**	**0.061**	**0.071**	**0.080**	**0.089**	**0.098**	**0.107**
		StdDev	**0.69**	**0.74**	**0.76**	**0.75**	**0.73**	**0.70**	**0.68**	**0.67**	**0.010**	**0.009**	**0.009**	**0.009**	**0.011**	**0.012**	**0.015**	**0.017**
Med	-24	1	27.50	26.69	25.79	24.90	24.01	23.13	22.26	21.40	0.047	0.049	0.050	0.052	0.053	0.055	0.056	0.058
V_a = 2.4%		2	23.57	22.84	21.99	21.10	20.19	19.26	18.31	17.36	0.048	0.052	0.057	0.061	0.066	0.070	0.075	0.079
		3	25.73	24.61	23.40	22.21	21.04	19.90	18.79	17.71	0.070	0.072	0.074	0.077	0.079	0.082	0.084	0.087
		4	27.45	26.48	25.36	24.20	23.00	21.77	20.53	19.29	0.054	0.059	0.065	0.071	0.076	0.082	0.087	0.093
		5	17.12	16.78	16.34	15.83	15.27	14.65	14.00	13.31	0.029	0.035	0.042	0.049	0.056	0.063	0.070	0.077
		Avg	**24.27**	**23.48**	**22.58**	**21.65**	**20.70**	**19.74**	**18.78**	**17.81**	**0.050**	**0.053**	**0.058**	**0.062**	**0.066**	**0.070**	**0.074**	**0.079**
		StdDev	**4.31**	**4.06**	**3.81**	**3.59**	**3.40**	**3.23**	**3.09**	**2.98**	**0.015**	**0.014**	**0.013**	**0.012**	**0.012**	**0.012**	**0.012**	**0.013**
	-18	1	18.95	18.48	17.73	16.79	15.69	14.47	13.16	11.80	0.032	0.049	0.069	0.088	0.108	0.127	0.147	0.166
		2	24.05	23.50	22.70	21.72	20.58	19.32	17.96	16.54	0.031	0.043	0.057	0.071	0.084	0.098	0.112	0.126
		3	24.67	24.04	23.12	21.97	20.64	19.18	17.61	15.99	0.033	0.048	0.065	0.082	0.098	0.115	0.131	0.148
		4	17.83	17.56	16.97	16.13	15.07	13.84	12.49	11.08	0.014	0.036	0.061	0.086	0.111	0.135	0.160	0.185
		5	23.35	22.48	21.54	20.61	19.69	18.80	17.93	17.07	0.060	0.061	0.063	0.065	0.066	0.068	0.070	0.071
		Avg	**21.77**	**21.21**	**20.41**	**19.44**	**18.34**	**17.12**	**15.83**	**14.50**	**0.034**	**0.048**	**0.063**	**0.078**	**0.093**	**0.109**	**0.124**	**0.139**
		StdDev	**3.14**	**2.99**	**2.86**	**2.78**	**2.73**	**2.73**	**2.76**	**2.83**	**0.016**	**0.009**	**0.004**	**0.010**	**0.018**	**0.027**	**0.035**	**0.044**

* Outlier that was omitted from analysis.

Table B.74 *BBR* Mixture Data for *R-2* RAP Source, 138 C, Evotherm™, 65 Gyrations Continued

P_{AC}	Test		Test Time (sec) and Mixture Stiffness (GPa)								Test Time (sec) and Mixture m-value							
(%)	Temp (C)	Rep	8	15	30	60	120	240	480	960	8	15	30	60	120	240	480	960
Low	-24	1	26.72	26.13	25.42	24.63	23.79	22.90	21.96	20.99	0.033	0.038	0.043	0.048	0.053	0.058	0.063	0.068
V_a = 4.0%		2	20.81	20.37	19.84	19.26	18.63	17.96	17.26	16.53	0.031	0.036	0.041	0.045	0.050	0.055	0.060	0.065
		3	27.04	26.74	26.14	25.28	24.18	22.88	21.41	19.82	0.010	0.025	0.041	0.056	0.072	0.088	0.104	0.119
		4	25.22	24.64	23.97	23.27	22.54	21.80	21.04	20.26	0.036	0.038	0.041	0.044	0.047	0.050	0.053	0.056
		5	25.05	24.20	23.23	22.24	21.21	20.17	19.13	18.08	0.052	0.057	0.061	0.066	0.070	0.075	0.079	0.084
		Avg	**24.97**	**24.42**	**23.72**	**22.94**	**22.07**	**21.14**	**20.16**	**19.13**	**0.033**	**0.039**	**0.045**	**0.052**	**0.058**	**0.065**	**0.072**	**0.078**
		StdDev	**2.49**	**2.49**	**2.45**	**2.37**	**2.25**	**2.10**	**1.94**	**1.81**	**0.015**	**0.011**	**0.009**	**0.009**	**0.012**	**0.016**	**0.020**	**0.025**
	-18	1	19.69	19.40	18.89	18.21	17.37	16.40	15.33	14.18	0.017	0.031	0.046	0.060	0.075	0.090	0.105	0.120
		2	15.52	15.27	14.92	14.51	14.03	13.49	12.90	12.27	0.022	0.029	0.037	0.045	0.053	0.060	0.068	0.076
		3	21.45	20.90	20.17	19.32	18.37	17.33	16.24	15.10	0.037	0.046	0.057	0.067	0.078	0.089	0.099	0.110
		4	19.80	19.28	18.63	17.89	17.08	16.22	15.31	14.36	0.038	0.046	0.054	0.062	0.071	0.079	0.087	0.096
		5	21.15	20.64	20.02	19.33	18.58	17.80	16.97	16.12	0.036	0.042	0.048	0.054	0.059	0.065	0.071	0.077
		Avg	**19.52**	**19.10**	**18.52**	**17.85**	**17.09**	**16.25**	**15.35**	**14.41**	**0.030**	**0.039**	**0.048**	**0.058**	**0.067**	**0.077**	**0.086**	**0.096**
		StdDev	**2.37**	**2.26**	**2.12**	**1.98**	**1.82**	**1.67**	**1.53**	**1.42**	**0.010**	**0.008**	**0.008**	**0.009**	**0.011**	**0.013**	**0.016**	**0.019**

* Outlier that was omitted from analysis.

Table B.75 *BBR* Mixture Data for *R-2* RAP Source, 154 C, None, 65 Gyrations

P_{AC}	Test		Test Time (sec) and Mixture Stiffness (GPa)								Test Time (sec) and Mixture m-value							
(%)	Temp (C)	Rep	8	15	30	60	120	240	480	960	8	15	30	60	120	240	480	960
High	-24	1	20.77	20.49	20.06	19.51	18.85	18.10	17.26	16.35	0.017	0.026	0.035	0.045	0.054	0.064	0.073	0.083
V_a = 0.9%		2	18.80	18.38	17.82	17.17	16.44	15.64	14.78	13.88	0.031	0.040	0.049	0.058	0.067	0.077	0.086	0.095
		3	20.70	20.17	19.42	18.53	17.52	16.42	15.24	14.01	0.036	0.048	0.061	0.074	0.087	0.101	0.114	0.127
		4	22.83	22.46	21.89	21.14	20.26	19.24	18.12	16.92	0.020	0.031	0.044	0.056	0.068	0.080	0.093	0.105
		5	21.83	21.27	20.54	19.70	18.77	17.77	16.72	15.62	0.037	0.046	0.055	0.065	0.074	0.084	0.093	0.103
		Avg	**20.98**	**20.55**	**19.95**	**19.21**	**18.37**	**17.43**	**16.42**	**15.36**	**0.028**	**0.038**	**0.049**	**0.060**	**0.070**	**0.081**	**0.092**	**0.103**
		StdDev	**1.50**	**1.50**	**1.49**	**1.47**	**1.45**	**1.42**	**1.39**	**1.37**	**0.009**	**0.009**	**0.010**	**0.011**	**0.012**	**0.013**	**0.015**	**0.016**
	-18	1	21.91	21.33	20.65	19.91	19.14	18.34	17.50	16.65	0.040	0.045	0.050	0.055	0.060	0.065	0.070	0.075
		2	23.98	23.48	22.68	21.65	20.43	19.05	17.55	15.99	0.026	0.041	0.058	0.075	0.092	0.109	0.126	0.143
		3	24.24	23.43	22.46	21.42	20.32	19.18	18.01	16.82	0.050	0.057	0.065	0.072	0.080	0.087	0.095	0.102
		4	22.38	21.68	20.82	19.86	18.84	17.76	16.65	15.51	0.046	0.054	0.063	0.072	0.081	0.089	0.098	0.107
		5	20.92	20.10	19.17	18.22	17.27	16.31	15.35	14.41	0.062	0.066	0.071	0.075	0.080	0.085	0.089	0.094
		Avg	**22.68**	**22.00**	**21.15**	**20.22**	**19.20**	**18.13**	**17.01**	**15.87**	**0.045**	**0.053**	**0.061**	**0.070**	**0.078**	**0.087**	**0.096**	**0.104**
		StdDev	**1.40**	**1.45**	**1.44**	**1.39**	**1.29**	**1.17**	**1.05**	**0.98**	**0.013**	**0.010**	**0.008**	**0.009**	**0.012**	**0.016**	**0.020**	**0.025**
Med	-24	1	29.15	27.96	26.45	24.79	23.01	21.15	19.25	17.35	0.060	0.073	0.087	0.101	0.115	0.129	0.143	0.157
V_a = 2.1%		2	26.02	25.02	23.86	22.65	21.40	20.12	18.84	17.55	0.059	0.065	0.072	0.079	0.085	0.092	0.098	0.105
		3	23.64	22.91	22.07	21.18	20.27	19.33	18.38	17.41	0.047	0.052	0.057	0.061	0.066	0.071	0.076	0.080
		4*	14.59	14.34	13.87	13.20	12.38	11.43	10.39	9.30	0.018	0.038	0.060	0.082	0.104	0.126	0.148	0.171
		5	20.81	20.68	20.49	20.23	19.93	19.57	19.17	18.72	0.008	0.012	0.016	0.020	0.024	0.028	0.032	0.036
		Avg	**24.91**	**24.14**	**23.22**	**22.21**	**21.15**	**20.04**	**18.91**	**17.76**	**0.044**	**0.051**	**0.058**	**0.065**	**0.073**	**0.080**	**0.087**	**0.095**
		StdDev	**3.54**	**3.10**	**2.56**	**1.99**	**1.39**	**0.81**	**0.40**	**0.65**	**0.024**	**0.027**	**0.031**	**0.034**	**0.038**	**0.042**	**0.046**	**0.050**
	-18	1	22.22	21.53	20.70	19.81	18.87	17.89	16.88	15.86	0.047	0.053	0.060	0.067	0.074	0.080	0.087	0.094
		2	18.10	17.65	17.16	16.66	16.15	15.64	15.13	14.62	0.039	0.040	0.042	0.044	0.045	0.047	0.049	0.051
		3*	11.99	11.03	10.03	9.09	8.21	7.40	6.64	5.94	0.130	0.135	0.139	0.144	0.149	0.154	0.158	0.163
		4*	12.38	11.83	11.16	10.46	9.73	8.98	8.23	7.48	0.068	0.078	0.089	0.099	0.110	0.121	0.132	0.142
		5*	29.57	28.42	27.04	25.54	23.97	22.34	20.67	19.00	0.058	0.067	0.077	0.087	0.097	0.107	0.117	0.126
		Avg	**20.16**	**19.59**	**18.93**	**18.24**	**17.51**	**16.77**	**16.01**	**15.24**	**0.043**	**0.047**	**0.051**	**0.056**	**0.060**	**0.064**	**0.068**	**0.073**
		StdDev	**2.91**	**2.74**	**2.50**	**2.23**	**1.92**	**1.59**	**1.24**	**0.88**	**0.006**	**0.009**	**0.013**	**0.016**	**0.021**	**0.023**	**0.027**	**0.030**

* Outlier that was omitted from analysis.

Table B.76 *BBR* Mixture Data for *R-2* RAP Source, 154 C, None, 65 Gyrations Continued

P_{AC}	Test		Test Time (sec) and Mixture Stiffness (GPa)								Test Time (sec) and Mixture m-value							
(%)	Temp (C)	Rep	8	15	30	60	120	240	480	960	8	15	30	60	120	240	480	960
Low	-24	1	21.36	21.02	20.47	19.77	18.91	17.94	16.87	15.72	0.020	0.031	0.044	0.057	0.070	0.083	0.096	0.108
V_a = 4.1%		2	27.45	26.81	25.81	24.53	23.03	21.34	19.53	17.64	0.029	0.046	0.064	0.082	0.101	0.119	0.137	0.156
		3	22.44	22.08	21.67	21.23	20.77	20.28	19.78	19.26	0.024	0.026	0.028	0.031	0.033	0.035	0.037	0.039
		4	30.91	30.48	29.78	28.86	27.74	26.46	25.03	23.49	0.017	0.028	0.039	0.051	0.063	0.074	0.086	0.098
		5	26.52	25.88	25.00	23.98	22.82	21.56	20.21	18.81	0.034	0.044	0.055	0.066	0.077	0.088	0.098	0.109
		Avg	**25.74**	**25.25**	**24.55**	**23.67**	**22.65**	**21.52**	**20.28**	**18.98**	**0.025**	**0.035**	**0.046**	**0.057**	**0.069**	**0.080**	**0.091**	**0.102**
		StdDev	**3.89**	**3.81**	**3.68**	**3.50**	**3.30**	**3.11**	**2.96**	**2.87**	**0.007**	**0.009**	**0.014**	**0.019**	**0.025**	**0.030**	**0.036**	**0.042**
	-18	1	20.00	19.63	19.17	18.66	18.11	17.51	16.89	16.23	0.028	0.032	0.037	0.041	0.046	0.050	0.055	0.059
		2	25.17	24.34	23.38	22.38	21.34	20.29	19.21	18.14	0.051	0.056	0.061	0.066	0.071	0.076	0.081	0.086
		3	18.01	17.64	17.13	16.54	15.87	15.13	14.33	13.49	0.029	0.038	0.046	0.055	0.064	0.073	0.082	0.091
		4*	6.51	6.46	6.39	6.31	6.22	6.11	6.00	5.87	0.011	0.014	0.017	0.020	0.023	0.026	0.029	0.032
		5	27.25	26.80	26.01	24.95	23.65	22.16	20.52	18.78	0.019	0.035	0.052	0.069	0.085	0.102	0.119	0.136
		Avg	**22.61**	**22.10**	**21.42**	**20.63**	**19.74**	**18.77**	**17.74**	**16.66**	**0.032**	**0.040**	**0.049**	**0.058**	**0.067**	**0.075**	**0.084**	**0.093**
		StdDev	**4.32**	**4.21**	**4.02**	**3.76**	**3.44**	**3.09**	**2.72**	**2.37**	**0.014**	**0.011**	**0.010**	**0.013**	**0.016**	**0.021**	**0.026**	**0.032**

* Outlier that was omitted from analysis.

Table B.77 *BBR* Mixture Data for *R-3* RAP Source, 116 C, None, 65 Gyrations

P_{AC}	Test		Test Time (sec) and Mixture Stiffness (GPa)								Test Time (sec) and Mixture m-value							
(%)	Temp (C)	Rep	8	15	30	60	120	240	480	960	8	15	30	60	120	240	480	960
High	-24	1	20.54	19.89	19.05	18.10	17.08	15.99	14.85	13.69	0.047	0.057	0.068	0.079	0.090	0.101	0.112	0.123
V_a = 2.0%		2	21.67	21.03	20.22	19.29	18.28	17.19	16.05	14.88	0.042	0.052	0.062	0.073	0.083	0.094	0.104	0.114
		3	20.81	20.05	19.16	18.22	17.25	16.25	15.25	14.23	0.056	0.062	0.069	0.076	0.082	0.089	0.096	0.102
		4	17.09	16.60	16.04	15.47	14.89	14.31	13.72	13.14	0.045	0.048	0.051	0.053	0.056	0.059	0.062	0.065
		5	24.16	23.47	22.53	21.42	20.17	18.81	17.38	15.90	0.040	0.052	0.066	0.080	0.094	0.107	0.121	0.135
		Avg	**20.85**	**20.21**	**19.40**	**18.50**	**17.53**	**16.51**	**15.45**	**14.37**	**0.046**	**0.054**	**0.063**	**0.072**	**0.081**	**0.090**	**0.099**	**0.108**
		StdDev	**2.54**	**2.48**	**2.34**	**2.15**	**1.92**	**1.65**	**1.37**	**1.07**	**0.006**	**0.006**	**0.007**	**0.011**	**0.015**	**0.019**	**0.023**	**0.027**
	-18	1	16.48	15.96	15.27	14.48	13.60	12.67	11.69	10.69	0.045	0.057	0.070	0.083	0.096	0.109	0.122	0.135
		2	19.88	19.05	18.11	17.15	16.18	15.21	14.24	13.28	0.065	0.070	0.076	0.081	0.087	0.092	0.098	0.103
		3	16.60	16.16	15.58	14.91	14.16	13.35	12.50	11.61	0.038	0.048	0.058	0.069	0.080	0.090	0.101	0.112
		4	22.07	21.32	20.40	19.42	18.39	17.31	16.21	15.09	0.052	0.059	0.067	0.075	0.083	0.091	0.099	0.107
		5	14.10	13.71	13.19	12.59	11.92	11.20	10.45	9.66	0.040	0.050	0.061	0.073	0.084	0.095	0.107	0.118
		Avg	**17.83**	**17.24**	**16.51**	**15.71**	**14.85**	**13.95**	**13.02**	**12.07**	**0.048**	**0.057**	**0.067**	**0.076**	**0.086**	**0.096**	**0.105**	**0.115**
		StdDev	**3.14**	**2.96**	**2.79**	**2.63**	**2.49**	**2.37**	**2.25**	**2.15**	**0.011**	**0.009**	**0.007**	**0.006**	**0.006**	**0.008**	**0.010**	**0.013**
Med	-24	1	21.60	21.16	20.51	19.68	18.72	17.63	16.46	15.21	0.026	0.039	0.052	0.066	0.079	0.093	0.106	0.120
V_a = 3.8%		2	18.58	18.10	17.53	16.93	16.30	15.66	14.99	14.32	0.040	0.044	0.048	0.052	0.056	0.060	0.065	0.069
		3	24.91	24.35	23.39	22.13	20.61	18.90	17.07	15.17	0.026	0.047	0.069	0.091	0.114	0.136	0.158	0.181
		4	18.12	17.62	16.97	16.23	15.42	14.54	13.61	12.66	0.040	0.049	0.059	0.069	0.080	0.090	0.100	0.110
		5	25.66	24.82	23.77	22.62	21.37	20.06	18.71	17.32	0.049	0.057	0.067	0.077	0.086	0.096	0.106	0.116
		Avg	**21.78**	**21.21**	**20.43**	**19.52**	**18.48**	**17.36**	**16.17**	**14.94**	**0.036**	**0.047**	**0.059**	**0.071**	**0.083**	**0.095**	**0.107**	**0.119**
		StdDev	**3.48**	**3.37**	**3.17**	**2.91**	**2.60**	**2.27**	**1.95**	**1.69**	**0.010**	**0.007**	**0.009**	**0.014**	**0.021**	**0.027**	**0.033**	**0.040**
	-18	1	21.17	20.52	19.81	19.13	18.46	17.81	17.17	16.56	0.050	0.050	0.051	0.051	0.052	0.052	0.052	0.053
		2	20.75	20.10	19.33	18.50	17.62	16.70	15.76	14.80	0.047	0.053	0.060	0.067	0.074	0.081	0.087	0.094
		3	25.11	24.57	23.80	22.87	21.79	20.59	19.29	17.93	0.029	0.040	0.052	0.064	0.076	0.088	0.100	0.111
		4	25.33	24.53	23.59	22.59	21.56	20.49	19.39	18.29	0.049	0.054	0.059	0.065	0.071	0.076	0.082	0.087
		5	25.72	24.92	23.93	22.84	21.66	20.42	19.14	17.83	0.046	0.054	0.063	0.072	0.081	0.089	0.098	0.107
		Avg	**23.62**	**22.93**	**22.09**	**21.18**	**20.22**	**19.20**	**18.15**	**17.08**	**0.044**	**0.050**	**0.057**	**0.064**	**0.070**	**0.077**	**0.084**	**0.091**
		StdDev	**2.44**	**2.40**	**2.31**	**2.18**	**2.01**	**1.82**	**1.62**	**1.43**	**0.008**	**0.006**	**0.005**	**0.008**	**0.011**	**0.015**	**0.019**	**0.023**

Table B.78 *BBR* Mixture Data for *R-3* RAP Source, 116 C, Evotherm™, 65 Gyrations

P_{AC}	Test		Test Time (sec) and Mixture Stiffness (GPa)								Test Time (sec) and Mixture m-value							
(%)	Temp (C)	Rep	8	15	30	60	120	240	480	960	8	15	30	60	120	240	480	960
High	-24	1	16.69	16.05	15.26	14.40	13.49	12.54	11.58	10.61	0.058	0.067	0.078	0.089	0.100	0.110	0.121	0.132
V_a = 2.2%		2	20.88	20.35	19.58	18.65	17.57	16.38	15.11	13.80	0.034	0.048	0.063	0.078	0.093	0.109	0.124	0.139
		3	24.04	23.31	22.40	21.39	20.30	19.16	17.96	16.74	0.045	0.053	0.062	0.071	0.080	0.088	0.097	0.106
		4	20.04	19.53	18.79	17.88	16.82	15.64	14.39	13.09	0.033	0.048	0.064	0.080	0.096	0.112	0.129	0.145
		5	20.89	20.46	19.84	19.10	18.24	17.28	16.25	15.16	0.028	0.038	0.050	0.061	0.072	0.083	0.095	0.106
		Avg	**20.51**	**19.94**	**19.17**	**18.28**	**17.28**	**16.20**	**15.06**	**13.88**	**0.040**	**0.051**	**0.063**	**0.076**	**0.088**	**0.101**	**0.113**	**0.125**
		StdDev	**2.63**	**2.60**	**2.57**	**2.53**	**2.49**	**2.43**	**2.37**	**2.30**	**0.012**	**0.011**	**0.010**	**0.011**	**0.012**	**0.014**	**0.016**	**0.018**
	-18	1	23.05	22.24	21.27	20.23	19.13	18.00	16.84	15.66	0.053	0.060	0.068	0.076	0.084	0.092	0.100	0.108
		2	24.12	23.28	22.19	20.96	19.62	18.19	16.72	15.22	0.050	0.062	0.076	0.089	0.102	0.115	0.129	0.142
		3	19.22	18.47	17.62	16.74	15.83	14.92	14.00	13.08	0.060	0.065	0.071	0.077	0.083	0.089	0.095	0.101
		4*	14.19	13.74	13.18	12.56	11.88	11.16	10.41	9.65	0.046	0.055	0.065	0.075	0.085	0.095	0.105	0.115
		5	26.52	25.63	24.56	23.42	22.22	20.98	19.71	18.42	0.051	0.058	0.065	0.072	0.079	0.087	0.094	0.101
		Avg	**23.23**	**22.41**	**21.41**	**20.34**	**19.20**	**18.02**	**16.82**	**15.60**	**0.054**	**0.061**	**0.070**	**0.079**	**0.087**	**0.096**	**0.105**	**0.113**
		StdDev	**3.04**	**2.98**	**2.88**	**2.76**	**2.62**	**2.48**	**2.33**	**2.19**	**0.005**	**0.003**	**0.005**	**0.007**	**0.010**	**0.013**	**0.017**	**0.020**
Med	-24	1	16.63	16.11	15.28	14.24	13.02	11.69	10.31	8.93	0.039	0.063	0.089	0.116	0.142	0.168	0.195	0.221
V_a = 3.6%		2	19.11	18.63	17.99	17.25	16.42	15.53	14.58	13.59	0.036	0.045	0.055	0.066	0.076	0.086	0.096	0.106
		3	20.81	20.28	19.59	18.81	17.96	17.03	16.06	15.05	0.037	0.045	0.054	0.063	0.072	0.080	0.089	0.098
		4	22.35	21.53	20.63	19.74	18.87	18.01	17.17	16.35	0.059	0.061	0.062	0.064	0.066	0.068	0.070	0.072
		5	21.55	21.12	20.50	19.72	18.80	17.78	16.66	15.48	0.026	0.037	0.050	0.062	0.075	0.087	0.100	0.112
		Avg	**20.09**	**19.53**	**18.80**	**17.95**	**17.01**	**16.01**	**14.96**	**13.88**	**0.039**	**0.050**	**0.062**	**0.074**	**0.086**	**0.098**	**0.110**	**0.122**
		StdDev	**2.27**	**2.21**	**2.23**	**2.31**	**2.44**	**2.60**	**2.77**	**2.94**	**0.012**	**0.011**	**0.016**	**0.023**	**0.031**	**0.040**	**0.049**	**0.058**
	-18	1	16.10	15.53	14.83	14.07	13.24	12.38	11.50	10.60	0.052	0.061	0.072	0.082	0.092	0.102	0.112	0.122
		2	22.68	22.02	21.16	20.18	19.11	17.97	16.77	15.53	0.043	0.052	0.063	0.073	0.084	0.094	0.105	0.115
		3	20.21	19.61	18.83	17.95	16.98	15.95	14.86	13.75	0.043	0.053	0.064	0.075	0.085	0.096	0.107	0.118
		4	25.85	25.16	24.15	22.89	21.44	19.83	18.13	16.37	0.035	0.051	0.068	0.086	0.103	0.121	0.139	0.156
		5	18.63	18.19	17.56	16.79	15.90	14.91	13.85	12.74	0.032	0.044	0.058	0.072	0.086	0.100	0.113	0.127
		Avg	**20.69**	**20.10**	**19.31**	**18.38**	**17.33**	**16.21**	**15.02**	**13.80**	**0.041**	**0.052**	**0.065**	**0.077**	**0.090**	**0.103**	**0.115**	**0.128**
		StdDev	**3.75**	**3.68**	**3.54**	**3.35**	**3.12**	**2.86**	**2.57**	**2.29**	**0.008**	**0.006**	**0.005**	**0.006**	**0.008**	**0.011**	**0.014**	**0.016**

* Outlier that was omitted from analysis.

Table B.79 *BBR* Mixture Data for *R-3* RAP Source, 138 C, None, 65 Gyrations

P_{AC}	Test		Test Time (sec) and Mixture Stiffness (GPa)								Test Time (sec) and Mixture m-value							
(%)	Temp (C)	Rep	8	15	30	60	120	240	480	960	8	15	30	60	120	240	480	960
High	-24	1	20.67	20.22	19.68	19.11	18.50	17.86	17.20	16.52	0.033	0.037	0.041	0.045	0.049	0.052	0.056	0.060
V_a = 2.2%		2	19.74	19.22	18.56	17.83	17.04	16.19	15.29	14.37	0.039	0.046	0.054	0.062	0.070	0.078	0.086	0.094
		3	18.85	18.43	17.84	17.15	16.37	15.51	14.59	13.63	0.032	0.041	0.052	0.062	0.072	0.083	0.093	0.104
		4	19.94	19.49	18.92	18.26	17.55	16.77	15.96	15.10	0.033	0.040	0.047	0.054	0.061	0.069	0.076	0.083
		5	16.80	16.33	15.80	15.24	14.67	14.08	13.49	12.89	0.043	0.047	0.050	0.053	0.057	0.060	0.064	0.067
		Avg	**19.20**	**18.74**	**18.16**	**17.52**	**16.82**	**16.08**	**15.31**	**14.50**	**0.036**	**0.042**	**0.049**	**0.055**	**0.062**	**0.068**	**0.075**	**0.082**
		StdDev	**1.49**	**1.49**	**1.48**	**1.46**	**1.43**	**1.41**	**1.40**	**1.40**	**0.005**	**0.004**	**0.005**	**0.007**	**0.010**	**0.012**	**0.015**	**0.018**
	-18	1	18.55	18.22	17.76	17.21	16.58	15.89	15.14	14.34	0.025	0.033	0.041	0.049	0.057	0.066	0.074	0.082
		2	19.10	18.69	18.08	17.34	16.49	15.53	14.50	13.42	0.029	0.041	0.054	0.067	0.080	0.092	0.105	0.118
		3	15.85	15.50	14.98	14.36	13.64	12.84	11.97	11.07	0.030	0.042	0.055	0.068	0.081	0.094	0.107	0.120
		4	16.11	15.60	14.92	14.15	13.29	12.37	11.40	10.42	0.045	0.057	0.070	0.084	0.097	0.110	0.123	0.137
		5	17.79	17.32	16.77	16.19	15.57	14.93	14.27	13.60	0.040	0.044	0.049	0.054	0.058	0.063	0.067	0.072
		Avg	**17.48**	**17.06**	**16.50**	**15.85**	**15.11**	**14.31**	**13.46**	**12.57**	**0.034**	**0.043**	**0.054**	**0.064**	**0.075**	**0.085**	**0.095**	**0.106**
		StdDev	**1.45**	**1.47**	**1.49**	**1.53**	**1.56**	**1.61**	**1.66**	**1.72**	**0.008**	**0.009**	**0.011**	**0.014**	**0.017**	**0.020**	**0.024**	**0.027**
Med	-24	1	20.69	19.97	19.16	18.34	17.51	16.67	15.83	15.00	0.054	0.058	0.062	0.065	0.069	0.073	0.076	0.080
V_a = 3.5%		2	23.25	22.76	22.09	21.31	20.41	19.43	18.37	17.26	0.029	0.038	0.048	0.057	0.067	0.076	0.086	0.095
		3	23.70	23.21	22.56	21.80	20.94	20.00	19.00	17.93	0.029	0.037	0.045	0.054	0.062	0.070	0.079	0.087
		4	21.94	21.35	20.63	19.85	19.02	18.14	17.24	16.31	0.041	0.046	0.053	0.059	0.065	0.071	0.077	0.083
		5	23.33	22.69	21.86	20.92	19.87	18.74	17.56	16.33	0.040	0.049	0.059	0.069	0.079	0.089	0.099	0.109
		Avg	**22.58**	**22.00**	**21.26**	**20.44**	**19.55**	**18.60**	**17.60**	**16.57**	**0.039**	**0.046**	**0.053**	**0.061**	**0.068**	**0.076**	**0.083**	**0.091**
		StdDev	**1.25**	**1.33**	**1.37**	**1.38**	**1.35**	**1.29**	**1.20**	**1.11**	**0.010**	**0.009**	**0.007**	**0.006**	**0.007**	**0.008**	**0.010**	**0.012**
	-18	1*	6.57	6.50	6.40	6.27	6.12	5.94	5.74	5.52	0.013	0.019	0.026	0.033	0.039	0.046	0.053	0.059
		2	27.90	27.26	26.37	25.32	24.13	22.83	21.43	19.97	0.032	0.042	0.053	0.064	0.075	0.086	0.097	0.108
		3	20.79	20.25	19.56	18.78	17.91	16.98	16.01	14.99	0.038	0.046	0.055	0.063	0.072	0.081	0.090	0.099
		4	22.24	21.54	20.78	20.03	19.29	18.55	17.83	17.12	0.050	0.051	0.052	0.054	0.055	0.057	0.058	0.060
		5	24.45	23.90	23.13	22.19	21.12	19.94	18.66	17.33	0.031	0.042	0.054	0.065	0.077	0.089	0.101	0.113
		Avg	**23.85**	**23.24**	**22.46**	**21.58**	**20.61**	**19.58**	**18.48**	**17.35**	**0.038**	**0.045**	**0.054**	**0.062**	**0.070**	**0.078**	**0.087**	**0.095**
		StdDev	**3.09**	**3.08**	**3.00**	**2.86**	**2.69**	**2.48**	**2.26**	**2.04**	**0.009**	**0.004**	**0.001**	**0.005**	**0.010**	**0.015**	**0.020**	**0.024**

* Outlier that was omitted from analysis.

Table B.80 *BBR* Mixture Data for *R-3* RAP Source, 138 C, None, 65 Gyrations Continued

P_{AC}	Test		Test Time (sec) and Mixture Stiffness (GPa)								Test Time (sec) and Mixture m-value							
(%)	Temp (C)	Rep	8	15	30	60	120	240	480	960	8	15	30	60	120	240	480	960
Low	-24	1	16.07	15.55	14.92	14.25	13.54	12.79	12.03	11.25	0.049	0.056	0.063	0.070	0.078	0.085	0.093	0.100
V_a = 6.1%		2	17.27	16.83	16.27	15.64	14.95	14.21	13.43	12.62	0.037	0.045	0.053	0.061	0.069	0.077	0.085	0.094
		3	17.15	16.78	16.28	15.70	15.04	14.32	13.55	12.75	0.031	0.039	0.048	0.057	0.066	0.075	0.084	0.093
		4	18.16	17.91	17.51	16.99	16.36	15.64	14.83	13.96	0.017	0.027	0.038	0.049	0.060	0.071	0.082	0.093
		5	17.63	17.18	16.61	15.97	15.28	14.54	13.76	12.96	0.038	0.045	0.052	0.060	0.068	0.075	0.083	0.091
		Avg	**17.26**	**16.85**	**16.32**	**15.71**	**15.03**	**14.30**	**13.52**	**12.71**	**0.034**	**0.042**	**0.051**	**0.059**	**0.068**	**0.077**	**0.085**	**0.094**
		StdDev	**0.77**	**0.86**	**0.93**	**0.98**	**1.01**	**1.01**	**1.00**	**0.97**	**0.012**	**0.010**	**0.009**	**0.008**	**0.006**	**0.005**	**0.004**	**0.004**
	-18	1	17.74	17.38	16.94	16.45	15.93	15.37	14.78	14.16	0.030	0.035	0.040	0.044	0.049	0.054	0.059	0.064
		2*	30.70	29.96	28.92	27.67	26.24	24.66	22.98	21.23	0.033	0.045	0.057	0.070	0.083	0.096	0.108	0.121
		3	20.55	19.95	19.05	17.94	16.66	15.25	13.77	12.26	0.038	0.056	0.077	0.097	0.117	0.137	0.157	0.178
		4	18.91	18.41	17.72	16.88	15.93	14.89	13.78	12.63	0.036	0.049	0.063	0.077	0.091	0.105	0.119	0.133
		5	22.43	21.46	20.33	19.15	17.94	16.72	15.49	14.27	0.067	0.074	0.082	0.090	0.098	0.106	0.114	0.122
		Avg	**19.91**	**19.30**	**18.51**	**17.61**	**16.62**	**15.56**	**14.46**	**13.33**	**0.043**	**0.054**	**0.066**	**0.077**	**0.089**	**0.101**	**0.112**	**0.124**
		StdDev	**2.04**	**1.79**	**1.49**	**1.21**	**0.95**	**0.80**	**0.84**	**1.03**	**0.017**	**0.016**	**0.019**	**0.024**	**0.029**	**0.034**	**0.040**	**0.047**

* Outlier that was omitted from analysis.

Table B.81 *BBR* Mixture Data for *R-3* RAP Source, 138 C, Sasobit®, 65 Gyrations

P_{AC}	Test		Test Time (sec) and Mixture Stiffness (GPa)								Test Time (sec) and Mixture m-value							
(%)	Temp (C)	Rep	8	15	30	60	120	240	480	960	8	15	30	60	120	240	480	960
High	-24	1	19.41	19.05	18.63	18.18	17.71	17.23	16.72	16.20	0.028	0.031	0.034	0.036	0.039	0.042	0.044	0.047
V_a = 2.2%		2	16.98	16.57	16.08	15.58	15.05	14.51	13.96	13.39	0.038	0.041	0.044	0.048	0.051	0.054	0.058	0.061
		3	20.58	19.99	19.26	18.44	17.55	16.61	15.63	14.61	0.042	0.050	0.058	0.067	0.075	0.084	0.092	0.101
		4	19.44	18.88	18.21	17.48	16.71	15.91	15.09	14.24	0.044	0.049	0.056	0.062	0.068	0.074	0.080	0.086
		5	18.62	18.06	17.31	16.44	15.46	14.41	13.31	12.17	0.042	0.055	0.068	0.081	0.095	0.108	0.122	0.135
		Avg	**19.01**	**18.51**	**17.90**	**17.22**	**16.50**	**15.73**	**14.94**	**14.12**	**0.039**	**0.045**	**0.052**	**0.059**	**0.066**	**0.072**	**0.079**	**0.086**
		StdDev	**1.33**	**1.29**	**1.24**	**1.20**	**1.20**	**1.25**	**1.35**	**1.49**	**0.006**	**0.009**	**0.013**	**0.017**	**0.022**	**0.026**	**0.030**	**0.034**
	-18	1	17.82	17.29	16.69	16.09	15.48	14.87	14.26	13.65	0.047	0.049	0.052	0.054	0.057	0.059	0.062	0.064
		2	18.33	17.68	16.90	16.06	15.17	14.25	13.31	12.36	0.053	0.061	0.069	0.078	0.086	0.094	0.103	0.111
		3	17.93	17.36	16.63	15.80	14.90	13.94	12.93	11.91	0.046	0.057	0.068	0.079	0.091	0.102	0.113	0.125
		4	19.03	18.37	17.61	16.81	15.98	15.14	14.28	13.42	0.053	0.059	0.064	0.070	0.075	0.081	0.087	0.092
		5	17.13	16.53	15.80	15.01	14.17	13.30	12.41	11.51	0.053	0.061	0.070	0.078	0.087	0.096	0.104	0.113
		Avg	**18.05**	**17.45**	**16.73**	**15.95**	**15.14**	**14.30**	**13.44**	**12.57**	**0.051**	**0.057**	**0.065**	**0.072**	**0.079**	**0.087**	**0.094**	**0.101**
		StdDev	**0.70**	**0.67**	**0.65**	**0.65**	**0.68**	**0.74**	**0.82**	**0.94**	**0.004**	**0.005**	**0.007**	**0.011**	**0.014**	**0.017**	**0.020**	**0.024**
Med	-24	1	20.38	19.76	19.01	18.19	17.31	16.39	15.44	14.47	0.045	0.052	0.060	0.067	0.075	0.082	0.090	0.097
V_a = 3.1%		2	24.20	23.35	22.41	21.46	20.52	19.57	18.63	17.70	0.055	0.058	0.061	0.064	0.067	0.070	0.072	0.075
		3	18.80	18.14	17.26	16.25	15.15	13.97	12.76	11.53	0.051	0.064	0.079	0.094	0.109	0.124	0.139	0.154
		4	13.18	13.07	12.85	12.53	12.11	11.61	11.03	10.40	0.007	0.018	0.031	0.043	0.055	0.067	0.080	0.092
		5	17.91	17.45	16.88	16.26	15.60	14.90	14.17	13.41	0.039	0.045	0.051	0.057	0.063	0.069	0.076	0.082
		Avg	**18.90**	**18.35**	**17.68**	**16.94**	**16.14**	**15.29**	**14.41**	**13.50**	**0.040**	**0.048**	**0.056**	**0.065**	**0.074**	**0.082**	**0.091**	**0.100**
		StdDev	**4.00**	**3.73**	**3.47**	**3.26**	**3.08**	**2.96**	**2.88**	**2.83**	**0.019**	**0.018**	**0.018**	**0.019**	**0.021**	**0.024**	**0.027**	**0.031**
	-18	1	19.01	18.46	17.87	17.30	16.73	16.18	15.64	15.12	0.046	0.047	0.047	0.048	0.048	0.049	0.049	0.050
		2	18.92	18.50	17.93	17.25	16.48	15.62	14.70	13.74	0.030	0.040	0.050	0.061	0.072	0.082	0.093	0.103
		3	19.57	19.03	18.37	17.65	16.88	16.06	15.22	14.35	0.042	0.048	0.054	0.061	0.068	0.075	0.081	0.088
		4	27.63	26.67	25.52	24.31	23.04	21.73	20.40	19.05	0.053	0.060	0.067	0.074	0.081	0.088	0.095	0.102
		5	16.10	15.53	14.83	14.07	13.24	12.38	11.50	10.60	0.052	0.061	0.072	0.082	0.092	0.102	0.112	0.122
		Avg	**20.24**	**19.64**	**18.91**	**18.11**	**17.27**	**16.40**	**15.49**	**14.57**	**0.045**	**0.051**	**0.058**	**0.065**	**0.072**	**0.079**	**0.086**	**0.093**
		StdDev	**4.34**	**4.16**	**3.96**	**3.75**	**3.56**	**3.37**	**3.19**	**3.04**	**0.009**	**0.009**	**0.011**	**0.013**	**0.016**	**0.020**	**0.023**	**0.027**

Table B.82 *BBR* Mixture Data for *R-3* RAP Source, 138 C, Sasobit®, 65 Gyrations Continued

P_{AC}	Test		Test Time (sec) and Mixture Stiffness (GPa)								Test Time (sec) and Mixture m-value							
(%)	Temp (C)	Rep	8	15	30	60	120	240	480	960	8	15	30	60	120	240	480	960
Low	-24	1*	8.25	8.15	8.03	7.90	7.75	7.60	7.43	7.26	0.018	0.021	0.023	0.025	0.028	0.030	0.033	0.035
V_a = 6.0%		2	16.99	16.45	15.70	14.84	13.87	12.83	11.74	10.63	0.045	0.059	0.074	0.090	0.105	0.120	0.136	0.151
		3	18.68	18.19	17.60	16.97	16.30	15.60	14.87	14.13	0.040	0.045	0.050	0.055	0.061	0.066	0.072	0.077
		4	16.26	15.79	15.21	14.58	13.90	13.19	12.45	11.69	0.043	0.050	0.057	0.065	0.072	0.080	0.087	0.095
		5	21.72	21.08	20.31	19.50	18.65	17.76	16.85	15.92	0.045	0.050	0.056	0.062	0.068	0.073	0.079	0.085
		Avg	**18.41**	**17.88**	**17.21**	**16.47**	**15.68**	**14.85**	**13.98**	**13.09**	**0.043**	**0.051**	**0.059**	**0.068**	**0.077**	**0.085**	**0.094**	**0.102**
		StdDev	**2.43**	**2.36**	**2.31**	**2.28**	**2.28**	**2.30**	**2.34**	**2.39**	**0.002**	**0.006**	**0.010**	**0.015**	**0.020**	**0.024**	**0.029**	**0.033**
	-18	1	17.00	16.53	15.97	15.37	14.72	14.05	13.35	12.63	0.042	0.047	0.053	0.059	0.065	0.071	0.077	0.083
		2	24.03	23.51	22.77	21.85	20.80	19.62	18.35	17.01	0.029	0.040	0.053	0.065	0.078	0.090	0.103	0.115
		3	18.89	18.17	17.41	16.66	15.93	15.23	14.55	13.88	0.061	0.062	0.063	0.064	0.065	0.066	0.067	0.068
		4	24.42	23.78	22.96	22.03	21.01	19.92	18.76	17.57	0.038	0.046	0.055	0.064	0.073	0.082	0.091	0.100
		5	20.74	20.00	19.13	18.24	17.32	16.38	15.44	14.49	0.056	0.061	0.066	0.072	0.077	0.083	0.088	0.094
		Avg	**21.02**	**20.40**	**19.65**	**18.83**	**17.96**	**17.04**	**16.09**	**15.12**	**0.045**	**0.051**	**0.058**	**0.065**	**0.072**	**0.078**	**0.085**	**0.092**
		StdDev	**3.22**	**3.21**	**3.14**	**3.02**	**2.85**	**2.63**	**2.38**	**2.10**	**0.013**	**0.010**	**0.006**	**0.005**	**0.006**	**0.010**	**0.014**	**0.018**

* Outlier that was omitted from analysis.

Table B.83 *BBR* Mixture Data for *R-3* RAP Source, 138 C, Evotherm™, 65 Gyrations

P_{AC}	Test		Test Time (sec) and Mixture Stiffness (GPa)								Test Time (sec) and Mixture m-value							
(%)	Temp (C)	Rep	8	15	30	60	120	240	480	960	8	15	30	60	120	240	480	960
High	-24	1	20.71	20.34	19.69	18.82	17.77	16.56	15.24	13.85	0.021	0.037	0.056	0.074	0.092	0.111	0.129	0.148
V_a = 2.2%		2	16.37	15.96	15.41	14.75	14.02	13.21	12.35	11.45	0.035	0.045	0.057	0.068	0.080	0.091	0.103	0.114
		3	18.60	17.98	17.28	16.56	15.83	15.08	14.32	13.57	0.051	0.055	0.059	0.064	0.068	0.072	0.076	0.080
		4	23.31	22.52	21.54	20.47	19.33	18.12	16.88	15.62	0.050	0.059	0.069	0.078	0.088	0.098	0.107	0.117
		5	21.85	21.17	20.33	19.41	18.42	17.39	16.31	15.21	0.046	0.054	0.063	0.071	0.079	0.088	0.096	0.105
		Avg	**20.17**	**19.59**	**18.85**	**18.01**	**17.07**	**16.07**	**15.02**	**13.94**	**0.041**	**0.050**	**0.061**	**0.071**	**0.081**	**0.092**	**0.102**	**0.113**
		StdDev	**2.73**	**2.62**	**2.47**	**2.31**	**2.14**	**1.96**	**1.79**	**1.64**	**0.013**	**0.009**	**0.005**	**0.006**	**0.009**	**0.014**	**0.019**	**0.024**
	-18	1	18.41	17.68	16.82	15.91	14.98	14.02	13.06	12.09	0.061	0.068	0.076	0.084	0.091	0.099	0.107	0.114
		2	18.62	18.09	17.45	16.76	16.02	15.25	14.45	13.63	0.043	0.049	0.055	0.062	0.068	0.075	0.081	0.087
		3	18.82	18.28	17.60	16.83	15.98	15.08	14.14	13.18	0.042	0.051	0.060	0.069	0.079	0.088	0.098	0.107
		4	15.33	14.89	14.34	13.73	13.05	12.32	11.57	10.78	0.041	0.050	0.059	0.068	0.078	0.087	0.096	0.106
		5	20.71	20.08	19.32	18.52	17.67	16.79	15.89	14.97	0.047	0.052	0.058	0.064	0.071	0.077	0.083	0.089
		Avg	**18.38**	**17.81**	**17.11**	**16.35**	**15.54**	**14.69**	**13.82**	**12.93**	**0.047**	**0.054**	**0.062**	**0.069**	**0.077**	**0.085**	**0.093**	**0.101**
		StdDev	**1.94**	**1.87**	**1.80**	**1.74**	**1.70**	**1.65**	**1.62**	**1.58**	**0.008**	**0.008**	**0.008**	**0.008**	**0.009**	**0.010**	**0.011**	**0.012**
Med	-24	1	16.65	16.10	15.41	14.63	13.79	12.90	11.97	11.03	0.048	0.058	0.069	0.080	0.091	0.102	0.113	0.124
V_a = 3.3%		2	15.78	15.53	15.15	14.65	14.06	13.38	12.63	11.83	0.020	0.030	0.042	0.054	0.065	0.077	0.089	0.100
		3	20.95	20.38	19.71	18.98	18.20	17.39	16.55	15.68	0.041	0.046	0.052	0.057	0.063	0.069	0.075	0.080
		4	20.42	19.82	19.10	18.31	17.47	16.58	15.67	14.73	0.044	0.050	0.057	0.064	0.071	0.078	0.085	0.092
		5	15.72	15.45	15.04	14.52	13.89	13.19	12.41	11.58	0.022	0.033	0.045	0.057	0.069	0.081	0.093	0.106
		Avg	**17.90**	**17.46**	**16.88**	**16.22**	**15.48**	**14.69**	**13.85**	**12.97**	**0.035**	**0.043**	**0.053**	**0.063**	**0.072**	**0.082**	**0.091**	**0.101**
		StdDev	**2.57**	**2.44**	**2.32**	**2.23**	**2.17**	**2.12**	**2.10**	**2.09**	**0.013**	**0.012**	**0.011**	**0.011**	**0.011**	**0.012**	**0.014**	**0.016**
	-18	1	20.59	19.97	19.12	18.11	16.97	15.74	14.43	13.10	0.041	0.055	0.071	0.086	0.101	0.117	0.132	0.148
		2	13.49	13.29	13.02	12.70	12.33	11.92	11.47	10.98	0.021	0.027	0.033	0.039	0.046	0.052	0.059	0.065
		3*	4.82	4.78	4.72	4.66	4.59	4.51	4.42	4.32	0.012	0.015	0.018	0.021	0.024	0.027	0.030	0.033
		4	14.59	14.23	13.69	13.02	12.23	11.36	10.43	9.46	0.032	0.047	0.064	0.081	0.098	0.115	0.132	0.149
		5	18.24	17.66	17.01	16.33	15.64	14.94	14.22	13.51	0.049	0.053	0.057	0.061	0.064	0.068	0.072	0.076
		Avg	**16.73**	**16.29**	**15.71**	**15.04**	**14.29**	**13.49**	**12.64**	**11.76**	**0.036**	**0.046**	**0.056**	**0.067**	**0.077**	**0.088**	**0.099**	**0.110**
		StdDev	**3.28**	**3.09**	**2.87**	**2.62**	**2.39**	**2.17**	**2.00**	**1.89**	**0.012**	**0.013**	**0.017**	**0.021**	**0.027**	**0.033**	**0.039**	**0.045**

* Outlier that was omitted from analysis.

Table B.84 *BBR* Mixture Data for *R-3* RAP Source, 138 C, Evotherm™, 65 Gyrations Continued

P_{AC}	Test		Test Time (sec) and Mixture Stiffness (GPa)								Test Time (sec) and Mixture m-value							
(%)	Temp (C)	Rep	8	15	30	60	120	240	480	960	8	15	30	60	120	240	480	960
Low	-24	1	20.75	20.30	19.53	18.50	17.27	15.88	14.38	12.82	0.025	0.045	0.067	0.089	0.110	0.132	0.154	0.176
V_a = 5.9%		2	17.06	16.56	16.00	15.43	14.84	14.26	13.67	13.08	0.046	0.049	0.051	0.054	0.057	0.060	0.062	0.065
		3	19.49	19.07	18.54	17.95	17.31	16.61	15.88	15.11	0.032	0.037	0.044	0.050	0.056	0.062	0.068	0.075
		4*	16.89	16.54	16.16	15.81	15.47	15.15	14.85	14.56	0.034	0.033	0.033	0.032	0.031	0.030	0.029	0.028
		5*	11.22	10.93	10.63	10.35	10.08	9.82	9.58	9.35	0.026	0.021	0.016	0.012	0.009	0.006	0.003	0.001
		Avg	**19.10**	**18.64**	**18.02**	**17.29**	**16.47**	**15.58**	**14.64**	**13.67**	**0.034**	**0.044**	**0.054**	**0.064**	**0.074**	**0.085**	**0.095**	**0.105**
		StdDev	**1.87**	**1.90**	**1.82**	**1.64**	**1.41**	**1.20**	**1.13**	**1.25**	**0.011**	**0.006**	**0.012**	**0.021**	**0.031**	**0.041**	**0.051**	**0.062**
	-18	1	14.20	13.79	13.23	12.57	11.83	11.02	10.18	9.30	0.040	0.053	0.067	0.081	0.095	0.109	0.123	0.136
		2	16.79	16.19	15.40	14.50	13.51	12.45	11.36	10.25	0.051	0.064	0.079	0.095	0.110	0.125	0.140	0.155
		3	19.52	18.98	18.27	17.44	16.52	15.52	14.47	13.38	0.039	0.049	0.061	0.073	0.084	0.096	0.107	0.119
		4	17.57	17.16	16.59	15.93	15.17	14.35	13.46	12.54	0.033	0.043	0.054	0.065	0.075	0.086	0.097	0.108
		5	18.23	17.74	17.15	16.52	15.85	15.15	14.42	13.68	0.041	0.046	0.051	0.057	0.062	0.068	0.074	0.079
		Avg	**17.26**	**16.77**	**16.13**	**15.39**	**14.58**	**13.70**	**12.78**	**11.83**	**0.041**	**0.051**	**0.062**	**0.074**	**0.085**	**0.097**	**0.108**	**0.120**
		StdDev	**1.98**	**1.95**	**1.92**	**1.90**	**1.90**	**1.91**	**1.92**	**1.95**	**0.006**	**0.008**	**0.011**	**0.015**	**0.018**	**0.022**	**0.025**	**0.029**

* Outlier that was omitted from analysis.

Table B.85 *BBR* Mixture Data for *R-3* RAP Source, 154 C, None, 65 Gyrations

P_{AC}	Test		Test Time (sec) and Mixture Stiffness (GPa)								Test Time (sec) and Mixture m-value							
(%)	Temp (C)	Rep	8	15	30	60	120	240	480	960	8	15	30	60	120	240	480	960
High	-24	1*	8.63	8.56	8.45	8.32	8.16	7.97	7.77	7.54	0.012	0.016	0.021	0.026	0.030	0.035	0.040	0.045
V_a = 1.6%		2	13.70	13.25	12.69	12.09	11.44	10.77	10.07	9.37	0.050	0.058	0.066	0.075	0.083	0.092	0.101	0.109
		3	17.98	17.54	16.94	16.23	15.43	14.55	13.61	12.63	0.034	0.044	0.056	0.067	0.079	0.090	0.102	0.113
		4	22.49	21.83	21.02	20.12	19.16	18.14	17.07	15.98	0.043	0.051	0.059	0.067	0.075	0.083	0.091	0.099
		5	21.05	20.44	19.67	18.81	17.89	16.90	15.88	14.82	0.043	0.051	0.060	0.068	0.077	0.086	0.095	0.104
		Avg	**18.81**	**18.27**	**17.58**	**16.81**	**15.98**	**15.09**	**14.16**	**13.20**	**0.043**	**0.051**	**0.060**	**0.069**	**0.079**	**0.088**	**0.097**	**0.106**
		StdDev	**3.89**	**3.79**	**3.68**	**3.54**	**3.40**	**3.24**	**3.08**	**2.91**	**0.007**	**0.006**	**0.004**	**0.004**	**0.003**	**0.004**	**0.005**	**0.006**
	-18	1	20.06	19.46	18.72	17.89	17.00	16.06	15.07	14.06	0.044	0.052	0.061	0.069	0.078	0.087	0.096	0.105
		2	18.16	17.52	16.77	15.98	15.16	14.32	13.47	12.61	0.055	0.060	0.067	0.073	0.079	0.085	0.092	0.098
		3	19.38	18.81	18.13	17.41	16.65	15.86	15.04	14.21	0.045	0.050	0.056	0.062	0.067	0.073	0.079	0.085
		4	17.75	17.20	16.52	15.77	14.98	14.14	13.28	12.39	0.047	0.054	0.062	0.071	0.079	0.087	0.095	0.104
		5	18.89	18.31	17.62	16.88	16.11	15.31	14.48	13.64	0.047	0.052	0.058	0.065	0.071	0.077	0.083	0.089
		Avg	**18.85**	**18.26**	**17.55**	**16.79**	**15.98**	**15.14**	**14.27**	**13.38**	**0.047**	**0.054**	**0.061**	**0.068**	**0.075**	**0.082**	**0.089**	**0.096**
		StdDev	**0.93**	**0.93**	**0.92**	**0.91**	**0.89**	**0.87**	**0.85**	**0.84**	**0.004**	**0.004**	**0.004**	**0.005**	**0.005**	**0.006**	**0.008**	**0.009**
Med	-24	1	24.75	24.14	23.41	22.62	21.78	20.90	19.98	19.03	0.037	0.042	0.047	0.052	0.057	0.062	0.068	0.073
V_a = 2.8%		2	25.05	24.52	23.79	22.91	21.89	20.77	19.55	18.27	0.029	0.038	0.049	0.060	0.071	0.082	0.092	0.103
		3	23.26	22.47	21.57	20.66	19.73	18.80	17.87	16.93	0.054	0.057	0.061	0.064	0.068	0.072	0.075	0.079
		4	25.34	24.44	23.45	22.44	21.44	20.43	19.43	18.44	0.056	0.059	0.062	0.065	0.068	0.071	0.074	0.077
		5	20.17	19.80	19.25	18.56	17.75	16.83	15.83	14.76	0.024	0.035	0.047	0.059	0.071	0.083	0.095	0.107
		Avg	**23.71**	**23.08**	**22.30**	**21.44**	**20.52**	**19.55**	**18.53**	**17.49**	**0.040**	**0.046**	**0.053**	**0.060**	**0.067**	**0.074**	**0.081**	**0.088**
		StdDev	**2.14**	**2.01**	**1.91**	**1.83**	**1.78**	**1.73**	**1.71**	**1.71**	**0.014**	**0.011**	**0.007**	**0.005**	**0.006**	**0.008**	**0.012**	**0.016**
	-18	1	19.76	19.13	18.37	17.56	16.70	15.81	14.89	13.96	0.048	0.055	0.062	0.069	0.076	0.083	0.090	0.097
		2	18.95	18.43	17.75	16.98	16.14	15.23	14.27	13.29	0.040	0.049	0.059	0.069	0.079	0.089	0.098	0.108
		3	15.03	14.76	14.41	14.00	13.54	13.03	12.48	11.89	0.025	0.031	0.038	0.045	0.052	0.059	0.066	0.073
		4	25.58	25.14	24.44	23.55	22.49	21.28	19.95	18.54	0.022	0.034	0.047	0.060	0.073	0.086	0.100	0.113
		5*	8.93	8.87	8.78	8.65	8.49	8.31	8.09	7.85	0.007	0.013	0.018	0.024	0.029	0.035	0.041	0.046
		Avg	**19.83**	**19.37**	**18.74**	**18.02**	**17.22**	**16.34**	**15.40**	**14.42**	**0.034**	**0.042**	**0.052**	**0.061**	**0.070**	**0.079**	**0.089**	**0.098**
		StdDev	**4.35**	**4.30**	**4.18**	**4.00**	**3.78**	**3.51**	**3.20**	**2.88**	**0.012**	**0.012**	**0.011**	**0.011**	**0.012**	**0.014**	**0.016**	**0.018**

* Outlier that was omitted from analysis.

Table B.86 *BBR* Mixture Data for *R-3* RAP Source, 154 C, None, 65 Gyrations Continued

P_{AC}	Test		Test Time (sec) and Mixture Stiffness (GPa)								Test Time (sec) and Mixture m-value							
(%)	Temp (C)	Rep	8	15	30	60	120	240	480	960	8	15	30	60	120	240	480	960
Low	-24	1*	6.88	6.72	6.52	6.30	6.05	5.79	5.52	5.24	0.034	0.040	0.047	0.054	0.060	0.067	0.073	0.080
V_a = 5.9%		2	20.51	19.82	19.01	18.15	17.26	16.34	15.41	14.46	0.052	0.057	0.063	0.070	0.076	0.082	0.088	0.094
		3*	30.96	29.58	28.07	26.57	25.09	23.64	22.21	20.82	0.071	0.074	0.077	0.081	0.084	0.088	0.091	0.095
		4*	17.12	16.74	16.42	16.19	16.06	16.02	16.06	16.20	0.039	0.032	0.024	0.016	0.008	0.000	-0.008	-0.016
		5*	33.24	31.52	29.99	28.78	27.87	27.22	26.82	26.66	0.090	0.078	0.066	0.053	0.040	0.028	0.015	0.002
		Avg	**20.51**	**19.82**	**19.01**	**18.15**	**17.26**	**16.34**	**15.41**	**14.46**	**0.052**	**0.057**	**0.063**	**0.07**	**0.076**	**0.082**	**0.088**	**0.094**
		StdDev	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	-18	1	15.08	14.80	14.45	14.07	13.68	13.26	12.82	12.36	0.029	0.032	0.036	0.040	0.043	0.047	0.050	0.054
		2	18.03	17.54	16.93	16.24	15.49	14.68	13.83	12.96	0.039	0.047	0.056	0.064	0.073	0.081	0.090	0.098
		3	18.94	18.46	17.85	17.17	16.42	15.61	14.77	13.89	0.037	0.044	0.052	0.060	0.068	0.076	0.084	0.092
		4	17.21	16.65	15.99	15.27	14.51	13.71	12.90	12.07	0.049	0.055	0.063	0.070	0.077	0.085	0.092	0.099
		5	18.59	18.34	17.87	17.21	16.40	15.44	14.38	13.24	0.014	0.029	0.046	0.062	0.078	0.095	0.111	0.127
		Avg	**17.57**	**17.16**	**16.62**	**15.99**	**15.30**	**14.54**	**13.74**	**12.90**	**0.034**	**0.042**	**0.050**	**0.059**	**0.068**	**0.077**	**0.086**	**0.094**
		StdDev	**1.54**	**1.51**	**1.44**	**1.34**	**1.20**	**1.04**	**0.87**	**0.72**	**0.013**	**0.011**	**0.010**	**0.012**	**0.014**	**0.018**	**0.022**	**0.026**

* Outlier that was omitted from analysis.

Table B.87 *BBR* Mixture Data for *R-3* RAP Source, 154 C, Evotherm™, 65 Gyrations

P_{AC}	Test		Test Time (sec) and Mixture Stiffness (GPa)								Test Time (sec) and Mixture m-value							
(%)	Temp (C)	Rep	8	15	30	60	120	240	480	960	8	15	30	60	120	240	480	960
High	-24	1	22.55	21.97	21.17	20.24	19.19	18.05	16.83	15.57	0.036	0.047	0.059	0.071	0.083	0.095	0.106	0.118
V_a = 1.7%		2	19.13	18.65	18.02	17.29	16.48	15.59	14.65	13.67	0.035	0.045	0.055	0.065	0.075	0.085	0.095	0.105
		3	19.69	19.27	18.64	17.85	16.92	15.89	14.77	13.59	0.028	0.041	0.055	0.070	0.084	0.098	0.113	0.127
		4	23.48	22.69	21.77	20.80	19.79	18.76	17.71	16.66	0.052	0.057	0.063	0.069	0.074	0.080	0.086	0.091
		5*	14.36	13.87	13.37	12.90	12.47	12.07	11.70	11.35	0.056	0.054	0.052	0.050	0.048	0.046	0.044	0.042
		Avg	**21.21**	**19.29**	**18.59**	**17.82**	**16.97**	**16.07**	**15.13**	**14.17**	**0.042**	**0.049**	**0.057**	**0.065**	**0.073**	**0.081**	**0.089**	**0.097**
		StdDev	**3.58**	**3.48**	**3.33**	**3.13**	**2.89**	**2.62**	**2.33**	**2.04**	**0.012**	**0.007**	**0.004**	**0.009**	**0.014**	**0.021**	**0.027**	**0.033**
	-18	1	20.88	20.14	19.20	18.16	17.03	15.83	14.60	13.34	0.052	0.063	0.075	0.087	0.099	0.111	0.123	0.135
		2	21.80	21.28	20.55	19.66	18.63	17.50	16.29	15.03	0.032	0.044	0.057	0.071	0.084	0.097	0.110	0.123
		3	23.39	22.64	21.70	20.68	19.58	18.43	17.23	16.02	0.048	0.056	0.065	0.074	0.083	0.092	0.101	0.110
		4	21.24	20.50	19.58	18.57	17.48	16.34	15.17	13.98	0.052	0.061	0.071	0.082	0.092	0.102	0.113	0.123
		5	20.52	20.17	19.44	18.40	17.10	15.60	13.98	12.29	0.015	0.039	0.066	0.093	0.119	0.146	0.172	0.199
		Avg	**21.57**	**20.95**	**20.10**	**19.09**	**17.97**	**16.74**	**15.45**	**14.13**	**0.040**	**0.053**	**0.067**	**0.081**	**0.095**	**0.110**	**0.124**	**0.138**
		StdDev	**1.12**	**1.05**	**1.03**	**1.06**	**1.11**	**1.20**	**1.31**	**1.45**	**0.016**	**0.010**	**0.007**	**0.009**	**0.015**	**0.021**	**0.028**	**0.035**
Med	-24	1	23.11	22.47	21.74	20.99	20.23	19.47	18.70	17.93	0.044	0.046	0.049	0.052	0.054	0.057	0.059	0.062
V_a = 2.8%		2	19.88	19.44	18.83	18.09	17.24	16.30	15.29	14.23	0.030	0.041	0.052	0.064	0.075	0.087	0.098	0.110
		3	19.42	18.96	18.31	17.54	16.64	15.66	14.60	13.49	0.032	0.044	0.056	0.069	0.082	0.094	0.107	0.120
		4	22.03	21.41	20.56	19.55	18.42	17.19	15.90	14.56	0.039	0.052	0.065	0.079	0.093	0.106	0.120	0.134
		5	24.65	24.13	23.45	22.68	21.83	20.91	19.92	18.89	0.031	0.037	0.045	0.052	0.059	0.066	0.073	0.080
		Avg	**21.82**	**21.28**	**20.58**	**19.77**	**18.87**	**17.91**	**16.88**	**15.82**	**0.035**	**0.044**	**0.053**	**0.063**	**0.073**	**0.082**	**0.092**	**0.101**
		StdDev	**2.19**	**2.14**	**2.11**	**2.11**	**2.15**	**2.21**	**2.30**	**2.42**	**0.006**	**0.006**	**0.008**	**0.012**	**0.016**	**0.020**	**0.025**	**0.029**
	-18	1	20.57	20.03	19.38	18.67	17.91	17.10	16.27	15.40	0.039	0.045	0.051	0.057	0.063	0.069	0.076	0.082
		2	25.18	24.52	23.64	22.63	21.49	20.26	18.96	17.61	0.037	0.047	0.058	0.069	0.080	0.090	0.101	0.112
		3	25.65	24.74	23.68	22.56	21.41	20.23	19.03	17.83	0.055	0.060	0.066	0.073	0.079	0.085	0.091	0.097
		4	24.27	23.57	22.68	21.67	20.58	19.41	18.18	16.92	0.042	0.051	0.060	0.070	0.080	0.089	0.099	0.109
		5	22.95	22.14	21.20	20.20	19.16	18.09	17.00	15.90	0.054	0.060	0.066	0.073	0.080	0.086	0.093	0.100
		Avg	**23.72**	**23.00**	**22.12**	**21.15**	**20.11**	**19.02**	**17.89**	**16.73**	**0.045**	**0.052**	**0.060**	**0.068**	**0.076**	**0.084**	**0.092**	**0.100**
		StdDev	**2.04**	**1.95**	**1.83**	**1.70**	**1.55**	**1.39**	**1.22**	**1.06**	**0.008**	**0.007**	**0.006**	**0.007**	**0.007**	**0.009**	**0.010**	**0.012**

* Outlier that was omitted from analysis.

Table B.88 *BBR* Mixture Data for *R-3* RAP Source, 154 C, Evotherm™, 65 Gyrations Continued

P_{AC}	Test		Test Time (sec) and Mixture Stiffness (GPa)								Test Time (sec) and Mixture m-value							
(%)	Temp (C)	Rep	8	15	30	60	120	240	480	960	8	15	30	60	120	240	480	960
Low	-24	1	15.31	14.79	14.15	13.47	12.74	11.98	11.20	10.41	0.051	0.059	0.067	0.076	0.084	0.093	0.101	0.110
V_a = 5.7%		2	14.62	14.22	13.70	13.13	12.51	11.84	11.14	10.43	0.041	0.049	0.057	0.066	0.075	0.083	0.092	0.101
		3	13.05	12.45	11.72	10.93	10.10	9.25	8.40	7.55	0.069	0.081	0.094	0.107	0.120	0.133	0.146	0.160
		4	21.49	20.81	19.96	19.00	17.97	16.87	15.72	14.55	0.046	0.055	0.066	0.076	0.086	0.096	0.107	0.117
		5	20.10	19.50	18.81	18.10	17.38	16.64	15.88	15.13	0.046	0.050	0.054	0.057	0.061	0.065	0.069	0.072
		Avg	**16.91**	**16.35**	**15.67**	**14.93**	**14.14**	**13.32**	**12.47**	**11.61**	**0.051**	**0.059**	**0.068**	**0.076**	**0.085**	**0.094**	**0.103**	**0.112**
		StdDev	**3.67**	**3.61**	**3.54**	**3.47**	**3.39**	**3.32**	**3.25**	**3.17**	**0.011**	**0.013**	**0.016**	**0.019**	**0.022**	**0.025**	**0.028**	**0.032**
	-18	1	19.77	19.14	18.38	17.56	16.70	15.79	14.86	13.92	0.048	0.055	0.062	0.069	0.077	0.084	0.091	0.098
		2	17.86	17.53	16.98	16.26	15.39	14.40	13.33	12.19	0.023	0.038	0.054	0.071	0.087	0.104	0.120	0.137
		3	16.25	15.81	15.28	14.71	14.10	13.46	12.80	12.12	0.041	0.046	0.052	0.058	0.064	0.070	0.076	0.082
		4	15.35	15.03	14.59	14.06	13.47	12.81	12.11	11.37	0.030	0.038	0.048	0.057	0.067	0.077	0.086	0.096
		5	10.62	10.25	9.80	9.31	8.79	8.24	7.68	7.11	0.052	0.060	0.069	0.079	0.088	0.097	0.106	0.116
		Avg	**15.97**	**15.55**	**15.01**	**14.38**	**13.69**	**12.94**	**12.16**	**11.34**	**0.039**	**0.047**	**0.057**	**0.067**	**0.077**	**0.086**	**0.096**	**0.106**
		StdDev	**3.43**	**3.36**	**3.26**	**3.14**	**3.01**	**2.86**	**2.70**	**2.54**	**0.012**	**0.010**	**0.009**	**0.009**	**0.011**	**0.014**	**0.018**	**0.021**

APPENDIX C – CANTABRO DATA

Table C.1 Durability Results for *9.5-100/RM-1* Relative Heating Experiment

Short Term Age Time (min)	Rep	V_a (%)	*ML* (%)
60	1	4.5	32.9
	2	4.9	27.9
	3	4.3	34.7
	Avg.	**4.5**	**31.9**
90	1	4.5	28.7
	2	4.2	27.9
	3	4.6	28.1
	Avg.	**4.4**	**28.3**
180	1	4.0	26.6
	2	3.5	26.7
	3	3.7	27.3
	Avg.	**3.7**	**26.9**
360	1	4.4	34.1
	2	4.4	31.1
	3	4.5	32.8
	Avg.	**4.5**	**32.7**
1440	1	6.5	65.5
	2	6.7	76.3
	3	6.6	62.1
	Avg.	**6.6**	**68.0**

Note: Total asphalt content was 7.4% with 1.0% Sasobit®, and compaction temperature was 146 C.

Table C.2 Durability Results for Designed 100% RAP Mixtures

Mixture ID	Gyr	Comp Temp (C)	Warm Mix Additive	P_{AC} (%)	Rep	V_a (%)	*ML* (%)
9.5-100/RM-1	65	116	Sasobit® 1.0%	7.4	1	5.2	33.9
					2	4.3	29.9
					3	4.4	31.5
					Avg.	**4.6**	**31.8**
9.5-100/RM-2	65	116	Sasobit® 1.0%	6.8	1	5.0	25.5
					2	6.0	25.7
					3	5.7	25.7
					Avg.	**5.6**	**25.7**
12.5-100/RM-3	65	116	Sasobit® 1.0%	6.4	1	4.9	36.8
					2	4.3	31.7
					3	4.5	32.6
					Avg.	**4.6**	**33.7**

Table C.3 Durability Results for 100% *R-1* at 116 C Compaction Temperature

Gyrations	P_{AC} (%)	Warm Mix Additive	V_a (%)	*ML* (%)
50	8.1	None	2.6	25.1
		Sasobit®	2.3	23.0
		Evotherm 3G™	2.3	26.1
	7.1	None	5.2	29.0
		Sasobit®	4.9	39.1
		Evotherm 3G™	4.8	31.2
	6.0	None	9.1	82.0
		Sasobit®	8.7	72.8
		Evotherm 3G™	8.5	62.8
65	8.1	None	1.8	21.2
		Sasobit®	2.0	23.8
		Evotherm 3G™	1.7	21.2
	7.1	None	4.8	32.8
		Sasobit®	4.5	38.9
		Evotherm 3G™	4.3	32.4
	6.0	None	8.0	59.9
		Sasobit®	7.8	64.7
		Evotherm 3G™	8.2	60.8
85	8.1	None	1.6	20.1
		Sasobit®	1.3	23.4
		Evotherm 3G™	1.7	23.6
	7.1	None	4.5	29.1
		Sasobit®	3.7	33.8
		Evotherm 3G™	3.6	29.9
	6.0	None	7.5	64.3
		Sasobit®	7.7	81.7
		Evotherm 3G™	7.2	63.6

Table C.4 Durability Results for 100% *R-1* at 138 C Compaction Temperature

Gyrations	P_{AC} (%)	Warm Mix Additive	V_a (%)	*ML* (%)
50	8.1	None	1.0	18.3
		Sasobit®	1.6	14.5
		Evotherm 3G™	1.2	18.2
	7.1	None	3.3	30.5
		Sasobit®	4.1	23.2
		Evotherm 3G™	3.6	36.8
	6.0	None	6.9	41.1
		Sasobit®	7.3	57.2
		Evotherm 3G™	7.1	57.9
65	8.1	None	1.6	20.2
		Sasobit®	0.6	20.1
		Evotherm 3G™	1.3	19.7
	7.1	None	4.3	36.1
		Sasobit®	3.0	29.7
		Evotherm 3G™	2.9	27.0
	6.0	None	6.9	51.9
		Sasobit®	5.8	45.7
		Evotherm 3G™	5.2	33.7
85	8.1	None	0.6	16.9
		Sasobit®	0.4	20.7
		Evotherm 3G™	1.1	19.5
	7.1	None	2.9	21.2
		Sasobit®	3.4	32.5
		Evotherm 3G™	2.1	22.5
	6.0	None	7.1	58.9
		Sasobit®	7.4	60.0
		Evotherm 3G™	5.6	46.5

Table C.5 Durability Results for 100% *R-1* at 154 C Compaction Temperature

Gyrations	P_{AC} (%)	Warm Mix Additive	V_a (%)	*ML* (%)
65	8.1	None	0.5	16.2
		Sasobit®	1.0	18.6
		Evotherm 3G™	0.6	17.5
	7.1	None	2.0	24.1
		Sasobit®	1.7	20.9
		Evotherm 3G™	1.9	18.3
	6.0	None	4.2	36.5
		Sasobit®	4.0	39.8
		Evotherm 3G™	3.7	34.7

Table C.6 Durability Results for 100% *R-2* at 65 Gyrations

Comp Temp (C)	P_{AC} (%)	Warm Mix Additive	V_a (%)	*ML* (%)
116	8.2	None	1.3	10.5
		Evotherm 3G™	1.7	11.6
	7.1	None	2.8	14.7
		Evotherm 3G™	2.5	12.3
	6.2	None	5.0	22.8
		Evotherm 3G™	5.1	25.7
138	8.2	None	1.7	8.3
		Sasobit®	1.9	10.5
		Evotherm 3G™	1.6	9.4
	7.1	None	2.3	12.0
		Sasobit®	2.3	13.1
		Evotherm 3G™	2.2	11.5
	6.2	None	4.1	21.1
		Sasobit®	4.1	18.7
		Evotherm 3G™	4.1	17.4
154	8.2	None	0.9	8.1
		Evotherm 3G™	0.5	7.9
	7.1	None	2.0	12.9
		Evotherm 3G™	1.9	7.6
	6.2	None	4.2	18.8
		Evotherm 3G™	3.3	11.2

Table C.7 Durability Results for 100% *R-3* at 65 Gyrations

Comp Temp (C)	P_{AC} (%)	Warm Mix Additive	V_a (%)	*ML* (%)
116	7.4	None	1.7	16.1
		Sasobit®	2.3	18.5
		Evotherm 3G™	2.1	18.2
	6.4	None	3.8	27.6
		Sasobit®	3.9	27.8
		Evotherm 3G™	3.6	23.3
	5.5	None	7.1	54.4
		Sasobit®	8.5	66.3
		Evotherm 3G™	6.6	53.4
138	7.4	None	2.3	15.6
		Sasobit®	2.2	17.4
		Evotherm 3G™	2.3	17.2
	6.4	None	3.4	19.6
		Sasobit®	3.3	23.1
		Evotherm 3G™	3.3	20.8
	5.5	None	6.1	33.7
		Sasobit®	6.1	42.8
		Evotherm 3G™	6.2	35.9
154	7.4	None	1.6	17.1
		Sasobit®	1.2	23.3
		Evotherm 3G™	1.7	20.8
	6.4	None	2.9	30.0
		Sasobit®	3.1	22.9
		Evotherm 3G™	2.9	21.2
	5.5	None	6.2	45.5
		Sasobit®	6.3	43.5
		Evotherm 3G™	5.4	31.7

Table C.8 Durability Results for Control Mixture *9.5-0/CM-1*

Comp Temp (C)	P_{AC} (%)	Warm Mix Additive	Specimen Aging Protocol	Rep	V_a (%)	ML (%)
146	5.70	None	None	1	4.5	12.2
				2	5.1	11.5
				3	5.9	11.3
				4	5.4	14.3
				5	4.3	8.5
				Avg.	**5.0**	**11.5**

Table C.9 Durability Results for Control Mixture *9.5-15/CM-2*

Comp Temp (C)	P_{AC} (%)	Warm Mix Additive	Specimen Aging Protocol	Rep	V_a (%)	ML (%)
118 to 127	6.25	None	None	1	5.6	6.8
				2	5.4	7.5
				3	6.0	9.0
				4	6.2	8.4
				5	6.1	8.4
				Avg.	**5.9**	**8.0**
			R-30	1	5.7	10.8
				2	5.5	10.3
				3	5.8	10.6
				Avg.	**5.7**	**10.6**
			MT-85	1	6.2	9.4
				2	5.8	9.4
				3	6.2	9.6
				Avg.	**6.1**	**9.5**

Table C.10 Durability Results for Control Mixture *9.5-15/CM-3*

Comp Temp (C)	P_{AC} (%)	Warm Mix Additive	Specimen Aging Protocol	Rep	V_a (%)	ML (%)
138	5.80	None[1]	None	1	3.3	4.3
				2	2.8	4.3
				3	2.8	4.5
				4	2.9	4.3
				5	3.2	5.9
				Avg.	**3.0**	**4.7**
			R-30	1	2.8	6.9
				2	2.8	7.7
				3	2.9	8.2
				Avg.	**2.8**	**7.6**
			MT-85	1	3.2	7.0
				2	2.7	7.9
				3	3.2	7.8
				Avg.	**3.0**	**7.6**

1: Plant produced mix that originally had foam but was reheated for compaction

Table C.11 Durability Results for Control Mixture *9.5-15/CM-4*

Mixture ID	Comp Temp (C)	P_{AC} (%)	Warm Mix Additive	Specimen Aging Protocol	Rep	V_a (%)	*ML* (%)
9.5-15/CM-4a	149 to 154	5.80	None	None	1	7.4	12.8
					2	7.3	11.4
					3	7.4	12.0
					4	7.5	12.1
					5	7.8	10.9
					Avg.	**7.5**	**11.8**
9.5-15/CM-4b	146	5.80	None	None	1	5.5	10.1
					2	6.5	12.3
					3	5.6	10.5
					4	6.2	11.8
					5	6.1	10.5
					Avg.	**6.0**	**11.0**
9.5-15/CM-4c	154	5.80	None	None	1	5.1	9.3
					2	5.3	9.5
					3	5.8	11.1
					Avg.	**5.4**	**9.9**

Table C.12 Durability Results for Control Mixture *9.5-15/CM-6*

Warm Mix Additive	Specimen Aging Protocol	Rep	V_a (%)	*ML* (%)
None	None	1	2.6	6.8
		2	2.6	6.3
		3	2.1	5.9
		4	3.4	7.9
		5	4.0	7.6
		6	2.6	6.6
		7	4.0	9.3
		8	3.0	7.2
		9	3.7	6.3
		10	2.8	5.5
		11	3.3	7.1
		12	3.0	7.6
		13	2.8	7.1
		14	3.7	7.7
P_{AC} = 6.2%		15	3.3	7.8
		16	3.8	8.2
		17	4.2	7.2
		18	3.0	7.8
		19	3.8	7.3
		20	2.9	7.3
		21	3.5	7.3
		22	3.2	6.7
		23	3.8	7.0
		24	3.4	7.1
		25	2.7	7.7
		26	4.0	7.9
		27	3.2	8.2
		28	3.4	6.4
		29	3.1	6.5
		30	3.7	7.5
		Avg.	**3.3**	**7.2**
		Std.dev	**0.52**	**0.77**

Table C.13 Durability Results for Control Mixture *9.5-15/CM-6* Aged Specimens

Warm Mix Additive	Specimen Aging Protocol	Rep	V_a (%)	*ML* (%)
None	*R-30*	1	3.6	10.3
		2	3.1	10.4
		3	3.9	10.9
		4	3.9	10.2
		5	2.8	8.2
		6	2.6	8.0
		7	3.0	10.8
		8	3.2	9.7
		9	3.1	12.4
		10	4.8	14.7
		11	4.7	11.2
		12	3.2	11.0
		13	3.4	9.9
		14	3.5	9.7
P_{AC} = 6.2%		15	3.3	10.5
		16	3.6	10.4
		17	3.5	10.3
		18	2.6	8.6
		19	3.4	9.8
		20	4.2	10.9
		21	3.0	11.0
		22	4.2	11.6
		23	3.7	10.4
		24	3.4	9.9
		25	3.6	10.0
		26	3.8	12.1
		27	3.4	10.5
		28	4.5	12.1
		29	4.5	10.6
		30	4.0	11.9
		Avg.	**3.6**	**10.6**
		Std.dev	**0.58**	**1.3**
	MT-85	1	4.0	10.0
		2	4.2	8.8
		3	3.1	10.1
		Avg.	**3.8**	**9.6**

Table C.14 Durability Results for Control Mixture *9.5-15/CM-7*

Warm Mix Additive	Specimen Aging Protocol	Rep	V_a (%)	*ML* (%)
None	None	1	5.0	7.7
		2	5.2	8.4
		3	5.3	9.0
		4	5.2	7.6
		5	5.4	8.7
		6	3.5	8.1
		7	4.3	7.7
		8	4.2	8.4
		9	5.2	8.2
		10	3.5	7.1
		11	3.2	6.7
		12	2.9	6.0
		13	3.3	6.4
		14	2.8	6.2
P_{AC} = 6.0%		15	6.0	10.2
		16	5.0	8.0
		17	4.9	9.7
		18	5.0	9.0
		19	1.3	6.1
		20	5.0	8.3
		21	4.9	7.7
		22	2.5	6.0
		23	5.7	9.5
		24	4.8	6.5
		25	3.4	8.0
		26	3.5	7.2
		27	3.7	7.9
		28	3.6	6.5
		29	3.7	5.9
		30	3.8	6.3
		Avg.	**4.2**	**7.6**
		Std.dev	**1.1**	**1.2**

Table C.15 Durability Results for Control Mixtures 8 to 22

Mixture ID	P_{AC} (%)	Warm Mix Additive	Rep	V_a (%)	*ML* (%)
9.5-15/CM-8	5.4	None	1	3.3	7.1
			2	3.2	7.6
			Avg.	**3.3**	**7.3**
9.5-15/CM-9	5.1	None	1	4.3	2.2
			2	4.3	3.3
			Avg.	**4.3**	**2.8**
9.5-10/CM-10	5.5	None	1	4.8	6.0
			2	5.0	10.0
			3	4.1	7.7
			4	4.5	9.2
			Avg.	**4.6**	**8.2**
9.5-15/CM-11	5.5	None	1	4.5	7.4
			2	4.5	7.1
			Avg.	**4.5**	**7.2**
9.5-15/CM-12	6.2	None	1	4.1	6.8
			2	4.0	7.7
			3	4.1	6.3
			4	4.2	9.8
			Avg.	**4.1**	**7.6**
9.5-15/CM-13	5.4	None	1	3.4	7.9
			2	3.3	6.4
			Avg.	**3.4**	**7.2**
9.5-15/CM-14	5.8	None	1	4.1	5.6
			2	4.0	6.3
			Avg.	**4.1**	**6.0**
9.5-15/CM-15	5.5	None	1	4.5	5.4
			2	4.5	5.3
			Avg.	**4.5**	**5.3**
9.5-15/CM-16	6.0	None	1	4.5	9.8
			2	4.2	11.2
			Avg.	**4.4**	**10.5**
9.5-15/CM-17	6.1	None	1	5.9	10.1
			2	5.9	11.1
			Avg.	**5.9**	**10.6**
9.5-15/CM-18	5.6	None	1	4.6	6.8
			2	4.5	10.2
			Avg.	**4.6**	**8.5**
9.5-15/CM-19	5.3	None	1	4.2	5.3
			2	4.2	5.1
			Avg.	**4.2**	**5.2**
9.5-15/CM-20	5.5	None	1	3.5	5.2
			2	3.4	5.5
			Avg.	**3.5**	**5.4**
9.5-15/CM-21	6.4	None	1	2.2	4.4
			2	2.3	3.4
			Avg.	**2.3**	**3.9**
9.5-10/CM-22	5.7	None	1	4.8	6.0
			2	4.7	7.6
			Avg.	**4.8**	**6.8**

Table C.16 Durability Results for Control Mixtures 23 to 29

Mixture ID	P_{AC} (%)	Warm Mix Additive	Rep	V_a (%)	ML (%)
9.5-15/CM-23	5.8	None	1	4.3	10.0
			2	4.5	11.4
			Avg.	**4.4**	**10.7**
9.5-0/CM-24	5.8	None	1	6.8	10.6
			2	7.3	12.8
			Avg.	**7.1**	**11.7**
9.5-10/CM-25	5.6	None	1	4.0	9.2
			2	4.1	9.6
			Avg.	**4.1**	**9.4**
9.5-10/CM-26	5.4	None	1	3.2	5.1
			2	3.0	4.4
			Avg.	**3.1**	**4.8**
9.5-6/CM-27	5.3	None	1	4.9	6.7
			2	4.5	8.4
			3	4.3	7.5
			4	4.8	6.7
			5	5.0	6.7
			6	4.3	9.5
			7	4.4	8.7
			8	4.7	6.8
			Avg.	**4.6**	**7.6**
9.5-10/CM-28	6.4	None	1	7.4	11.9
			2	4.6	9.0
			3	7.8	12.1
			4	5.0	10.0
			Avg.	**6.2**	**10.7**
9.5-10/CM-29	5.2	None	1	5.7	5.3
			2	5.8	8.0
			Avg.	**5.8**	**6.6**

Table C.17 Durability Results for Recycled Mixture *9.5-25/RM-1*

Comp Temp (C)	P_{AC} (%)	Warm Mix Additive	Specimen Aging Protocol	Rep	V_a (%)	ML (%)
116	6.1	Sasobit®	None	1	5.1	12.1
				2	4.4	11.4
				3	4.5	12.3
				Avg.	**4.6**	**11.9**
			R-30	1	4.8	17.2
				2	4.3	17.6
				3	5.1	18.5
				Avg.	**4.7**	**17.8**

Table C.18 Durability Results for Recycled Mixture *9.5-25/RM-2*

Comp Temp (C)	P_{AC} (%)	Warm Mix Additive	Specimen Aging Protocol	Rep	V_a (%)	ML (%)
116	5.6	Sasobit®	None	1	5.7	14.0
				2	4.4	11.6
				3	5.6	14.0
				Avg.	**5.2**	**13.2**

Table C.19 Durability Results for Recycled Mixture *9.5-50/RM-1*

Comp Temp (C)	P_{AC} (%)	Warm Mix Additive	Specimen Aging Protocol	Rep	V_a (%)	ML (%)
116	6.5	Sasobit®	None	1	4.9	15.6
				2	5.5	17.5
				3	5.3	17.0
				Avg.	**5.2**	**16.7**
			R-30	1	5.4	25.4
				2	5.7	24.6
				3	6.2	26.6
				Avg.	**5.7**	**25.6**

Table C.20 Durability Results for Recycled Mixture *9.5-50/RM-2*

Comp Temp (C)	P_{AC} (%)	Warm Mix Additive	Specimen Aging Protocol	Rep	V_a (%)	ML (%)
116	6.2	Sasobit®	None	1	5.3	15.9
				2	4.6	13.2
				3	5.6	13.3
				Avg.	**5.2**	**14.1**

APPENDIX D – *APA* DATA

Table D.1 *APA* Results for Designed 100% RAP Mixture *9.5-100/RM-1*

		Rut Depth (mm)		Linear Rutting Rate[2]			Power Law[3]		
Rep	**Avg. V_a[1]**	**2000**	**8000**	**Slope (10^{-6})**	**Intercept**	**R^2**	***a***	***b***	**R^2**
1	6.7	0.8	1.2	---	---	---	---	---	---
2	6.8	0.8	1.1	---	---	---	---	---	---
Avg.	**6.7**	**0.8**	**1.1**	**57**	**0.69**	**0.98**	**0.082**	**0.293**	**0.95**
1	9.5	1.1	1.7	---	---	---	---	---	---
2	9.7	1.3	2.3	---	---	---	---	---	---
Avg.	**9.6**	**1.2**	**2.0**	**128**	**0.96**	**0.99**	**0.059**	**0.389**	**0.98**

1: Average air voids is based on *AASHTO T 331* measurements of bulk specific gravity.
2: Rutting rate regression analysis is based on data between 2000 and 8000 cycles.
3: Power law regression analysis is based on Eq. 2.3.

Table D.2 *APA* Results for Designed 100% RAP Mixture *9.5-100/RM-2*

		Rut Depth (mm)		Linear Rutting Rate[2]			Power Law[3]		
Rep	**Avg. V_a[1]**	**2000**	**8000**	**Slope (10^{-6})**	**Intercept**	**R^2**	***a***	***b***	**R^2**
1	7.1	0.8	1.3	---	---	---	---	---	---
2	7.1	0.7	1.1	---	---	---	---	---	---
Avg.	**7.1**	**0.8**	**1.2**	**132**	**0.75**	**0.98**	**0.029**	**0.458**	**0.99**
1	10.1	1.2	2.3	---	---	---	---	---	---
2	10.1	1.1	2.2	---	---	---	---	---	---
Avg.	**10.1**	**1.2**	**2.3**	**184**	**0.85**	**0.99**	**0.025**	**0.504**	**0.99**

1: Average air voids is based on *AASHTO T 331* measurements of bulk specific gravity.
2: Rutting rate regression analysis is based on data between 2000 and 8000 cycles.
3: Power law regression analysis is based on Eq. 2.3.

Table D.3 *APA* Results for Designed 100% RAP Mixture *12.5-100/RM-3*

		Rut Depth (mm)		Linear Rutting Rate[2]			Power Law[3]		
Rep	**Avg. V_a[1]**	**2000**	**8000**	**Slope (10^{-6})**	**Intercept**	**R^2**	***a***	***b***	**R^2**
1	7.1	0.9	1.4	---	---	---	---	---	---
2	7.0	1.0	1.6	---	---	---	---	---	---
Avg.	**7.0**	**1.0**	**1.5**	**89**	**0.81**	**0.98**	**0.065**	**0.351**	**0.97**
1	9.9	0.8	1.4	---	---	---	---	---	---
2	9.8	0.9	1.5	---	---	---	---	---	---
Avg.	**9.8**	**0.8**	**1.5**	**100**	**0.68**	**0.99**	**0.047**	**0.381**	**0.99**

1: Average air voids is based on *AASHTO T 331* measurements of bulk specific gravity.
2: Rutting rate regression analysis is based on data between 2000 and 8000 cycles.
3: Power law regression analysis is based on Eq. 2.3.

Table D.4 *APA* Rut Depth Results for 100% *R-1* Compacted at 116 C

N_{design}	Warm Mix Additive	P_{AC} (%)	V_a (%)	Avg. Rut Depth (mm)	
				Manual	*APA*
50	None	8.1	2.0	0.7	1.5
		7.1	4.1	---[1]	1.5
		6.0	7.6	1.4	0.7
	Sasobit®	8.1	2.8	1.3	1.3
		7.1	3.9	0.9	1.0
		6.0	8.4	0.4	0.5
	Evotherm 3G™	8.1	2.0	2.0	1.7
		7.1	3.9	1.2	1.0
		6.0	8.4	0.9	0.5
65	None	8.1	1.3	1.0	1.2
		7.1	3.2	1.0	0.8
		6.0	7.6	0.9	0.8
	Sasobit®	8.1	1.5	0.5	1.3
		7.1	3.4	0.6	0.9
		6.0	7.2	0.5	0.5
	Evotherm 3G™	8.1	1.7	1.1	1.3
		7.1	3.5	1.3	1.0
		6.0	7.7	1.5	1.0
85	None	8.1	0.9	0.9	1.4
		7.1	2.8	0.8	0.8
		6.0	6.1	0.1	1.0
	Sasobit®	8.1	1.1	1.0	1.2
		7.1	3.6	---[1]	1.2
		6.0	6.9	0.5	0.8
	Evotherm 3G™	8.1	1.8	1.6	1.6
		7.1	3.2	0.8	1.2
		6.0	7.9	1.8	1.0

1: Measurement was invalid.

Table D.5 *APA* Rut Depth Results for 100% *R-1* Compacted at 138 C

N_{design}	Warm Mix Additive	P_{AC} (%)	V_a (%)	Avg. Rut Depth (mm) Manual	*APA*
50	None	8.1	0.8	1.1	0.8
		7.1	2.7	0.4	1.5
		6.0	7.0	0.6	0.8
	Sasobit®	8.1	1.2	0.8	0.9
		7.1	2.3	0.7	0.5
		6.0	7.0	---[1]	0.4
	Evotherm 3G™	8.1	0.5	1.2	1.3
		7.1	3.6	0.9	0.9
		6.0	6.1	---[1]	0.8
65	None	8.1	0.7	1.1	1.1
		7.1	2.4	0.8	0.8
		6.0	4.6	0.7	0.6
	Sasobit®	8.1	0.7	---[1]	1.5
		7.1	3.0	0.9	0.5
		6.0	7.0	0.1	0.8
	Evotherm 3G™	8.1	0.5	1.2	1.0
		7.1	2.2	0.4	0.8
		6.0	6.0	0.1	0.7
85	None	8.1	0.6	1.0	1.2
		7.1	2.0	0.8	1.0
		6.0	4.6	0.8	1.0
	Sasobit®	8.1	0.5	---[1]	1.4
		7.1	1.8	0.5	0.8
		6.0	4.6	---[1]	0.7
	Evotherm 3G™	8.1	0.7	0.8	0.7
		7.1	1.6	0.5	1.2
		6.0	5.0	0.0	0.4

1: Measurement was invalid.

Table D.6 *APA* Results for Control Mixture *9.5-15/CM-2*

		Rut Depth (mm)		Linear Rutting Rate[2]			Power Law[3]		
Rep	**Avg. V_a[1]**	**2000**	**8000**	**Slope (10^{-6})**	**Intercept**	**R^2**	***a***	***b***	**R^2**
1	5.9	9.2	12.6	---	---	---	---	---	---
2	5.6	8.9	12.7	---	---	---	---	---	---
3	5.7	8.8	11.4	---	---	---	---	---	---
Avg.	**5.8**	**9.0**	**12.2**	**496**	**8.56**	**0.94**	**0.574**	**0.350**	**0.93**
1	9.8	9.4	11.2	---	---	---	---	---	---
2	9.8	9.8	12.6	---	---	---	---	---	---
3	9.3	7.8	11.0	---	---	---	---	---	---
Avg.	**9.6**	**9.0**	**11.6**	**381**	**8.86**	**0.91**	**0.654**	**0.332**	**0.90**

1: Average air voids is based on *AASHTO T 331* measurements of bulk specific gravity.
2: Rutting rate regression analysis is based on data between 2000 and 8000 cycles.
3: Power law regression analysis is based on Eq. 2.3.

Table D.7 *APA* Results for Control Mixture *9.5-15/CM-3*

		Rut Depth (mm)		Linear Rutting Rate[2]			Power Law[3]		
Rep	**Avg. V_a[1]**	**2000**	**8000**	**Slope (10^{-6})**	**Intercept**	**R^2**	***a***	***b***	**R^2**
1	6.7	2.0	3.4	---	---	---	---	---	---
2	6.9	1.9	3.4	---	---	---	---	---	---
3	6.8	2.1	3.5	---	---	---	---	---	---
Avg.	**6.8**	**2.0**	**3.5**	**243**	**1.64**	**0.97**	**0.059**	**0.458**	**0.99**
1	9.5	4.2	6.2	---	---	---	---	---	---
2	9.4	4.4	6.3	---	---	---	---	---	---
3	9.7	4.7	6.4	---	---	---	---	---	---
Avg.	**9.5**	**4.4**	**6.3**	**299**	**4.04**	**0.97**	**0.181**	**0.405**	**0.92**

1: Average air voids is based on *AASHTO T 331* measurements of bulk specific gravity.
2: Rutting rate regression analysis is based on data between 2000 and 8000 cycles.
3: Power law regression analysis is based on Eq. 2.3.

Table D.8 *APA* Results for Control Mixture *9.5-15/CM-4a*

		Rut Depth (mm)		Linear Rutting Rate[2]			Power Law[3]		
Rep	**Avg. V_a[1]**	**2000**	**8000**	**Slope (10^{-6})**	**Intercept**	**R^2**	***a***	***b***	**R^2**
1	6.8	3.7	5.1	---	---	---	---	---	---
2	6.9	3.3	4.8	---	---	---	---	---	---
3	6.8	3.7	5.1	---	---	---	---	---	---
Avg.	**6.8**	**3.6**	**5.0**	**228**	**3.32**	**0.96**	**0.102**	**0.448**	**0.91**
1	9.4	2.5	3.6	---	---	---	---	---	---
2	9.5	2.8	4.0	---	---	---	---	---	---
3	9.4	2.3	3.3	---	---	---	---	---	---
Avg.	**9.4**	**2.5**	**3.7**	**182**	**2.27**	**0.98**	**0.112**	**0.396**	**0.94**

1: Average air voids is based on *AASHTO T 331* measurements of bulk specific gravity.
2: Rutting rate regression analysis is based on data between 2000 and 8000 cycles.
3: Power law regression analysis is based on Eq. 2.3.

Table D.9 *APA* Results for Control Mixture *9.5-15/CM-4b*

		Rut Depth (mm)		Linear Rutting Rate[2]			Power Law[3]		
Rep	**Avg. V_a[1]**	**2000**	**8000**	**Slope (10^{-6})**	**Intercept**	**R^2**	***a***	***b***	**R^2**
1	7.1	3.1	5.0	---	---	---	---	---	---
2	7.0	3.2	4.6	---	---	---	---	---	---
3	7.0	3.1	4.4	---	---	---	---	---	---
Avg.	**7.1**	**3.1**	**4.7**	**238**	**2.91**	**0.95**	**0.072**	**0.474**	**0.92**

1: Average air voids is based on *AASHTO T 331* measurements of bulk specific gravity.
2: Rutting rate regression analysis is based on data between 2000 and 8000 cycles.
3: Power law regression analysis is based on Eq. 2.3.

Table D.10 *APA* Results for Control Mixture *9.5-15/CM-4c*

		Rut Depth (mm)		Linear Rutting Rate[2]			Power Law[3]		
Rep	**Avg. V_a[1]**	**2000**	**8000**	**Slope (10^{-6})**	**Intercept**	**R^2**	***a***	***b***	**R^2**
1	7.0	2.0	2.9	---	---	---	---	---	---
2	6.8	0.9	1.4	---	---	---	---	---	---
Avg.	**6.9**	**1.4**	**2.1**	**113**	**1.23**	**1.00**	**0.113**	**0.327**	**0.95**

1: Average air voids is based on *AASHTO T 331* measurements of bulk specific gravity.
2: Rutting rate regression analysis is based on data between 2000 and 8000 cycles.
3: Power law regression analysis is based on Eq. 2.3.

Table D.11 *APA* Results for Recycled Mixture *9.5-25/RM-1*

		Rut Depth (mm)		Linear Rutting Rate[2]			Power Law[3]		
Rep	**Avg. V_a[1]**	**2000**	**8000**	**Slope (10^{-6})**	**Intercept**	**R^2**	***a***	***b***	**R^2**
1	6.9	1.4	2.6	---	---	---	---	---	---
2	6.9	1.2	2.3	---	---	---	---	---	---
Avg.	**6.9**	**1.3**	**2.4**	**180**	**1.04**	**0.99**	**0.047**	**0.439**	**0.99**
1	9.5	2.8	4.1	---	---	---	---	---	---
2	9.5	3.7	5.9	---	---	---	---	---	---
Avg.	**9.5**	**3.3**	**5.0**	**266**	**3.04**	**0.94**	**0.071**	**0.488**	**0.95**

1: Average air voids is based on *AASHTO T 331* measurements of bulk specific gravity.
2: Rutting rate regression analysis is based on data between 2000 and 8000 cycles.
3: Power law regression analysis is based on Eq. 2.3.

Table D.12 *APA* Results for Recycled Mixture *9.5-25/RM-2*

		Rut Depth (mm)		Linear Rutting Rate[2]			Power Law[3]		
Rep	**Avg. V_a[1]**	**2000**	**8000**	**Slope (10^{-6})**	**Intercept**	**R^2**	***a***	***b***	**R^2**
1	7.0	1.6	3.9	---	---	---	---	---	---
2	6.9	1.4	2.7	---	---	---	---	---	---
Avg.	**6.9**	**1.5**	**3.0**	**251**	**1.03**	**1.00**	**0.045**	**0.462**	**0.99**
1	9.8	2.5	3.8	---	---	---	---	---	---
2	9.9	4.1	6.2	---	---	---	---	---	---
Avg.	**9.9**	**3.3**	**5.0**	**268**	**2.96**	**0.97**	**0.093**	**0.454**	**0.94**

1: Average air voids is based on *AASHTO T 331* measurements of bulk specific gravity.
2: Rutting rate regression analysis is based on data between 2000 and 8000 cycles.
3: Power law regression analysis is based on Eq. 2.3.

Table D.13 *APA* Results for Recycled Mixture *9.5-50/RM-1*

		Rut Depth (mm)		Linear Rutting Rate[2]			Power Law[3]		
Rep	**Avg. V_a[1]**	**2000**	**8000**	**Slope (10^{-6})**	**Intercept**	**R^2**	***a***	***b***	**R^2**
1	7.0	1.3	2.1	---	---	---	---	---	---
2	7.0	1.1	1.7	---	---	---	---	---	---
Avg.	**7.0**	**1.2**	**1.9**	**107**	**1.08**	**0.99**	**0.083**	**0.352**	**0.97**
1	10.0	1.5	2.8	---	---	---	---	---	---
2	9.8	1.5	2.9	---	---	---	---	---	---
Avg.	**9.9**	**1.5**	**2.9**	**212**	**1.21**	**0.98**	**0.056**	**0.438**	**1.00**

1: Average air voids is based on *AASHTO T 331* measurements of bulk specific gravity.
2: Rutting rate regression analysis is based on data between 2000 and 8000 cycles.
3: Power law regression analysis is based on Eq. 2.3.

Table D.14 *APA* Results for Recycled Mixture *9.5-50/RM-2*

		Rut Depth (mm)		Linear Rutting Rate[2]			Power Law[3]		
Rep	**Avg. V_a[1]**	**2000**	**8000**	**Slope (10^{-6})**	**Intercept**	**R^2**	***a***	***b***	**R^2**
1	6.9	1.7	3.3	---	---	---	---	---	---
2	7.1	2.8	5.2	---	---	---	---	---	---
Avg.	**7.0**	**2.2**	**4.3**	**319**	**1.80**	**0.98**	**0.036**	**0.537**	**0.99**
1	10.0	3.2	5.5	---	---	---	---	---	---
2	9.9	3.3	5.7	---	---	---	---	---	---
Avg.	**10.0**	**3.3**	**5.6**	**369**	**2.86**	**0.96**	**0.054**	**0.527**	**0.97**

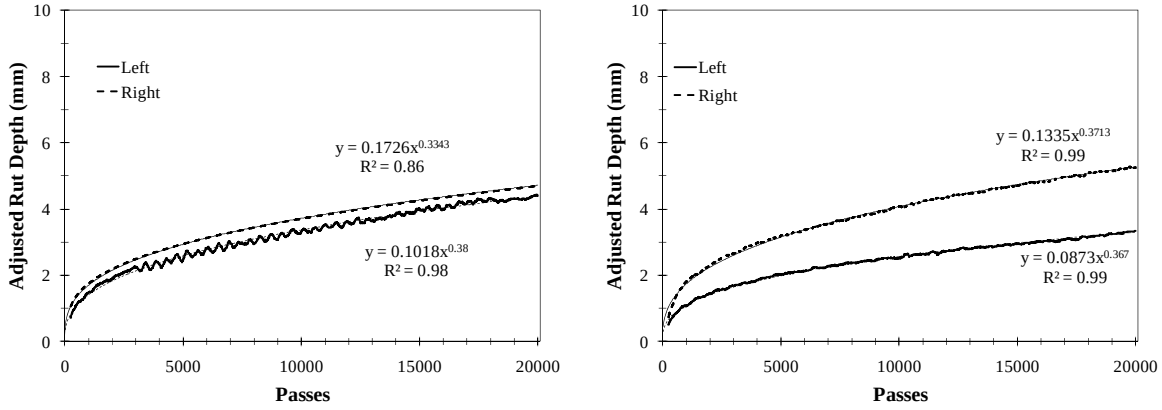
1: Average air voids is based on *AASHTO T 331* measurements of bulk specific gravity.
2: Rutting rate regression analysis is based on data between 2000 and 8000 cycles.
3: Power law regression analysis is based on Eq. 2.3.

APPENDIX E – PURWHEEL DATA

Table E.1 PURWheel Dry Test Results for Mixture *9.5-100/RM-1*

Replicate 1 (Air Voids 9.5%)				Replicate 2 (Air Voids 9.8%)			
Left Specimen (mm)		Right Specimen (mm)		Left Specimen (mm)		Right Specimen (mm)	
Pass	Adj. Rut	Pass	Adj. Rut	Pass	Adj. Rut	Pass	Adj. Rut
250	0.7	250	1.1	250	0.5	250	0.7
500	1.1	500	1.2	500	0.8	500	1.2
1000	1.5	1000	2.0	1000	1.1	1000	1.8
2000	1.9	2000	2.3	2000	1.5	2000	2.3
4000	2.3	4000	3.0	4000	1.9	4000	3.0
8000	2.9	8000	3.5	8000	2.4	8000	3.7
12000	3.6	12000	3.9	12000	2.7	12000	4.4
16000	4.0	16000	4.1	16000	3.0	16000	4.8
20000	4.4 **(6.3)**[1]	20000	5.0 **(5.0)**[1]	20000	3.3 **(4.4)**[1]	20000	5.3 **(4.3)**[1]

1: Value in bold in parentheses is manual measurement. If dashes are present rut was too deep to measure.
Test Temperature: 64 C Tire Pressure: 862 kPa Wheel Load: 178.6 kg



a) Replicate 1 *b) Replicate 2*

Figure E.1 PURWheel Dry Test Results for Mixture *9.5-100/RM-1*

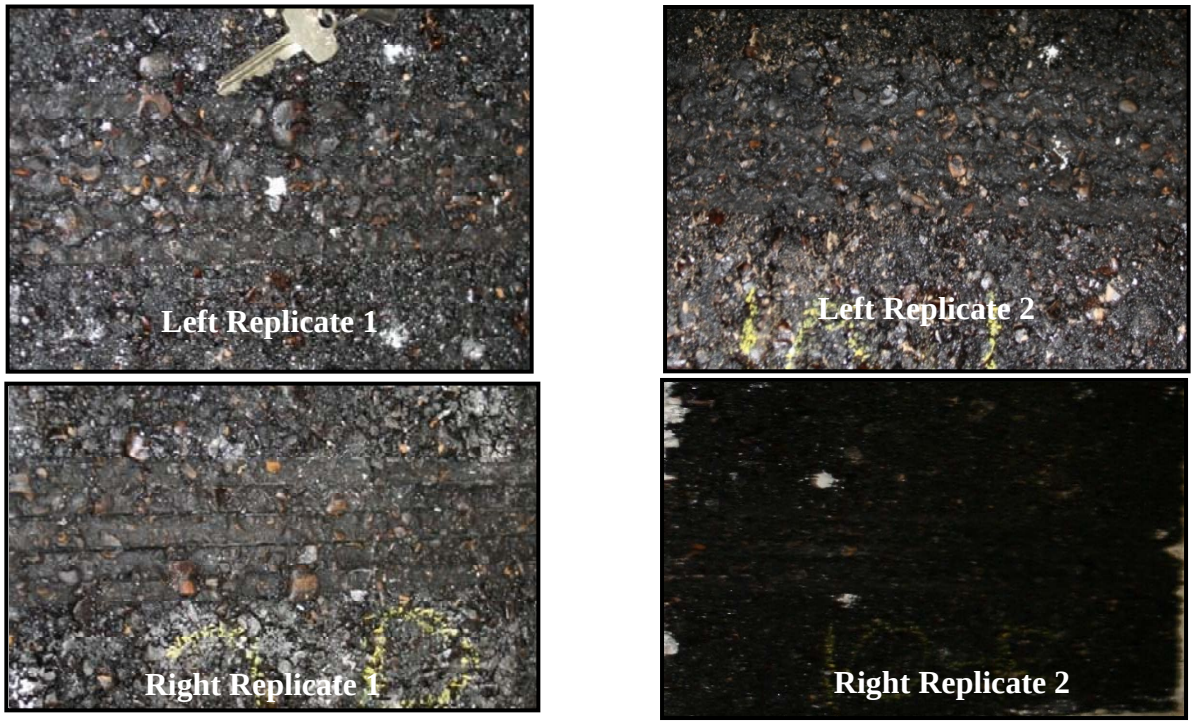
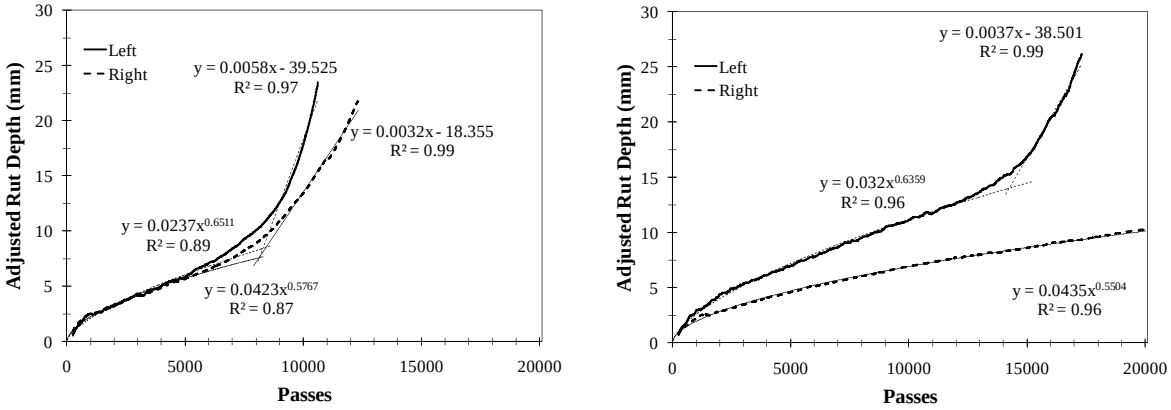


Table E.2 PURWheel Wet Test Results for Mixture *9.5-100/RM-1*

Replicate 1 (Air Voids 9.8%)				Replicate 2 (Air Voids 11.3%)			
Left Specimen (mm)		Right Specimen (mm)		Left Specimen (mm)		Right Specimen (mm)	
Pass	Adj. Rut	Pass	Adj. Rut	Pass	Adj. Rut	Pass	Adj. Rut
250	0.5	250	0.9	250	0.8	250	0.7
500	1.7	500	1.7	500	1.6	500	1.4
1000	2.6	1000	2.6	1000	2.9	1000	2.2
2000	3.3	2000	3.2	2000	4.4	2000	2.8
4000	5.0	4000	5.0	4000	6.1	4000	4.1
8000	10.1	8000	8.9	8000	9.5	8000	6.0
10620	23.5 **(---)**[1]	12000	20.3	12000	12.7	12000	7.8
---	---	12314	21.8 **(---)**[1]	16000	20.4	16000	9.0
---	---	---	---	17312	26.1 **(20.0)**[1]	20000	10.3 **(9.7)**[1]

1: Value in bold in parentheses is manual measurement. If dashes are present rut was too deep to measure.
Test Temperature: 64 C Tire Pressure: 862 kPa Wheel Load: 178.6 kg



a) Replicate 1 *b) Replicate 2*

Figure E.2 PURWheel Wet Test Results for Mixture *9.5-100/RM-1*

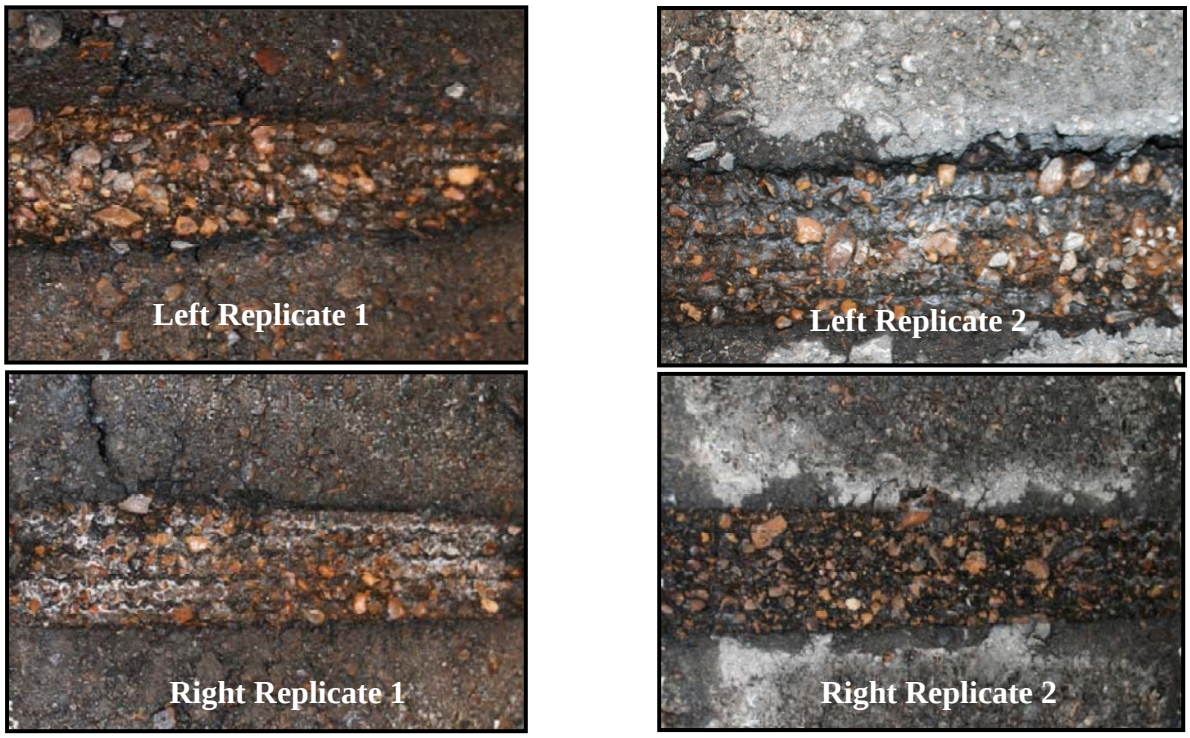
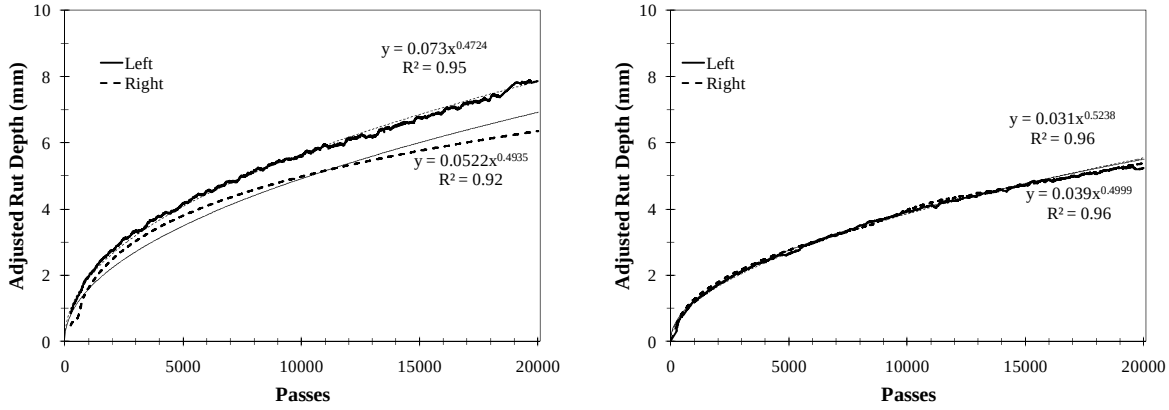


Table E.3 PURWheel Dry Test Results for Mixture *9.5-100/RM-2*

Replicate 1 (Air Voids 10.0%)				Replicate 2 (Air Voids 9.6%)			
Left Specimen (mm)		Right Specimen (mm)		Left Specimen (mm)		Right Specimen (mm)	
Pass	Adj. Rut	Pass	Adj. Rut	Pass	Adj. Rut	Pass	Adj. Rut
250	0.8	250	0.5	250	0.3	250	0.5
500	1.3	500	0.6	500	0.8	500	0.9
1000	2.0	1000	1.8	1000	1.2	1000	1.3
2000	2.7	2000	2.2	2000	1.7	2000	1.8
4000	3.8	4000	3.5	4000	2.4	4000	2.5
8000	5.2	8000	4.1	8000	3.5	8000	3.4
12000	6.1	12000	5.5	12000	4.3	12000	4.3
16000	6.9	16000	5.7	16000	4.9	16000	4.9
20000	8.7 **(8.8)**[1]	20000	7.1 **(6.7)**[1]	20000	5.2 **(6.4)**[1]	20000	5.4 **(7.9)**[1]

1: Value in bold in parentheses is manual measurement. If dashes are present rut was too deep to measure.
Test Temperature: 64 C Tire Pressure: 862 kPa Wheel Load: 178.6 kg



a) Replicate 1 *b) Replicate 2*

Figure E.3 PURWheel Dry Test Results for Mixture *9.5-100/RM-2*

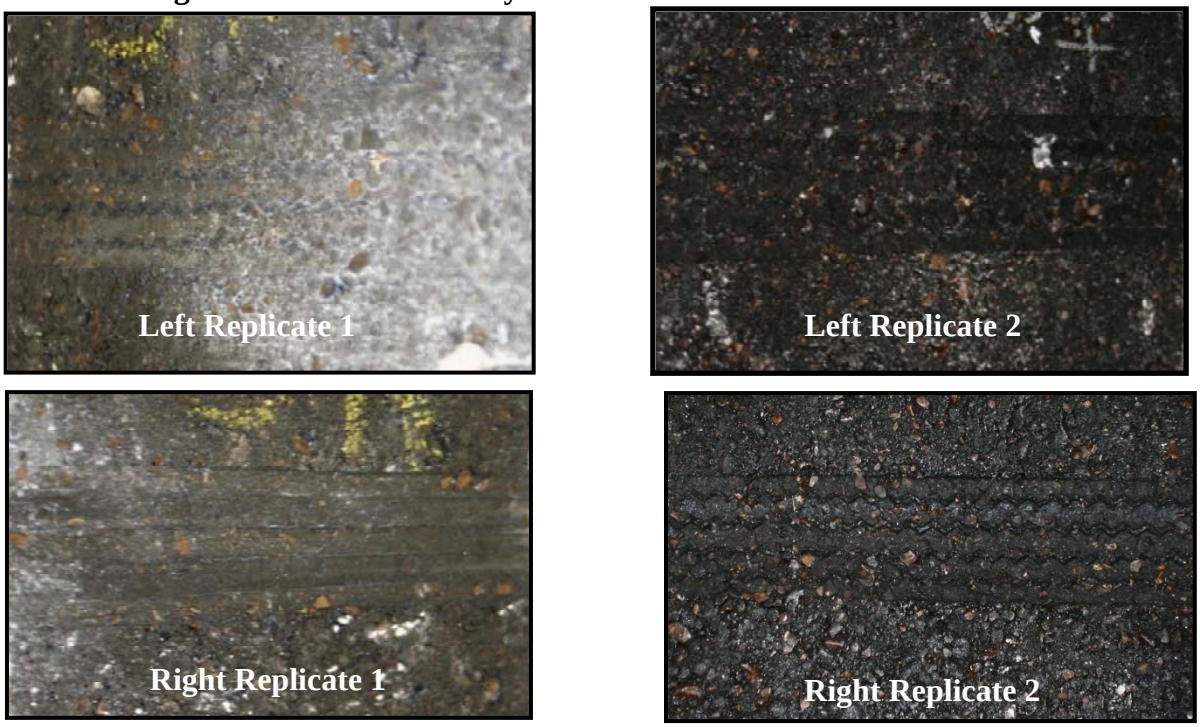
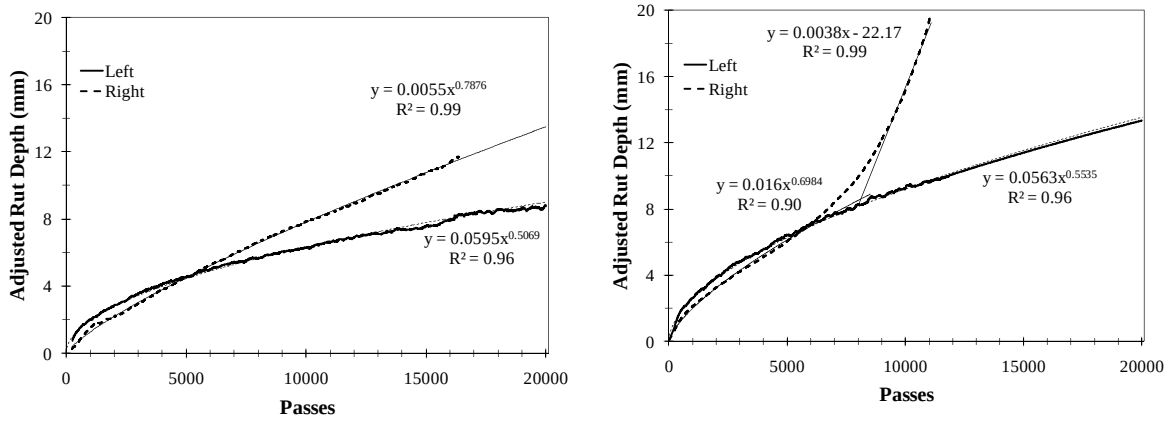


Table E.4 PURWheel Wet Test Results for Mixture *9.5-100/RM-2*

Replicate 1 (Air Voids 8.8%)				Replicate 2 (Air Voids 10.6%)			
Left Specimen (mm)		Right Specimen (mm)		Left Specimen (mm)		Right Specimen (mm)	
Pass	Adj. Rut	Pass	Adj. Rut	Pass	Adj. Rut	Pass	Adj. Rut
250	0.7	250	0.3	250	0.9	250	0.7
500	1.4	500	0.7	500	1.9	500	1.4
1000	2.0	1000	1.5	1000	2.6	1000	2.1
2000	2.9	2000	2.2	2000	3.9	2000	3.3
4000	4.1	4000	3.8	4000	5.6	4000	5.1
8000	5.7	8000	6.6	8000	8.3	8000	9.9
12000	6.9	12000	8.9	12000	10.1	11490	19.8 **(---)**[1]
16000	7.9	16000	11.4	16000	11.8	---	---
20000	8.8 **(8.3)**[1]	16412	11.7 **(11.5)**[1]	20000	13.3 **(9.5)**[1]	---	---

1: Value in bold in parentheses is manual measurement. If dashes are present rut was too deep to measure.
Test Temperature: 64 C Tire Pressure: 862 kPa Wheel Load: 178.6 kg



a) Replicate 1 *b) Replicate 2*

Figure E.4 PURWheel Wet Test Results for Mixture *9.5-100/RM-2*

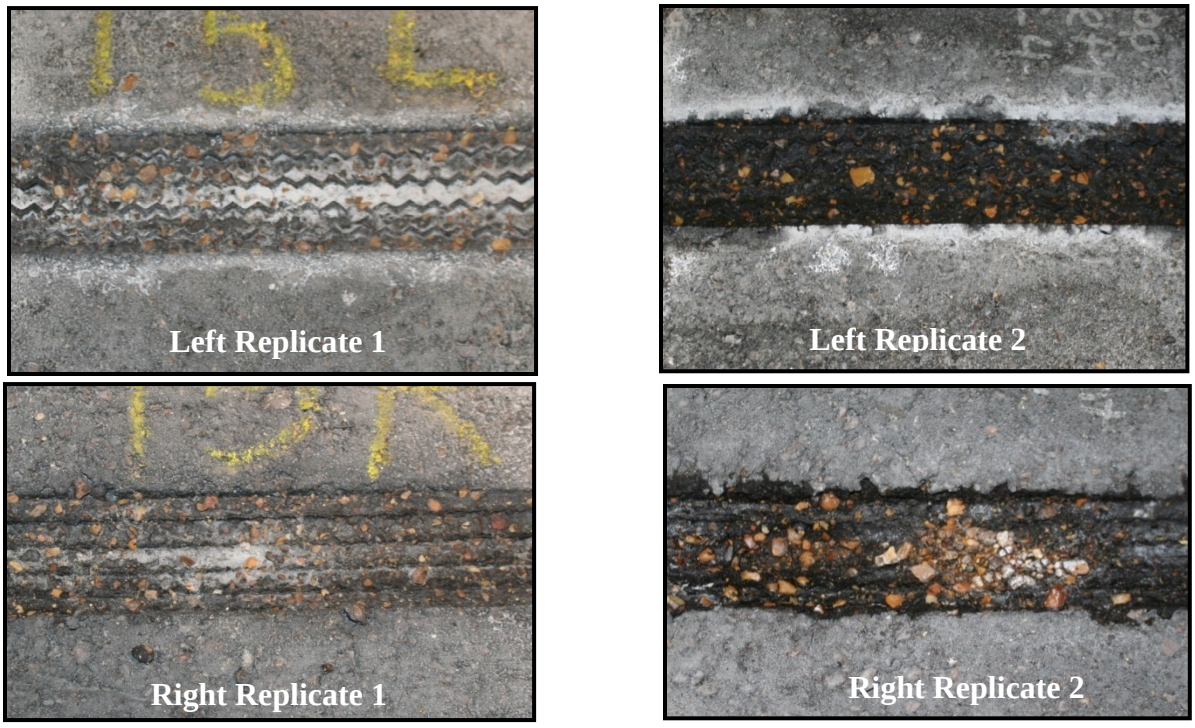
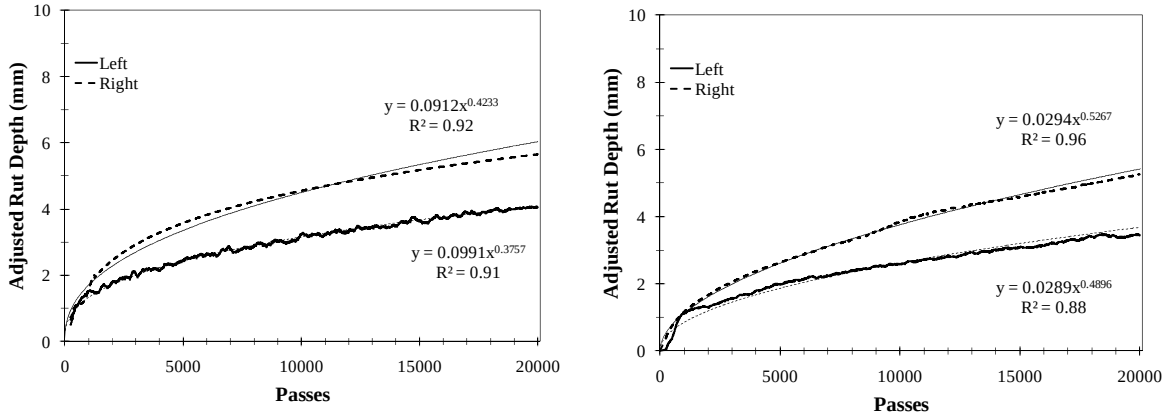


Table E.5 PURWheel Dry Test Results for Mixture *12.5-100/RM-3*

Replicate 1 (Air Voids 9.5%)				Replicate 2 (Air Voids 11.2%)			
Left Specimen (mm)		Right Specimen (mm)		Left Specimen (mm)		Right Specimen (mm)	
Pass	Adj. Rut	Pass	Adj. Rut	Pass	Adj. Rut	Pass	Adj. Rut
250	0.5	250	0.7	250	0.1	250	0.4
500	1.1	500	1.1	500	0.4	500	0.8
1000	1.5	1000	1.6	1000	1.1	1000	1.2
2000	1.8	2000	2.5	2000	1.3	2000	1.7
4000	2.2	4000	3.2	4000	1.8	4000	2.4
8000	2.9	8000	4.0	8000	2.4	8000	2.4
12000	3.3	12000	5.0	12000	2.8	12000	3.3
16000	3.7	16000	5.4	16000	3.1	16000	4.2
20000	4.1 **(5.2)**[1]	20000	5.7 **(6.1)**[1]	20000	3.4 **(4.5)**[1]	20000	5.3 **(6.4)**[1]

1: Value in bold4.1 in parentheses is manual measurement. If dashes are present rut was too deep to measure.
Test Temperature: 64 C Tire Pressure: 862 kPa Wheel Load: 178.6 kg



a) Replicate 1 *b) Replicate 2*

Figure E.5 PURWheel DryTest Results for Mixture *12.5-100/RM-3*

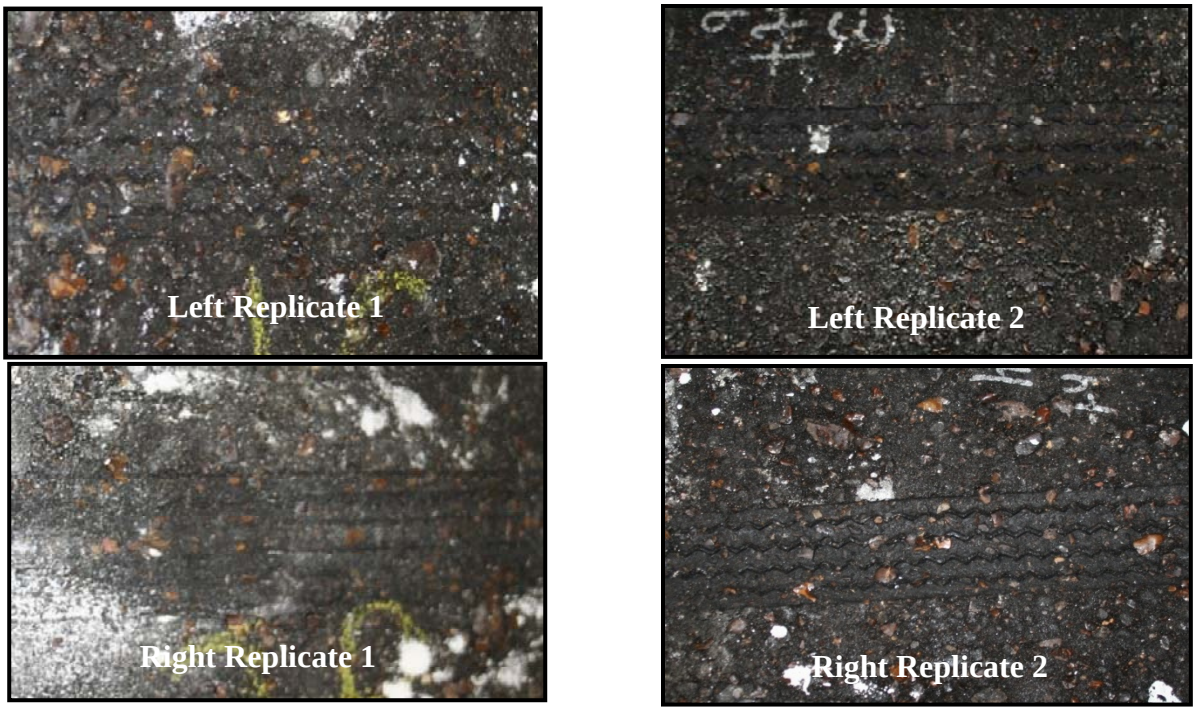
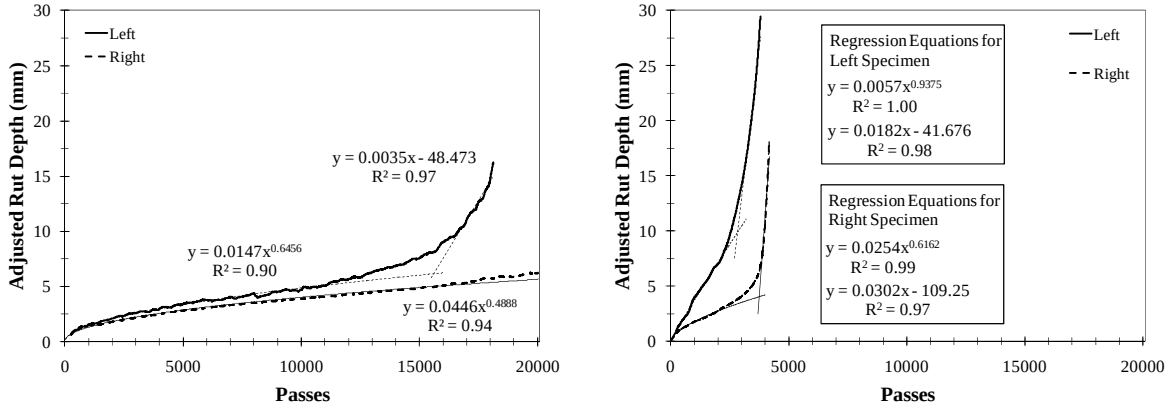


Table E.6 PURWheel Wet Test Results for Mixture *12.5-100/RM-3*

Replicate 1 (Air Voids 8.7%)				Replicate 2 (Air Voids 11.5%)			
Left Specimen (mm)		Right Specimen (mm)		Left Specimen (mm)		Right Specimen (mm)	
Pass	Adj. Rut	Pass	Adj. Rut	Pass	Adj. Rut	Pass	Adj. Rut
250	0.7	250	0.6	250	1.0	250	0.8
500	1.1	500	1.1	500	1.9	500	1.2
1000	1.5	1000	1.5	1000	4.0	1000	1.8
2000	2.1	2000	1.8	2000	7.0	2000	2.8
4000	2.9	4000	2.5	3800	29.5 **(---)**[1]	4000	10.8
8000	4.4	8000	3.5	---	---	4174	18.1 **(---)**[1]
12000	5.7	12000	4.3	---	---	---	---
16000	9.0	16000	5.1	---	---	---	---
18130	16.2 **(13.1)**[1]	20000	6.2 **(5.4)**[1]	---	---	---	---

1: Value in bold in parentheses is manual measurement. If dashes are present rut was too deep to measure.
Test Temperature: 64 C Tire Pressure: 862 kPa Wheel Load: 178.6 kg



a) Replicate 1 *b) Replicate 2*

Figure E.6 PURWheel Wet Test Results for Mixture *12.5-100/RM-3*

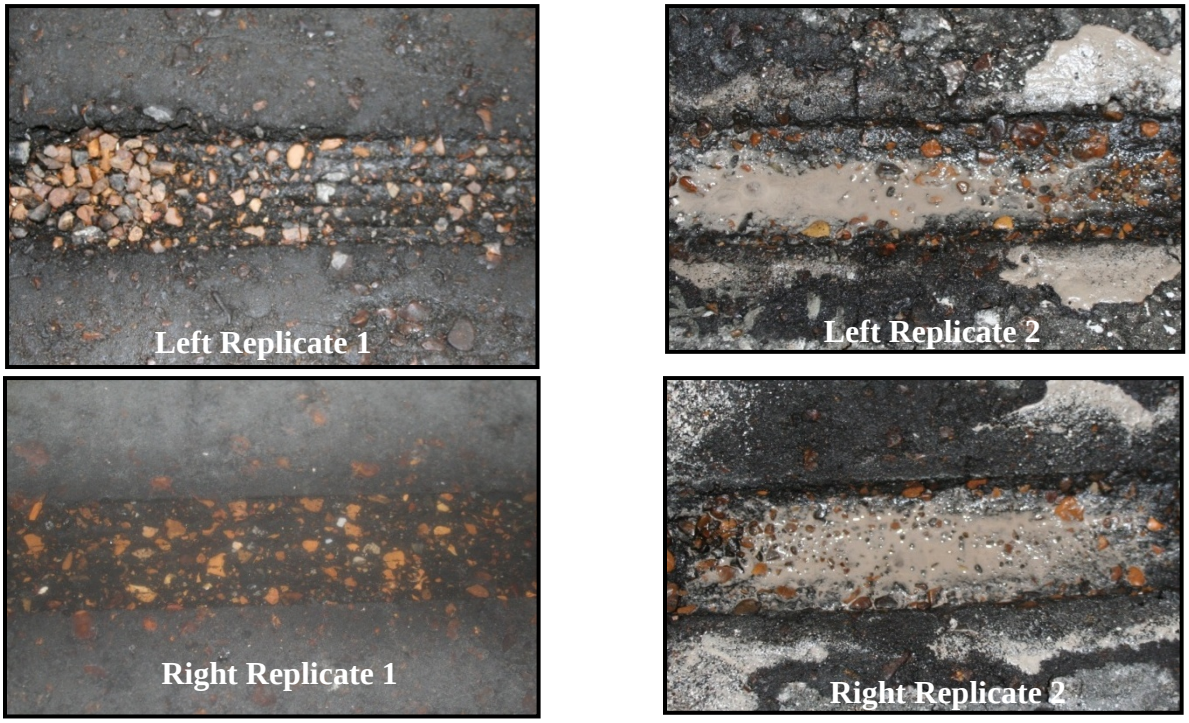
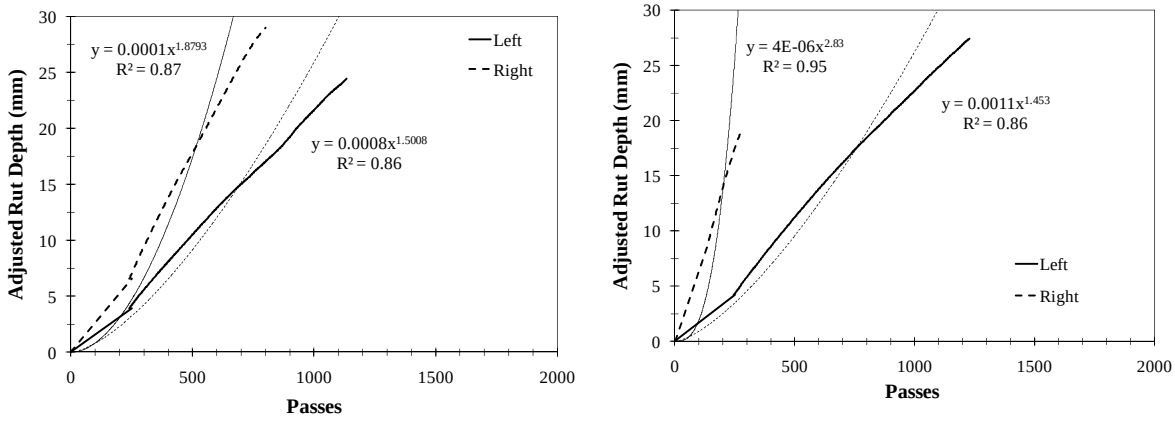


Table E.7 PURWheel Dry Test Results for Mixture *9.5-15/CM-2*

Replicate 1 (Air Voids 9.2%)				Replicate 2 (Air Voids 9.1%)			
Left Specimen (mm)		Right Specimen (mm)		Left Specimen (mm)		Right Specimen (mm)	
Pass	Adj. Rut	Pass	Adj. Rut	Pass	Adj. Rut	Pass	Adj. Rut
250	4.2	250	7.0	250	4.3	250	10.9
500	10.5	500	17.8	500	11.3	272	12.5 **(18.6)**[1]
1000	21.7	800	29.0 **(---)**[1]	1000	22.7	---	---
1134	24.5 **(22.9)**[1]	---	---	1230	27.5 **(---)**[1]	---	---
---	---	---	---	---	---	---	---
---	---	---	---	---	---	---	---
---	---	---	---	---	---	---	---
---	---	---	---	---	---	---	---
---	---	---	---	---	---	---	---

1: Value in bold in parentheses is manual measurement. If dashes are present rut was too deep to measure.
Test Temperature: 64 C Tire Pressure: 862 kPa Wheel Load: 178.6 kg



a) Replicate 1 *b) Replicate 2*

Figure E.7 PURWheel Dry Test Results for Mixture *9.5-15/CM-2*

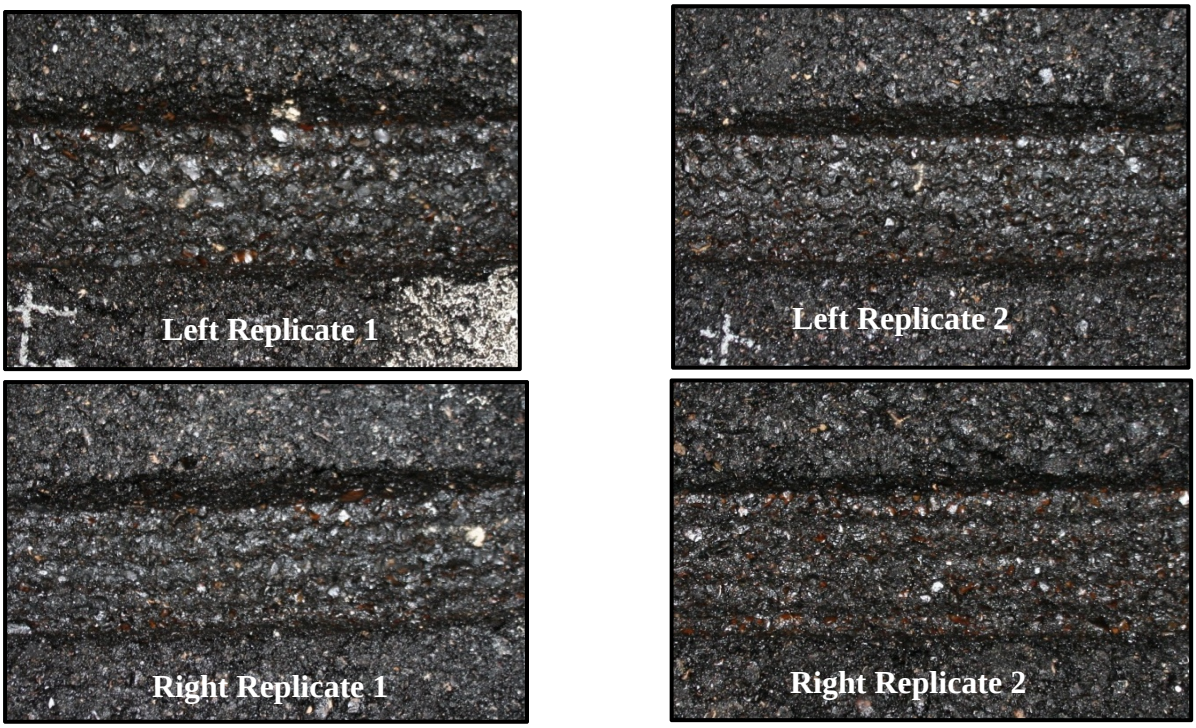
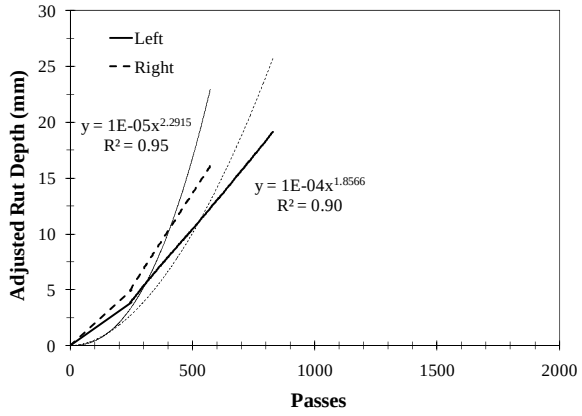


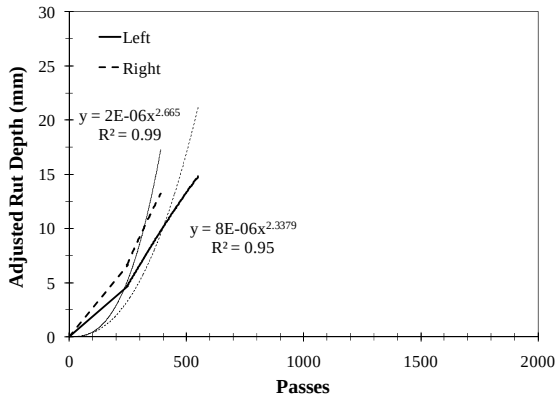
Table E.8 PURWheel Wet Test Results for Mixture *9.5-15/CM-2*

Replicate 1 (Air Voids 9.1%)				Replicate 2 (Air Voids 9.2%)			
Left Specimen (mm)		Right Specimen (mm)		Left Specimen (mm)		Right Specimen (mm)	
Pass	Adj. Rut	Pass	Adj. Rut	Pass	Adj. Rut	Pass	Adj. Rut
250	4.0	250	5.1	250	4.8	250	6.8
500	10.4	500	13.6	500	13.3	390	13.2 **(17.5)**[1]
828	19.1 **(18.7)**[1]	572	16.1 **(17.3)**[1]	550	14.8 **(17.6)**[1]	---	---
---	---	---	---	---	---	---	---
---	---	---	---	---	---	---	---
---	---	---	---	---	---	---	---
---	---	---	---	---	---	---	---
---	---	---	---	---	---	---	---
---	---	---	---	---	---	---	---

1: Value in bold in parentheses is manual measurement. If dashes are present rut was too deep to measure.
Test Temperature: 64 C Tire Pressure: 862 kPa Wheel Load: 178.6 kg



a) Replicate 1



b) Replicate 2

Figure E.8 PURWheel Wet Test Results for Mixture *9.5-15/CM-2*

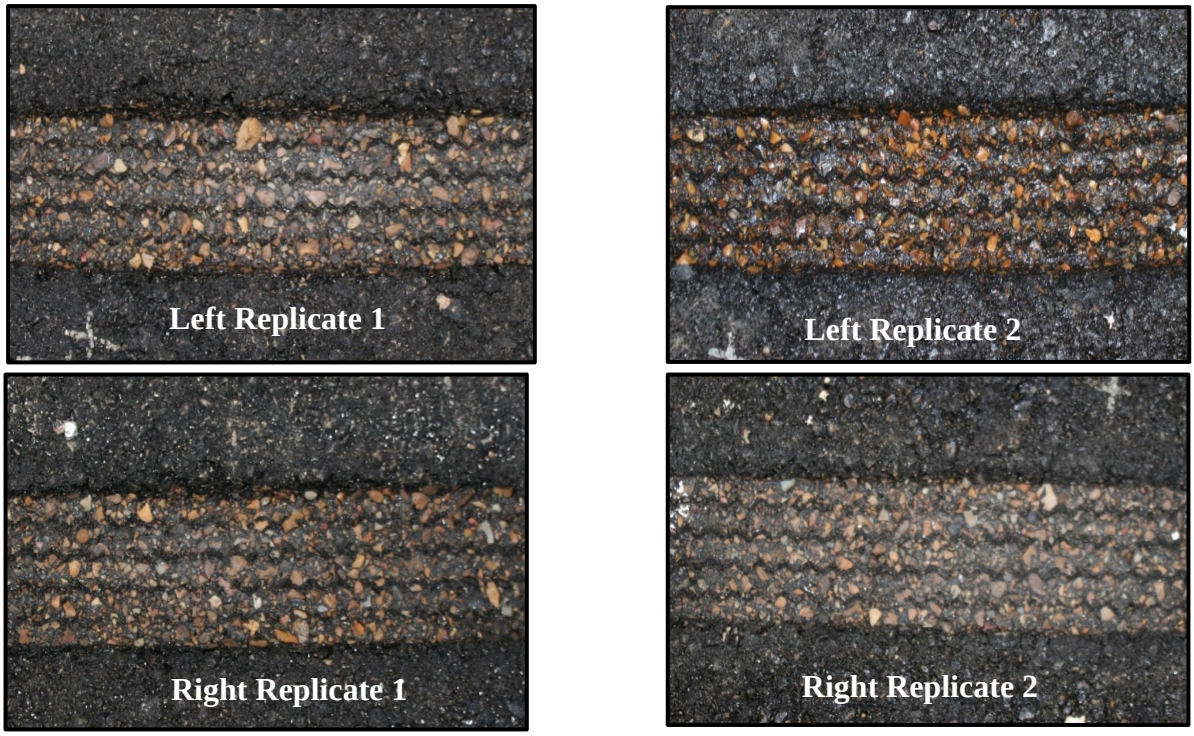
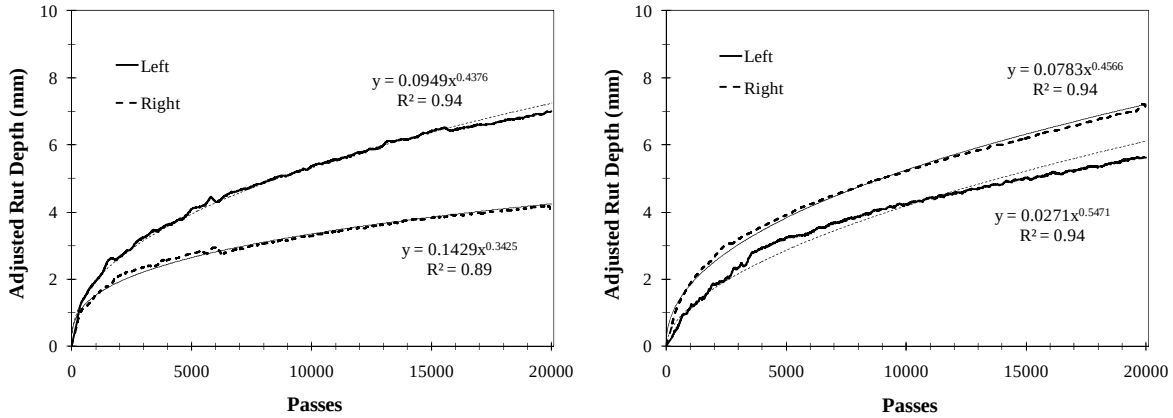


Table E.9 PURWheel Dry Test Results for Mixture *9.5-15/CM-3*

Replicate 1 (Air Voids 6.9%)				Replicate 2 (Air Voids 8.8%)			
Left Specimen (mm)		Right Specimen (mm)		Left Specimen (mm)		Right Specimen (mm)	
Pass	Adj. Rut	Pass	Adj. Rut	Pass	Adj. Rut	Pass	Adj. Rut
250	0.9	250	0.7	250	0.3	250	0.7
500	1.4	500	1.1	500	0.6	500	1.2
1000	1.9	1000	1.5	1000	1.1	1000	1.9
2000	2.7	2000	2.1	2000	1.8	2000	2.7
4000	3.6	4000	2.6	4000	2.9	4000	3.6
8000	4.9	8000	3.1	8000	3.9	8000	4.8
12000	5.8	12000	3.5	12000	4.6	12000	5.7
16000	6.5	16000	3.9	16000	5.2	16000	6.4
20000	7.0 **(8.6)**[1]	20000	4.0 **(5.8)**[1]	20000	5.6 **(6.9)**[1]	20000	7.1 **(9.2)**[1]

1: Value in bold in parentheses is manual measurement. If dashes are present rut was too deep to measure.
Test Temperature: 64 C Tire Pressure: 862 kPa Wheel Load: 178.6 kg



a) Replicate 1 *b) Replicate 2*

Figure E.9 PURWheel Dry Test Results for Mixture *9.5-15/CM-3*

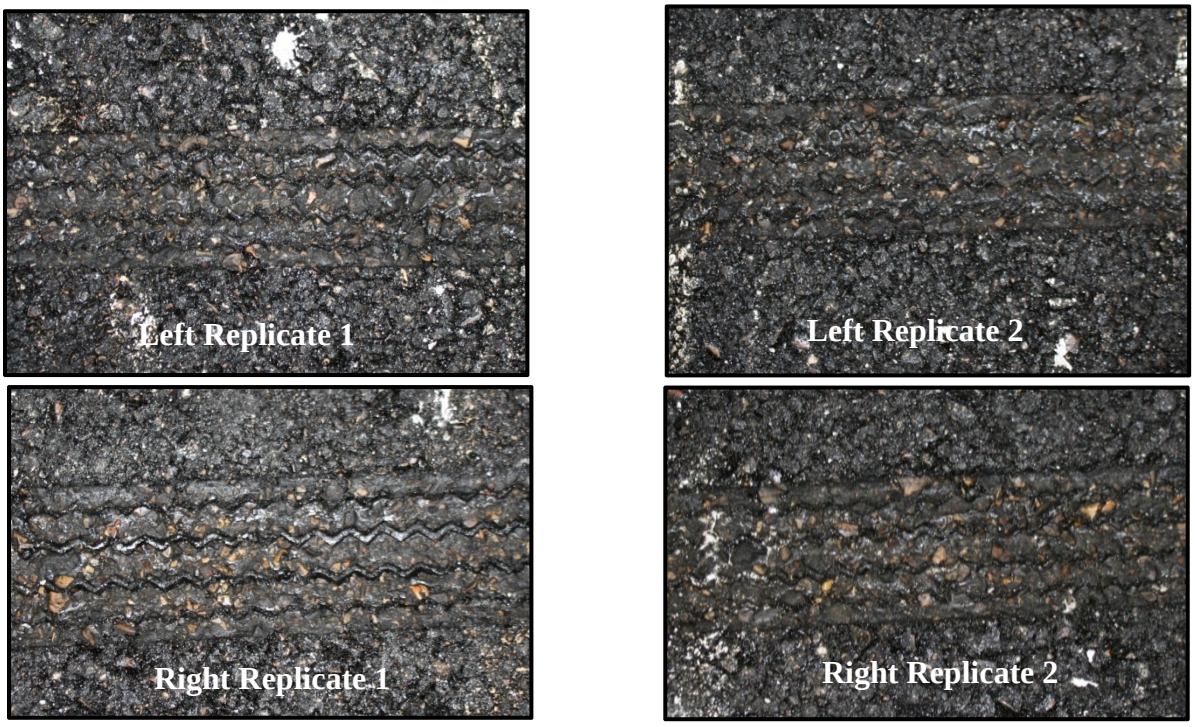
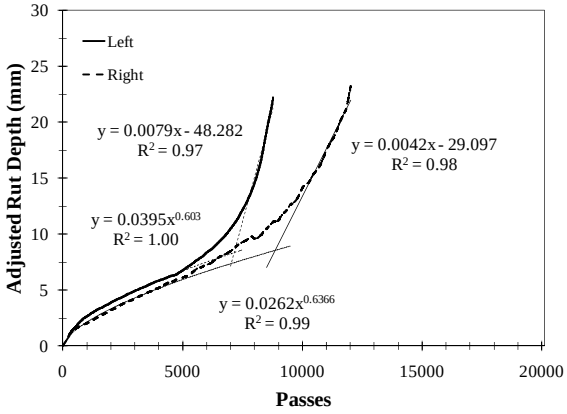


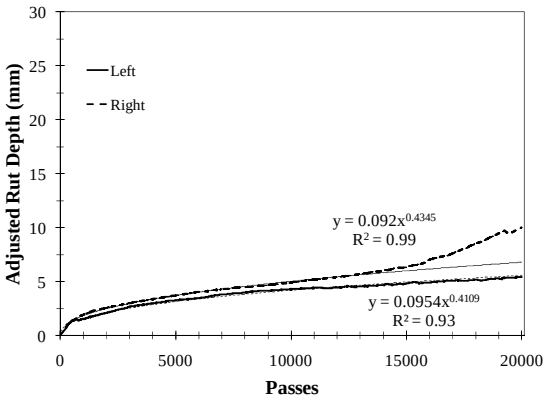
Table E.10 PURWheel Wet Test Results for Mixture *9.5-15/CM-3*

Replicate 1 (Air Voids 7.0%)				Replicate 2 (Air Voids 7.3%)			
Left Specimen (mm)		Right Specimen (mm)		Left Specimen (mm)		Right Specimen (mm)	
Pass	Adj. Rut	Pass	Adj. Rut	Pass	Adj. Rut	Pass	Adj. Rut
250	0.9	250	0.9	250	0.7	250	0.8
500	1.7	500	1.5	500	1.4	500	1.3
1000	2.6	1000	2.0	1000	1.5	1000	1.9
2000	3.9	2000	3.2	2000	2.1	2000	2.6
4000	5.8	4000	5.2	4000	3.0	4000	3.4
8000	14.5	8000	9.6	8000	8.2	8000	4.5
8782	22.2 **(---)**[1]	12000	23.0	12000	8.7	12000	5.4
---	---	12020	23.2 **(---)**[1]	16000	9.2	16000	7.0
---	---	---	---	20000	9.7 **(6.1)**[1]	20000	10.0 **(11.7)**[1]

1: Value in bold in parentheses is manual measurement. If dashes are present rut was too deep to measure.
Test Temperature: 64 C Tire Pressure: 862 kPa Wheel Load: 178.6 kg



a) Replicate 1



b) Replicate 2

Figure E.10 PURWheel Wet Test Results for Mixture *9.5-15/CM-3*

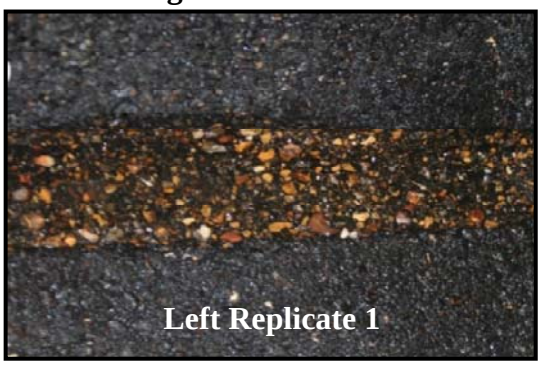




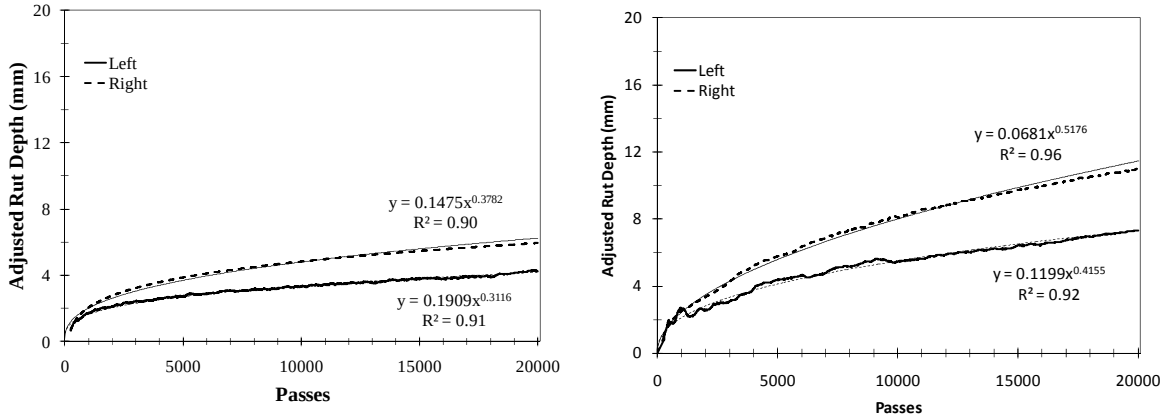




Table E.11 PURWheel Dry Test Results for Mixture *9.5-15/CM-4a*

Replicate 1 (Air Voids 8.0%)				Replicate 2 (Air Voids 11.5%)			
Left Specimen (mm)		Right Specimen (mm)		Left Specimen (mm)		Right Specimen (mm)	
Pass	Adj. Rut	Pass	Adj. Rut	Pass	Adj. Rut	Pass	Adj. Rut
250	0.7	250	0.7	250	0.8	250	1.0
500	1.3	500	1.4	500	1.8	500	1.7
1000	1.7	1000	2.4	1000	2.7	1000	2.5
2000	2.1	2000	2.8	2000	2.6	2000	3.3
4000	2.6	4000	3.0	4000	3.9	4000	5.2
8000	3.2	8000	3.9	8000	5.2	8000	7.4
12000	3.5	12000	4.6	12000	5.9	12000	8.8
16000	3.8	16000	5.4	16000	6.5	16000	10.0
20000	4.2 **(5.2)**[1]	20000	6.0 **(5.9)**[1]	20000	7.3 **(10.4)**[1]	20000	11.0 **(10.2)**[1]

1: Value in bold in parentheses is manual measurement. If dashes are present rut was too deep to measure.
Test Temperature: 64 C Tire Pressure: 862 kPa Wheel Load: 178.6 kg



a) Replicate 1 *b) Replicate 2*

Figure E.11 PURWheel Dry Test Results for Mixture *9.5-15/CM-4a*

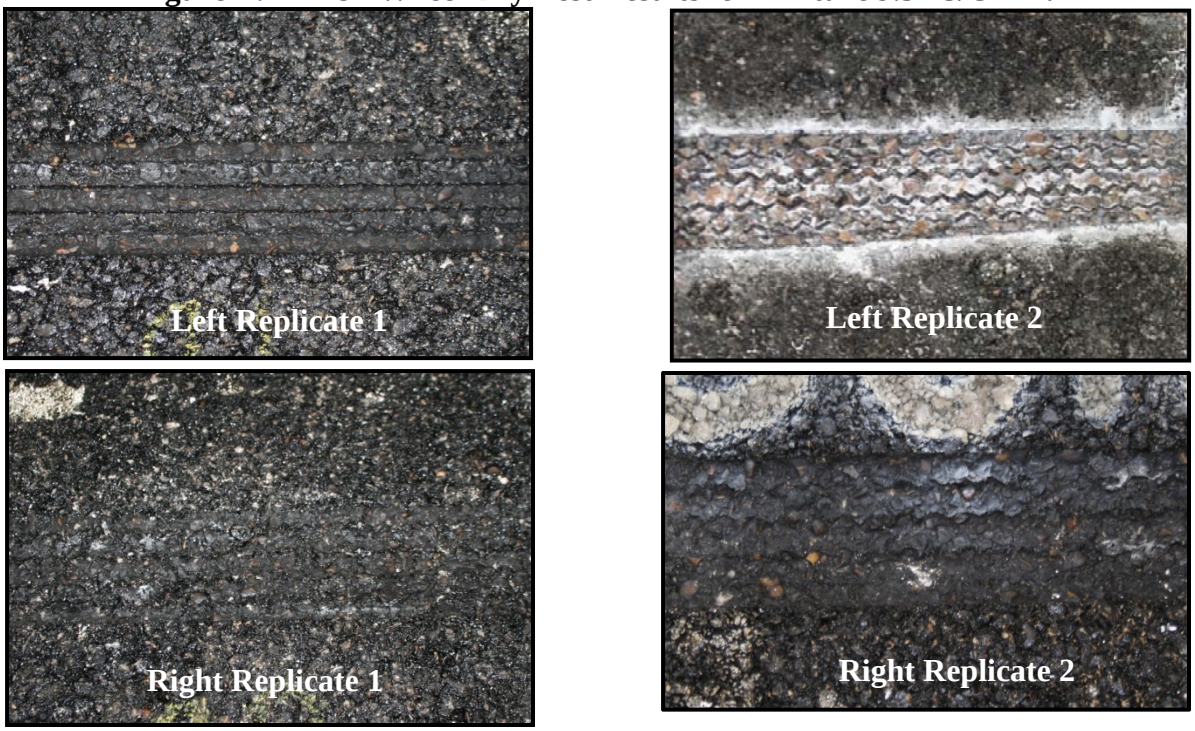
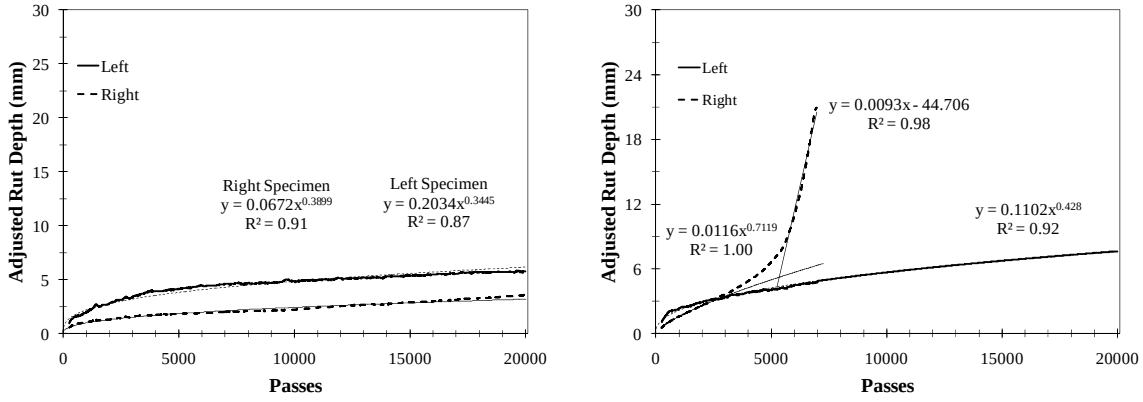


Table E.12 PURWheel Wet Test Results for Mixture *9.5-15/CM-4a*

Replicate 1 (Air Voids 7.4%)				Replicate 2 (Air Voids 4.8%)			
Left Specimen (mm)		Right Specimen (mm)		Left Specimen (mm)		Right Specimen (mm)	
Pass	Adj. Rut	Pass	Adj. Rut	Pass	Adj. Rut	Pass	Adj. Rut
250	1.0	250	0.5	250	1.0	250	0.5
500	1.6	500	0.9	500	1.9	500	1.0
1000	2.0	1000	1.1	1000	2.3	1000	1.6
2000	2.8	2000	1.3	2000	2.9	2000	2.0
4000	3.9	4000	1.7	4000	3.8	4000	4.9
8000	4.7	8000	2.1	8000	4.8	6978	21.0 **(---)**[1]
12000	5.1	12000	2.5	12000	5.7	---	---
16000	5.5	16000	3.0	16000	7.3	---	---
20000	5.8 **(5.1)**[1]	20000	3.6 **(6.3)**[1]	20000	7.9 **(6.1)**[1]	---	---

1: Value in bold in parentheses is manual measurement. If dashes are present rut was too deep to measure.
Test Temperature: 64 C Tire Pressure: 862 kPa Wheel Load: 178.6 kg



a) Replicate 1 *b) Replicate 2*

Figure E.12 PURWheel Wet Test Results for Mixture *9.5-15/CM-4a*

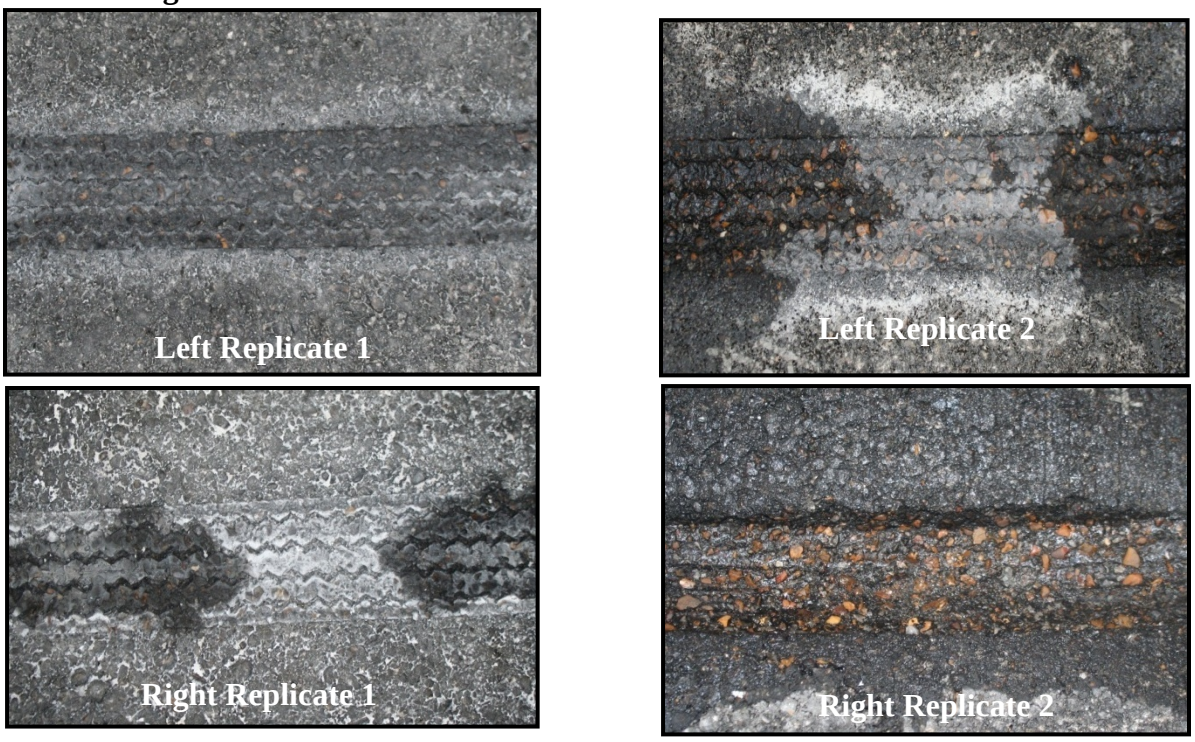
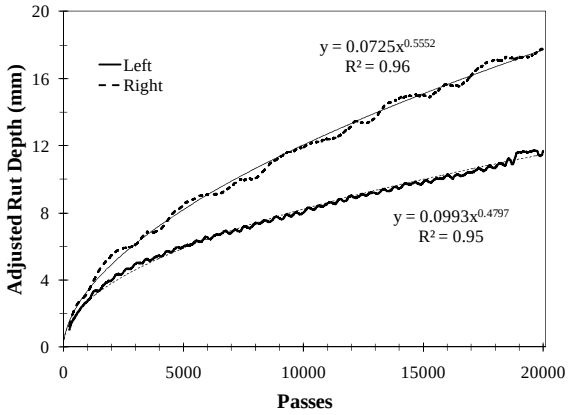


Table E.13 PURWheel Dry Test Results for Mixture *9.5-15/CM-4b*

Replicate 1 (Air Voids 10.8%)			
Left Specimen (mm)		**Right Specimen (mm)**	
Pass	**Adj. Rut**	**Pass**	**Adj. Rut**
250	1.1	250	1.3
500	1.9	500	2.4
1000	2.8	1000	3.3
2000	4.0	2000	5.5
4000	5.4	4000	7.0
8000	7.4	8000	10.1
12000	9.0	12000	13.2
16000	10.3	16000	15.7
20000	11.7 **(13.1)**[1]	20000	17.8 **(15.1)**[1]

1: Value in bold in parentheses is manual measurement. If dashes are present rut was too deep to measure.
Test Temperature: 64 C Tire Pressure: 862 kPa Wheel Load: 178.6 kg



a) Replicate 1

Figure E.13 PURWheel Dry Test Results for Mixture *9.5-15/CM-4b*



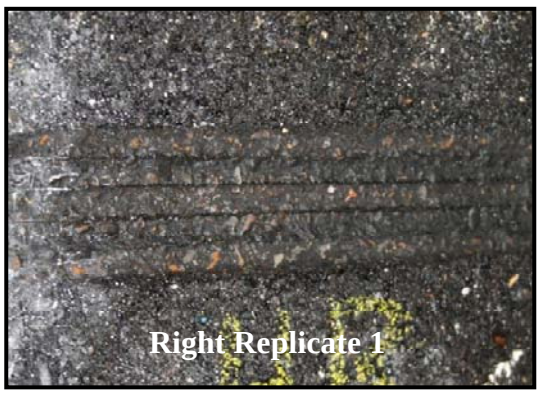
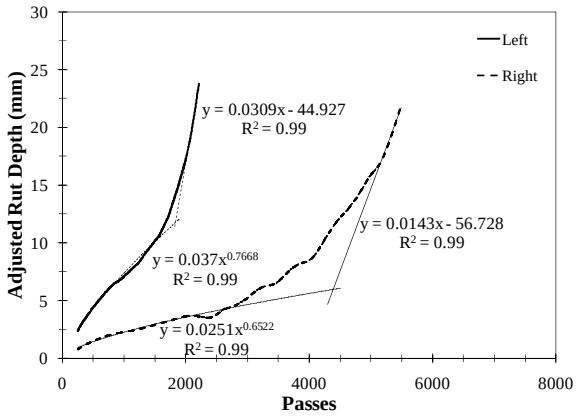


Table E.14 PURWheel Wet Test Results for Mixture *9.5-15/CM-4b*

Replicate 1 (Air Voids 10.7%)			
Left Specimen (mm)		**Right Specimen (mm)**	
Pass	**Adj. Rut**	**Pass**	**Adj. Rut**
250	2.3	250	0.8
500	4.4	500	1.5
1000	7.1	1000	2.3
2000	17.3	2000	3.6
2214	23.8 **(16.3)**[1]	4000	8.5
---	---	5490	22.0 **(---)**[1]
---	---	---	---
---	---	---	---
---	---	---	---

1: Value in bold in parentheses is manual measurement. If dashes are present rut was too deep to measure.
Test Temperature: 64 C Tire Pressure: 862 kPa Wheel Load: 178.6 kg



a) Replicate 1

Figure E.14 PURWheel Wet Test Results for Mixture *9.5-15/CM-4b*

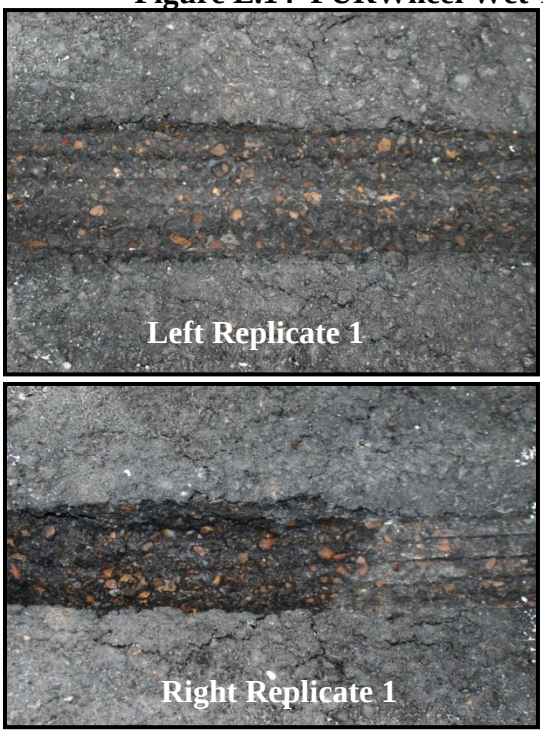
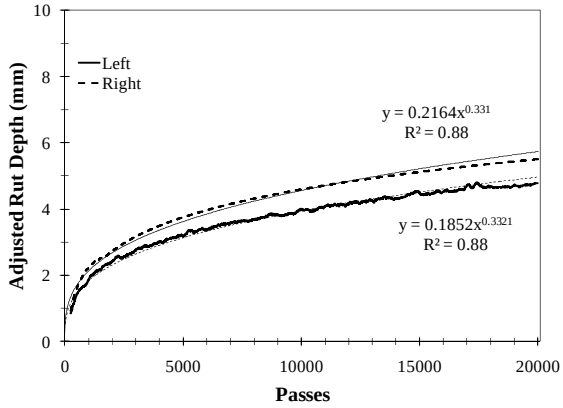


Table E.15 PURWheel Dry Test Results for Mixture *9.5-15/CM-4c*

Replicate 1 (Air Voids 11.2%)			
Left Specimen (mm)		**Right Specimen (mm)**	
Pass	**Adj. Rut**	**Pass**	**Adj. Rut**
250	0.8	250	0.9
500	1.4	500	1.6
1000	1.9	1000	2.2
2000	2.4	2000	2.7
4000	3.0	4000	3.5
8000	3.7	8000	4.3
12000	4.2	12000	4.8
16000	4.5	16000	5.2
20000	4.8 **(5.5)**[1]	20000	5.5 **(6.3)**[1]

1: Value in bold in parentheses is manual measurement. If dashes are present rut was too deep to measure.
Test Temperature: 64 C Tire Pressure: 862 kPa Wheel Load: 178.6 kg



a) Replicate 1

Figure E.15 PURWheel Dry Test Results for Mixture *9.5-15/CM-4c*



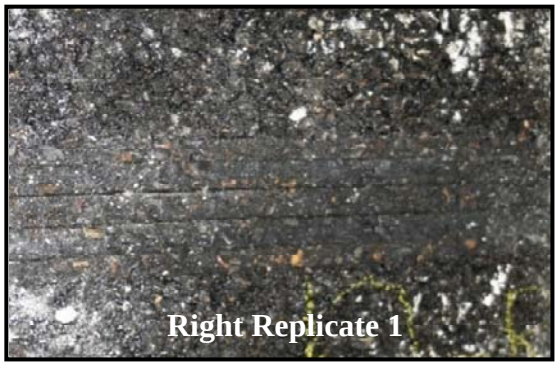
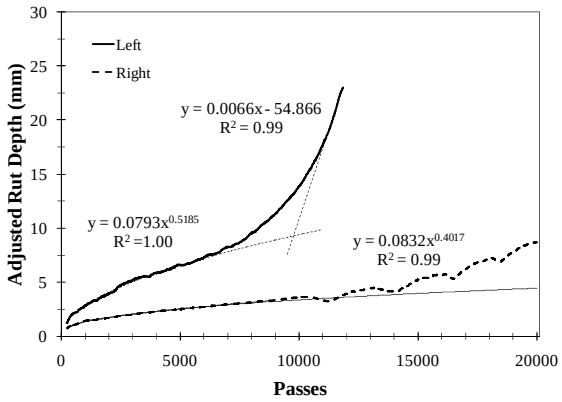


Table E.16 PURWheel Wet Test Results for Mixture *9.5-15/CM-4c*

Replicate 1 (Air Voids 10.7%)			
Left Specimen (mm)		**Right Specimen (mm)**	
Pass	**Adj. Rut**	**Pass**	**Adj. Rut**
250	1.3	250	0.7
500	2.1	500	1.0
1000	2.8	1000	1.4
2000	4.0	2000	1.7
4000	5.8	4000	2.3
8000	9.6	8000	3.1
11842	23.0 **(---)**[1]	12000	3.9
---	---	16000	5.6
---	---	20000	8.7 **(13.7)**[1]

1: Value in bold in parentheses is manual measurement. If dashes are present rut was too deep to measure.
Test Temperature: 64 C Tire Pressure: 862 kPa Wheel Load: 178.6 kg



a) Replicate 1

Figure E.16 PURWheel Wet Test Results for Mixture *9.5-15/CM-4c*

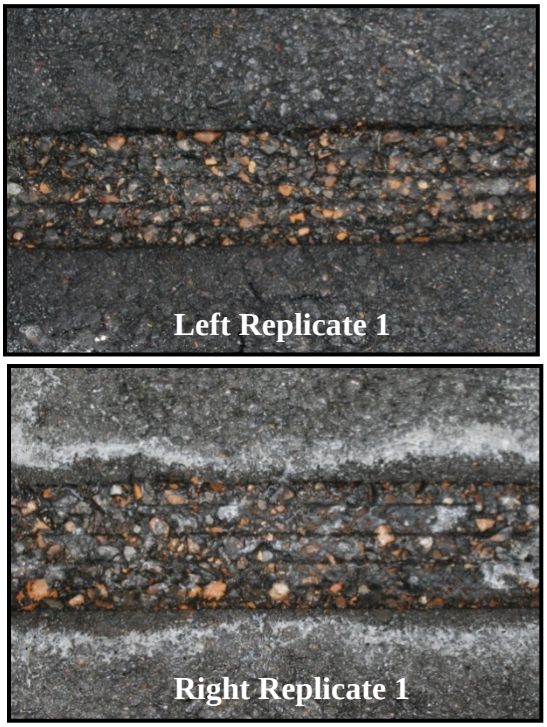
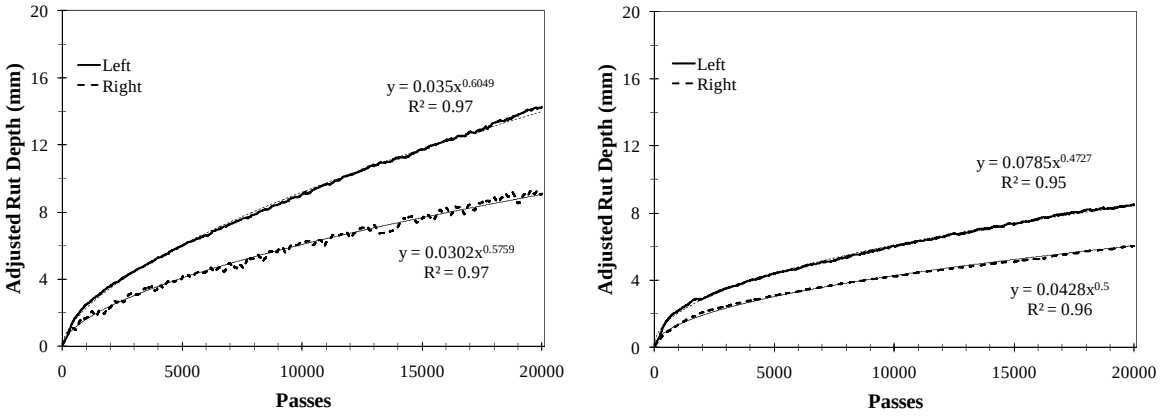


Table E.17 PURWheel Dry Test Results for Mixture *9.5-25/RM-1*

Replicate 1 (Air Voids 10.3%)				Replicate 2 (Air Voids 9.0%)			
Left Specimen (mm)		Right Specimen (mm)		Left Specimen (mm)		Right Specimen (mm)	
Pass	Adj. Rut	Pass	Adj. Rut	Pass	Adj. Rut	Pass	Adj. Rut
250	0.8	250	0.8	250	0.8	250	0.5
500	1.6	500	1.0	500	1.6	500	0.9
1000	2.5	1000	1.7	1000	2.2	1000	1.3
2000	3.6	2000	2.3	2000	2.9	2000	2.1
4000	5.3	4000	3.5	4000	4.0	4000	2.8
8000	7.8	8000	5.2	8000	5.4	6978	3.8
12000	10.2	12000	6.5	12000	6.6	12000	4.6
16000	12.3	16000	8.2	16000	7.7	16000	5.3
20000	14.3**(13.9)**[1]	20000	9.1 **(9.5)**[1]	20000	8.5 **(10.2)**[1]	20000	6.0 **(7.2)**[1]

1: Value in bold in parentheses is manual measurement. If dashes are present rut was too deep to measure.
Test Temperature: 64 C Tire Pressure: 862 kPa Wheel Load: 178.6 kg



a) Replicate 1 *b) Replicate 2*

Figure E.17 PURWheel Wet Test Results for Mixture *9.5-25/RM-1*

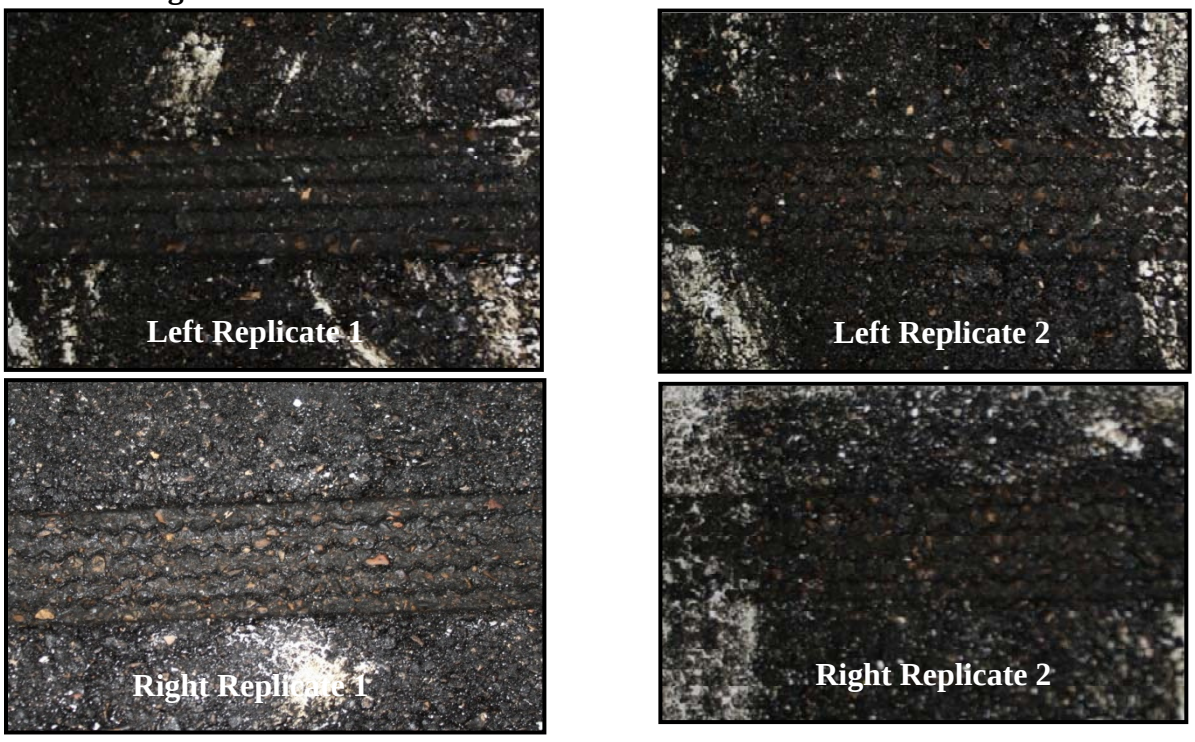
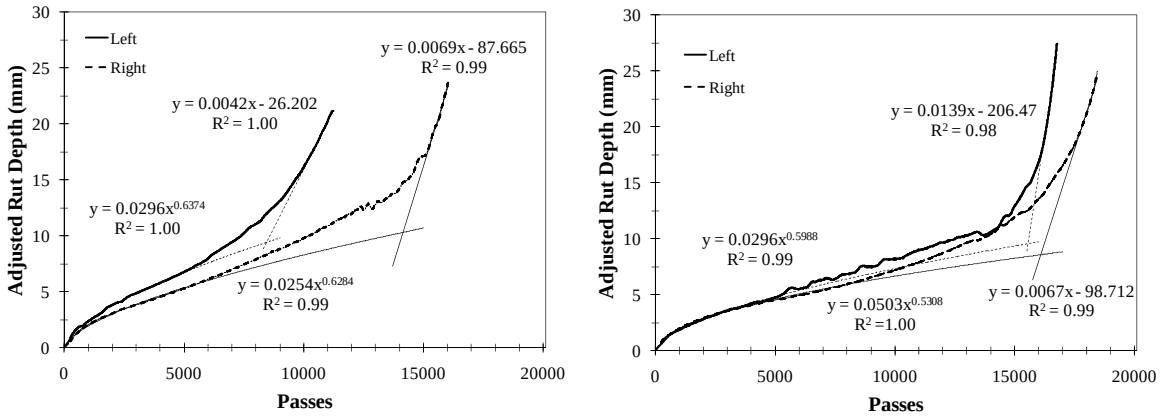


Table E.18 PURWheel Wet Test Results for Mixture *9.5-25/RM-1*

Replicate 1 (Air Voids 9.5%)				Replicate 2 (Air Voids 9.1%)			
Left Specimen (mm)		Right Specimen (mm)		Left Specimen (mm)		Right Specimen (mm)	
Pass	Adj. Rut	Pass	Adj. Rut	Pass	Adj. Rut	Pass	Adj. Rut
250	0.9	250	0.6	250	0.6	250	0.8
500	1.7	500	1.2	500	1.2	500	1.3
1000	2.4	1000	2.1	1000	1.9	1000	2.0
2000	3.8	2000	3.1	2000	2.8	2000	2.9
4000	5.8	4000	4.6	4000	4.2	4000	4.1
8000	11.1	8000	7.9	8000	6.8	6978	5.9
11232	21.2**(18.2)**[1]	12000	12.0	12000	9.7	12000	8.7
---	---	16000	23.5	16000	16.8	16000	13.5
---	---	16022	23.7 **(22.1)**[1]	16766	27.4 **(---)**[1]	18452	25.0 **(---)**[1]

1: Value in bold in parentheses is manual measurement. If dashes are present rut was too deep to measure.
Test Temperature: 64 C Tire Pressure: 862 kPa Wheel Load: 178.6 kg



a) Replicate 1 *b) Replicate 2*

Figure E.18 PURWheel Wet Test Results for Mixture *9.5-25/RM-1*

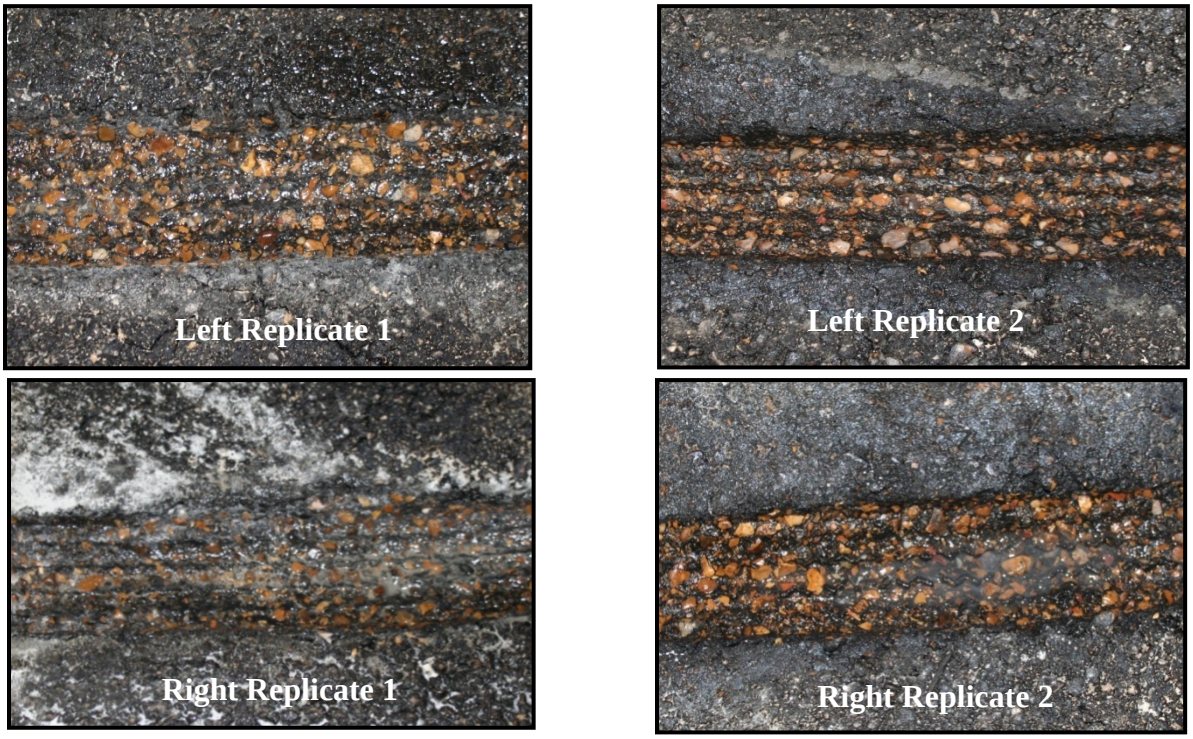
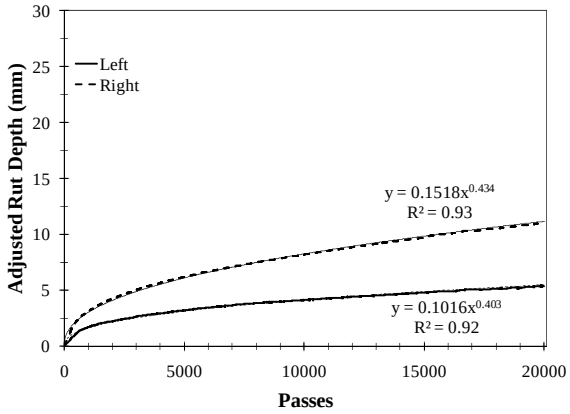


Table E.19 PURWheel Dry Test Results for Mixture *9.5-25/RM-2*

Replicate 1				Replicate 2 (Air Voids 10.4%)			
Left Specimen (mm)		Right Specimen (mm)		Left Specimen (mm)		Right Specimen (mm)	
Pass	Adj. Rut	Pass	Adj. Rut	Pass	Adj. Rut	Pass	Adj. Rut
---	---	---	---	250	0.6	250	1.3
---	---	---	---	500	1.2	500	2.2
---	---	---	---	1000	1.7	1000	3.2
---	---	---	---	2000	2.2	2000	4.3
---	---	---	---	4000	3.0	4000	5.7
---	---	---	---	8000	3.9	6978	7.5
---	---	---	---	12000	4.4	12000	8.9
---	---	---	---	16000	4.9	16000	10.1
---	---	---	---	20000	5.4 **(5.8)**[1]	20000	11.0 **(---)**[1]

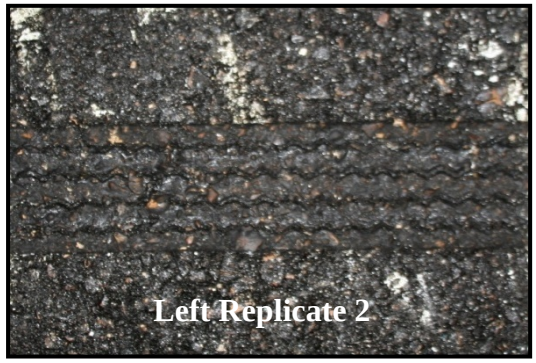
1: Value in bold in parentheses is manual measurement. If dashes are present rut was not measured.
Test Temperature: 64 C Tire Pressure: 862 kPa Wheel Load: 178.6 kg

Replicate 1 was found to be incorrect due to a laboratory batching error and was not re-made.



a) Replicate 1 *b) Replicate 2*

Figure E.19 PURWheel Wet Test Results for Mixture *9.5-25/RM-2*



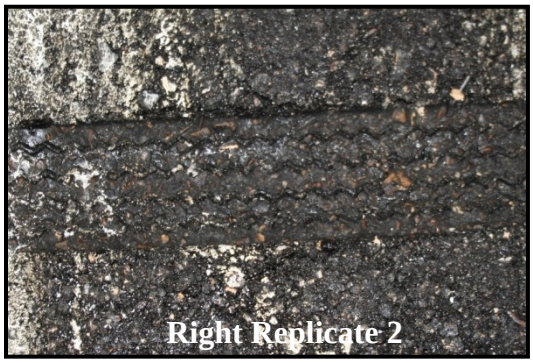
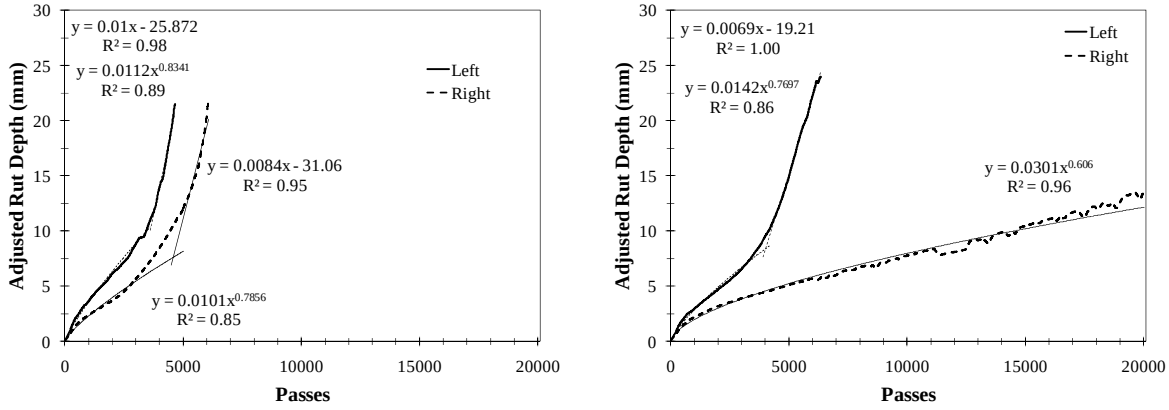


Table E.20 PURWheel Wet Test Results for Mixture *9.5-25/RM-2*

Replicate 1 (Air Voids 9.1%)				Replicate 2 (Air Voids 8.9%)			
Left Specimen (mm)		Right Specimen (mm)		Left Specimen (mm)		Right Specimen (mm)	
Pass	Adj. Rut	Pass	Adj. Rut	Pass	Adj. Rut	Pass	Adj. Rut
250	1.2	250	0.8	250	1.0	250	0.8
500	2.3	500	1.5	500	2.0	500	1.4
1000	3.7	1000	2.4	1000	2.9	1000	2.2
2000	6.1	2000	3.7	2000	4.7	2000	3.2
4000	14.0	4000	8.5	4000	9.5	4000	4.5
4660	21.5 **(20.8)**[1]	6066	22.0 **(---)**[1]	6342	24.0 **(---)**[1]	6978	6.7
---	---	---	---	---	---	12000	8.1
---	---	---	---	---	---	16000	11.1
---	---	---	---	---	---	20000	13.6 **(13.8)**[1]

1: Value in bold in parentheses is manual measurement. If dashes are present rut was too deep to measure.
Test Temperature: 64 C Tire Pressure: 862 kPa Wheel Load: 178.6 kg



a) Replicate 1 *b) Replicate 2*

Figure E.20 PURWheel Wet Test Results for Mixture *9.5-25/RM-2*

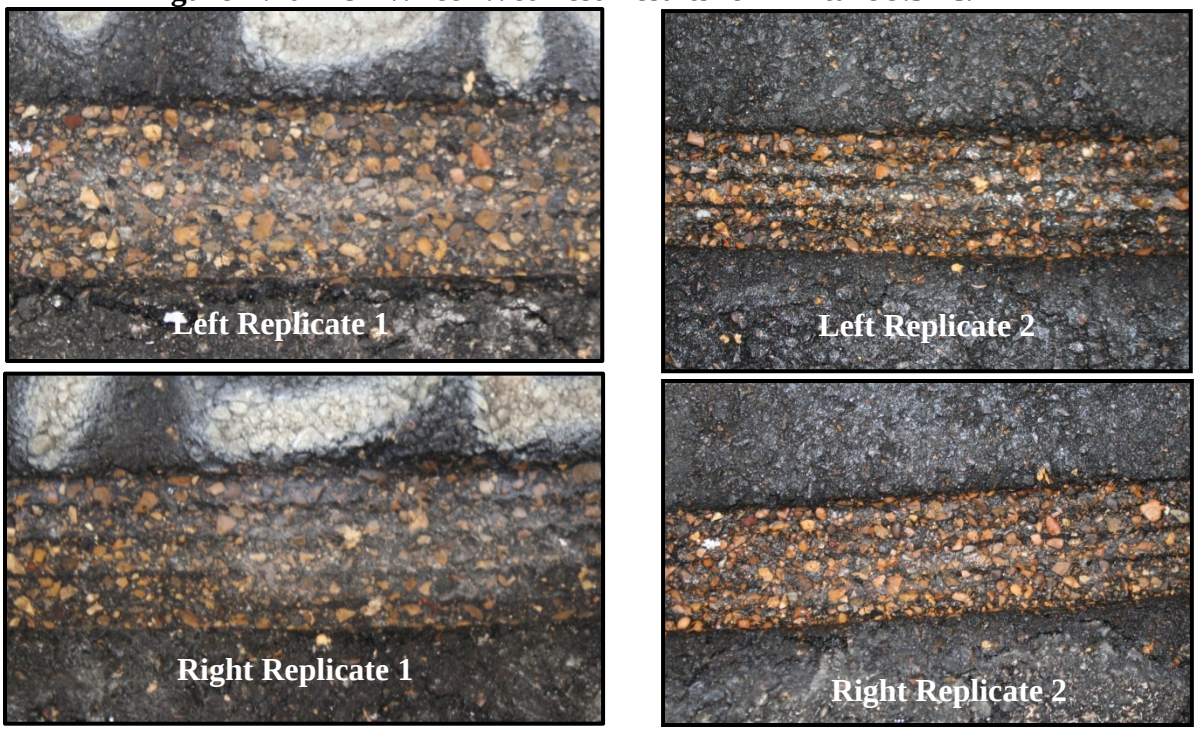
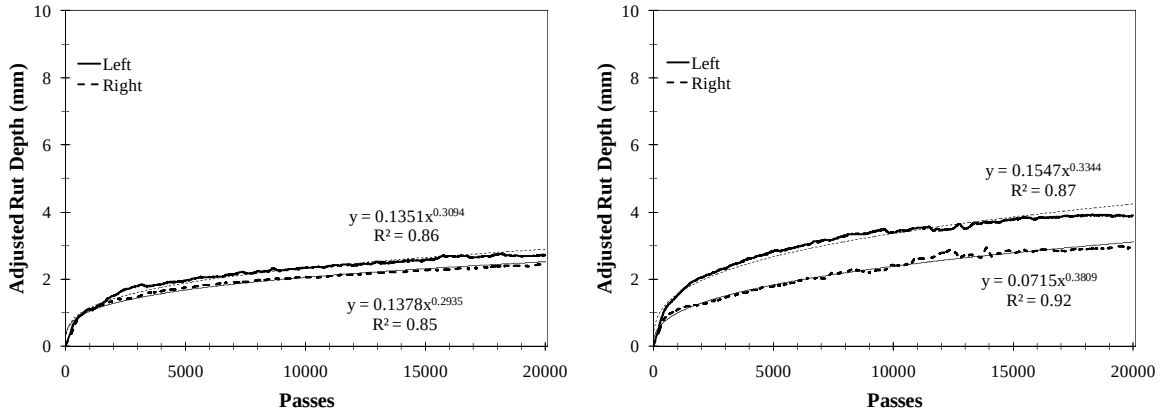


Table E.21 PURWheel Dry Test Results for Mixture *9.5-50/RM-1*

Replicate 1 (Air Voids 8.1%)				Replicate 2 (Air Voids 8.7%)			
Left Specimen (mm)		Right Specimen (mm)		Left Specimen (mm)		Right Specimen (mm)	
Pass	Adj. Rut	Pass	Adj. Rut	Pass	Adj. Rut	Pass	Adj. Rut
250	0.5	250	0.4	250	0.6	250	0.5
500	0.8	500	0.8	500	1.1	500	0.9
1000	1.1	1000	1.1	1000	1.5	1000	1.1
2000	1.5	2000	1.4	2000	2.1	2000	1.2
4000	1.9	4000	1.6	4000	2.6	4000	1.6
8000	2.2	8000	2.0	8000	3.3	6978	2.2
12000	2.4	12000	2.1	12000	3.5	12000	2.8
16000	2.7	16000	2.3	16000	3.8	16000	2.9
20000	2.7**(3.3)**[1]	20000	2.4 **(3.4)**[1]	20000	3.9 **(5.3)**[1]	20000	2.9 **(4.0)**[1]

1: Value in bold in parentheses is manual measurement. If dashes are present rut was too deep to measure.
Test Temperature: 64 C Tire Pressure: 862 kPa Wheel Load: 178.6 kg



a) Replicate 1 *b) Replicate 2*

Figure E.21 PURWheel Wet Test Results for Mixture *9.5-50/RM-1*

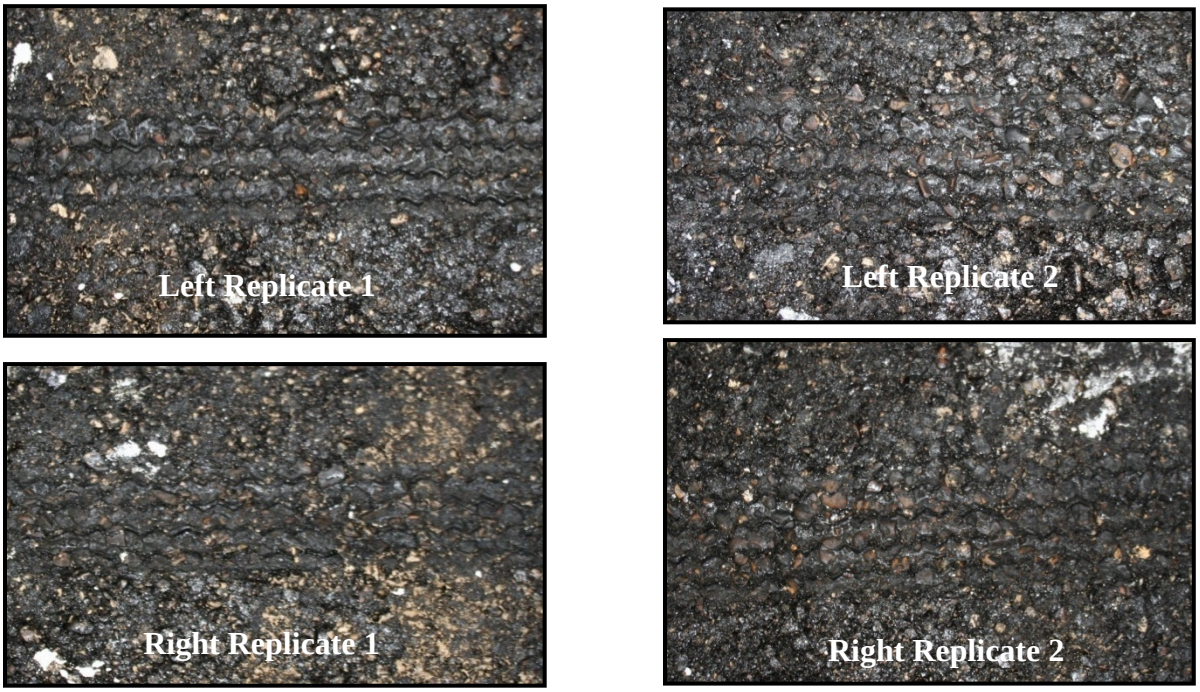
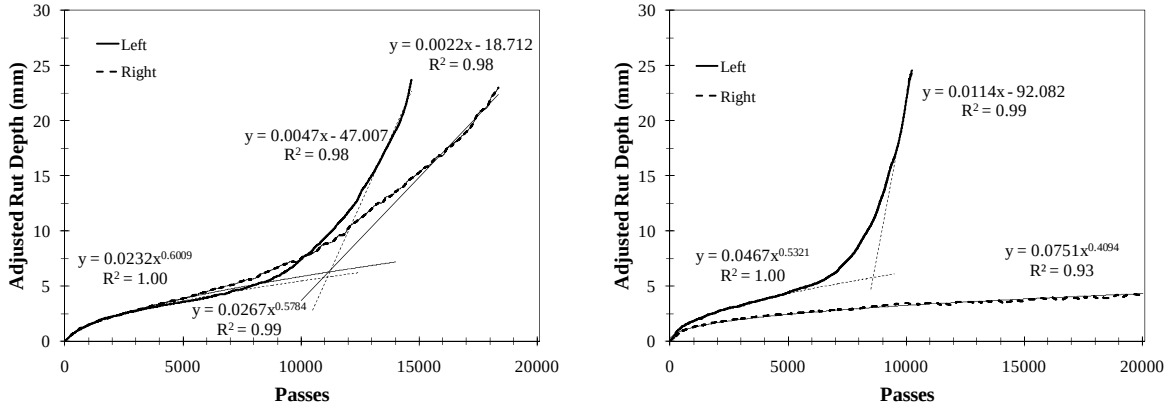


Table E.22 PURWheel Wet Test Results for Mixture *9.5-50/RM-1*

Replicate 1 (Air Voids 8.2%)				Replicate 2 (Air Voids 8.3%)			
Left Specimen (mm)		Right Specimen (mm)		Left Specimen (mm)		Right Specimen (mm)	
Pass	Adj. Rut	Pass	Adj. Rut	Pass	Adj. Rut	Pass	Adj. Rut
250	0.5	250	0.5	250	0.8	250	0.5
500	0.9	500	1.0	500	1.3	500	0.9
1000	1.5	1000	1.5	1000	1.9	1000	1.3
2000	2.3	2000	2.2	2000	2.7	2000	1.7
4000	3.2	4000	3.4	4000	3.8	4000	2.3
8000	5.1	8000	5.7	8000	8.7	6978	3.0
12000	11.7	12000	10.3	10238	24.6 **(---)**[1]	12000	3.4
14690	23.7**(---)**[1]	16000	16.8	---	---	16000	3.9
---	---	18360	23.0 **(20.2)**[1]	---	---	20000	4.3 **(4.8)**[1]

1: Value in bold in parentheses is manual measurement. If dashes are present rut was too deep to measure.
Test Temperature: 64 C Tire Pressure: 862 kPa Wheel Load: 178.6 kg



a) Replicate 1 *b) Replicate 2*

Figure E.22 PURWheel Wet Test Results for Mixture *9.5-50/RM-1*

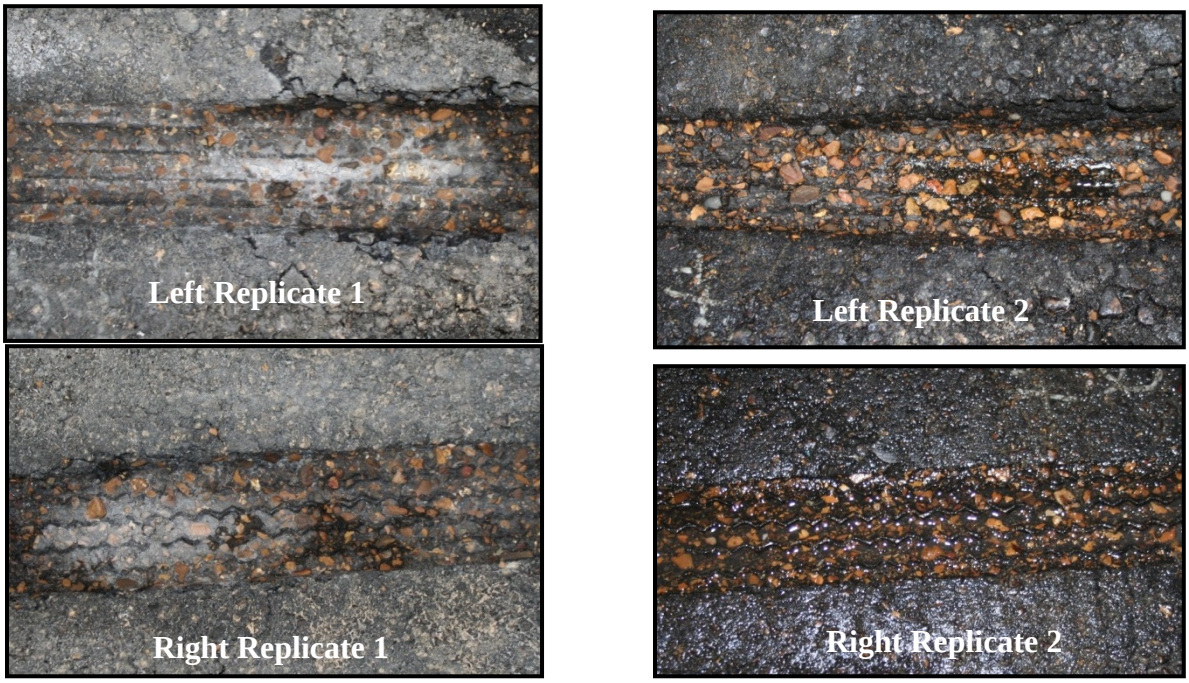
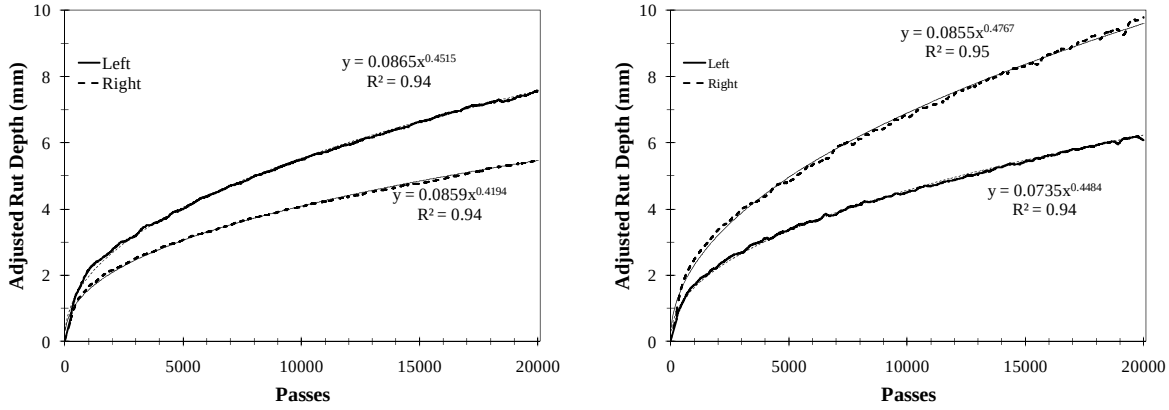


Table E.23 PURWheel Dry Test Results for Mixture *9.5-50/RM-2*

Replicate 1 (Air Voids 6.4%)				Replicate 2 (Air Voids 8.0%)			
Left Specimen (mm)		Right Specimen (mm)		Left Specimen (mm)		Right Specimen (mm)	
Pass	Adj. Rut	Pass	Adj. Rut	Pass	Adj. Rut	Pass	Adj. Rut
250	0.8	250	0.7	250	0.7	250	0.9
500	1.5	500	1.2	500	1.2	500	1.7
1000	2.2	1000	1.6	1000	1.7	1000	2.5
2000	2.8	2000	2.1	2000	2.3	2000	3.4
4000	3.6	4000	2.8	4000	3.1	4000	4.4
8000	5.0	8000	3.7	8000	4.1	6978	6.1
12000	6.0	12000	4.4	12000	4.9	12000	7.5
16000	6.8	16000	4.9	16000	5.6	16000	8.7
20000	7.6 **(9.1)**[1]	20000	5.5 **(6.3)**[1]	20000	6.1 **(7.5)**[1]	20000	9.8 **(10.1)**[1]

1: Value in bold in parentheses is manual measurement. If dashes are present rut was too deep to measure.
Test Temperature: 64 C Tire Pressure: 862 kPa Wheel Load: 178.6 kg



a) Replicate 1 *b) Replicate 2*

Figure E.23 PURWheel Wet Test Results for Mixture *9.5-50/RM-2*

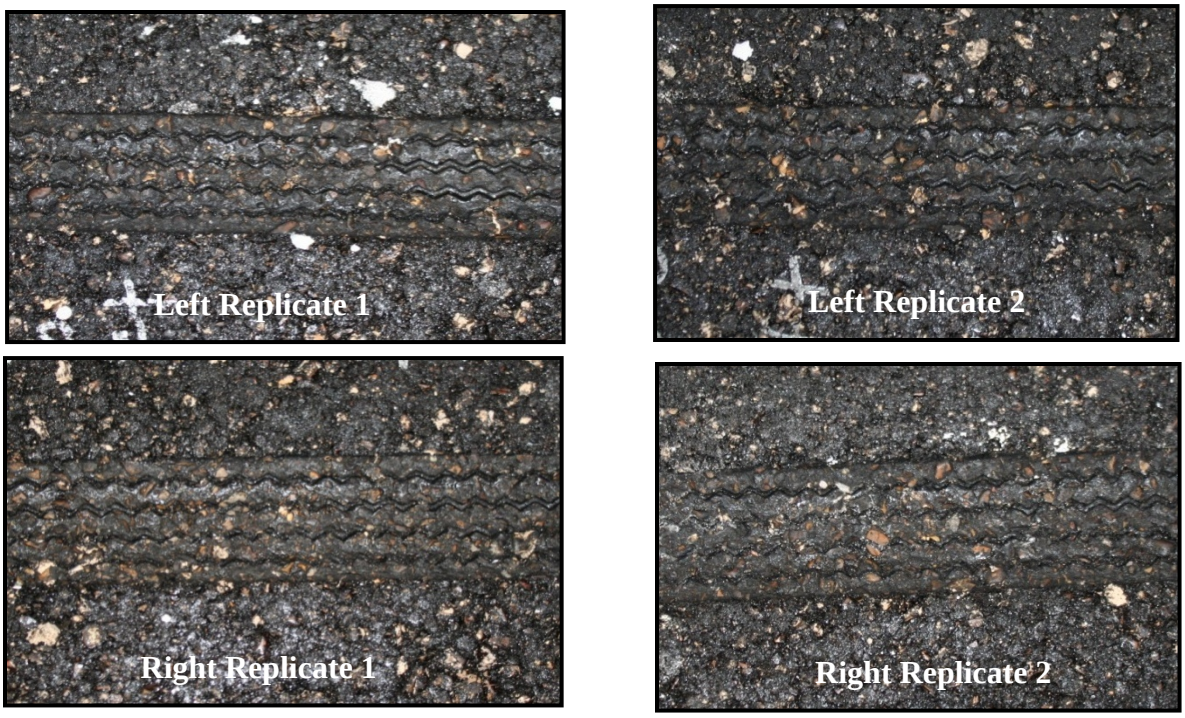
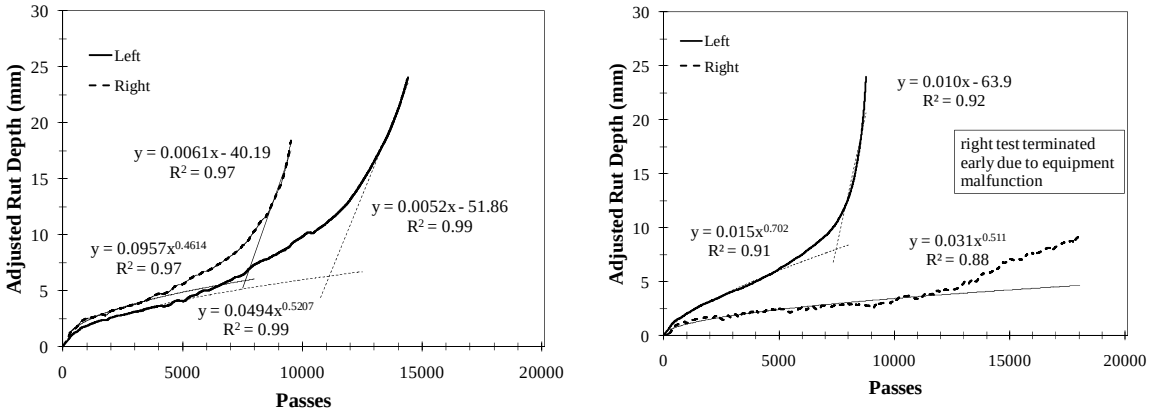


Table E.24 PURWheel Wet Test Results for Mixture *9.5-50/RM-2*

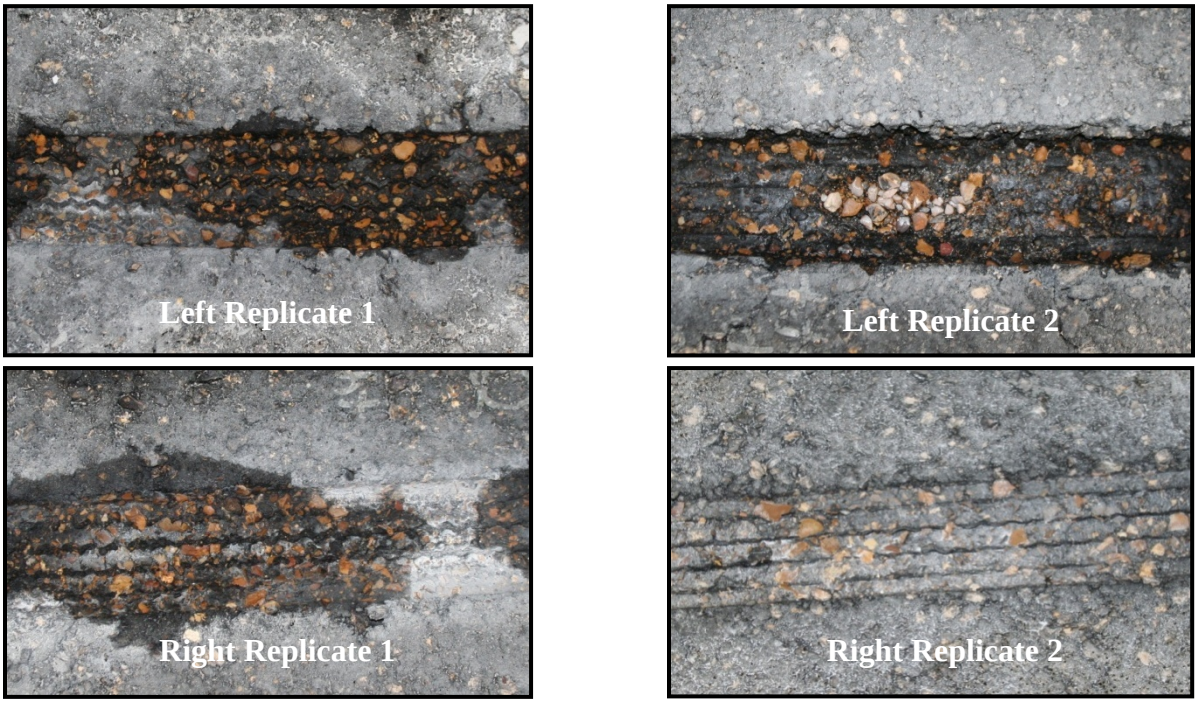
Replicate 1 (Air Voids 6.7%)				Replicate 2 (Air Voids 7.6%)			
Left Specimen (mm)		Right Specimen (mm)		Left Specimen (mm)		Right Specimen (mm)	
Pass	Adj. Rut	Pass	Adj. Rut	Pass	Adj. Rut	Pass	Adj. Rut
250	0.7	250	1.0	250	0.7	250	0.2
500	1.3	500	1.6	500	1.4	500	0.9
1000	1.9	1000	2.5	1000	2.0	1000	1.2
2000	2.6	2000	3.2	2000	3.1	2000	1.6
4000	3.6	4000	4.7	4000	5.0	4000	2.3
8000	7.3	8000	10.3	8000	12.7	6978	2.9
12000	13.1	9526	18.4 **(---)**[1]	8774	24.0 **(---)**[1]	12000	4.0
14406	24.1**(22.4)**[1]	---	---	---	---	16000	7.6
---	---	---	---	---	---	18012	9.2 **(10.7)**[1]

1: Value in bold in parentheses is manual measurement. If dashes are present rut was too deep to measure.
Test Temperature: 64 C Tire Pressure: 862 kPa Wheel Load: 178.6 kg



a) Replicate 1 *b) Replicate 2*

Figure E.24 PURWheel Wet Test Results for Mixture *9.5-50/RM-2*



APPENDIX F – *TSR* DATA

Table F.1 *TSR* Test Results for Mixture *9.5-0/CM-1*

			Initial		Agg. Visual Assessment	
Type	**Rep**	**V_a (%)**	**Saturation (%)**	**S_t (kPa)**	**Stripped (%)**	**Broken (%)**
Conditioned	1	7.7	64.8	1084.3	---	---
	2	7.4	65.5	1037.2	---	---
	3	7.5	55.9	1210.5	---	---
	Avg	**7.5**	**62.0**	**1110.6**	**23**	**6**
Unconditioned	1	7.6	---	1172.3	---	---
	2	7.6	---	1221.0	---	---
	3	7.6	---	1229.1	---	---
	Avg	**7.6**	---	**1207.5**	---	**5**
			***TSR* (%)**	**92.0**		

Note: Test was performed according to *ASTM D 4867*.
Visual assessment was performed by three examiners and averaged.

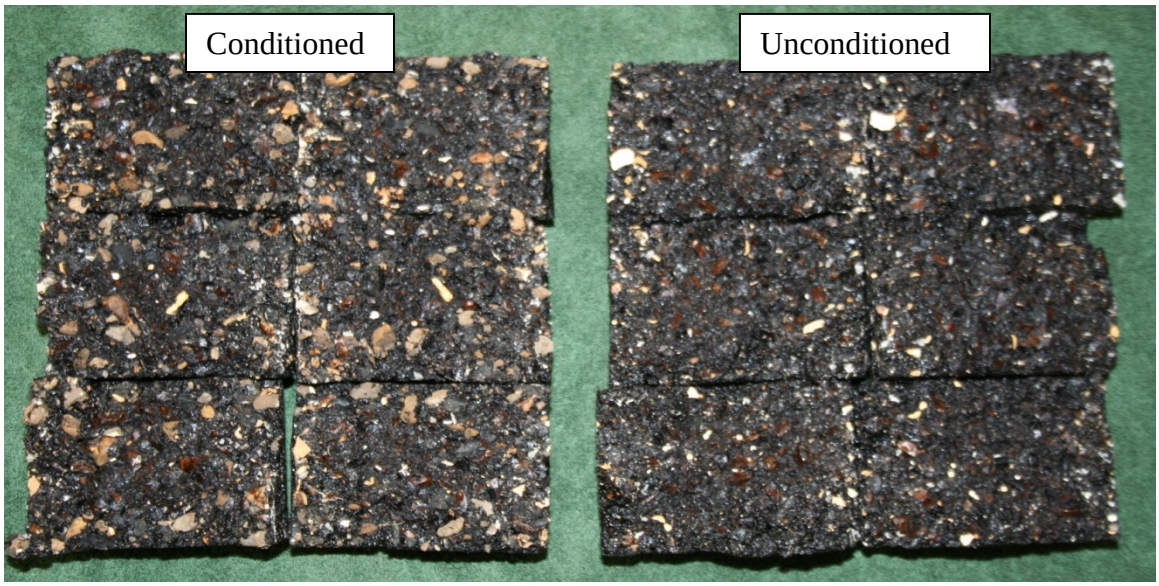


Figure F.1 Tested *TSR* Specimens for Mixture *9.5-0/CM-1*

Table F.2 *TSR* Test Results for Mixture *9.5-25/RM-1*

			Initial		Agg. Visual Assessment	
Type	**Rep**	**V_a (%)**	**Saturation (%)**	**S_t (kPa)**	**Stripped (%)**	**Broken (%)**
Conditioned	1	7.8	59.3	1206.7	---	---
	2	7.3	57.2	1478.1	---	---
	3	7.3	59.0	1536.5	---	---
	Avg	**7.5**	**58.5**	**1407.1**	**12**	**10**
Unconditioned	1	7.1	---	1476.4	---	---
	2	7.8	---	1368.7	---	---
	3	7.4	---	1495.6	---	---
	Avg	**7.4**	---	**1446.9**	---	**7**
			***TSR* (%)**	**97.2**		

Note: Test was performed according to *ASTM D 4867*.
Visual assessment was performed by three examiners and averaged.

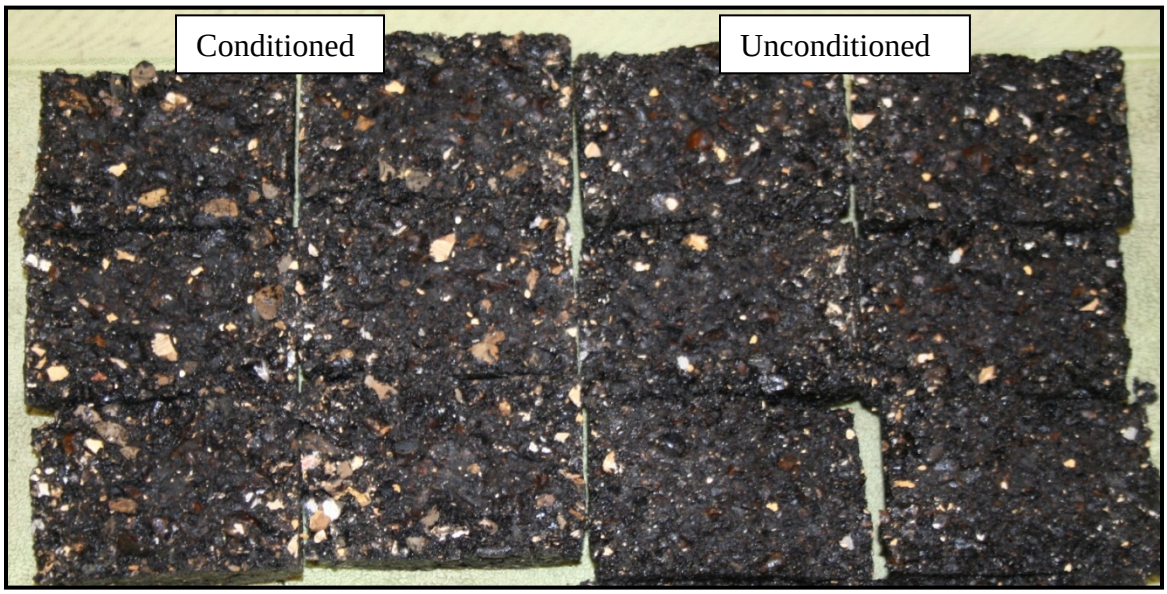


Figure F.2 Tested *TSR* Specimens for Mixture *9.5-25/RM-1*

Table F.3 *TSR* Test Results for Mixture *9.5-25/RM-2*

			Initial		Agg. Visual Assessment	
Type	**Rep**	**V_a (%)**	**Saturation (%)**	**S_t (kPa)**	**Stripped (%)**	**Broken (%)**
Conditioned	1	8.0	64.8	1439.1	---	---
	2	8.0	63.7	1582.6	---	---
	3	7.6	63.0	1690.6	---	---
	Avg	**7.9**	**63.8**	**1570.8**	**15**	**12**
Unconditioned	1	7.9	---	1554.9	---	---
	2	7.9	---	1656.9	---	---
	3	7.5	---	1629.6	---	---
	Avg	**7.8**	---	**1613.8**	---	**7**
			***TSR* (%)**	**97.3**		

Note: Test was performed according to *ASTM D 4867*.
Visual assessment was performed by three examiners and averaged.

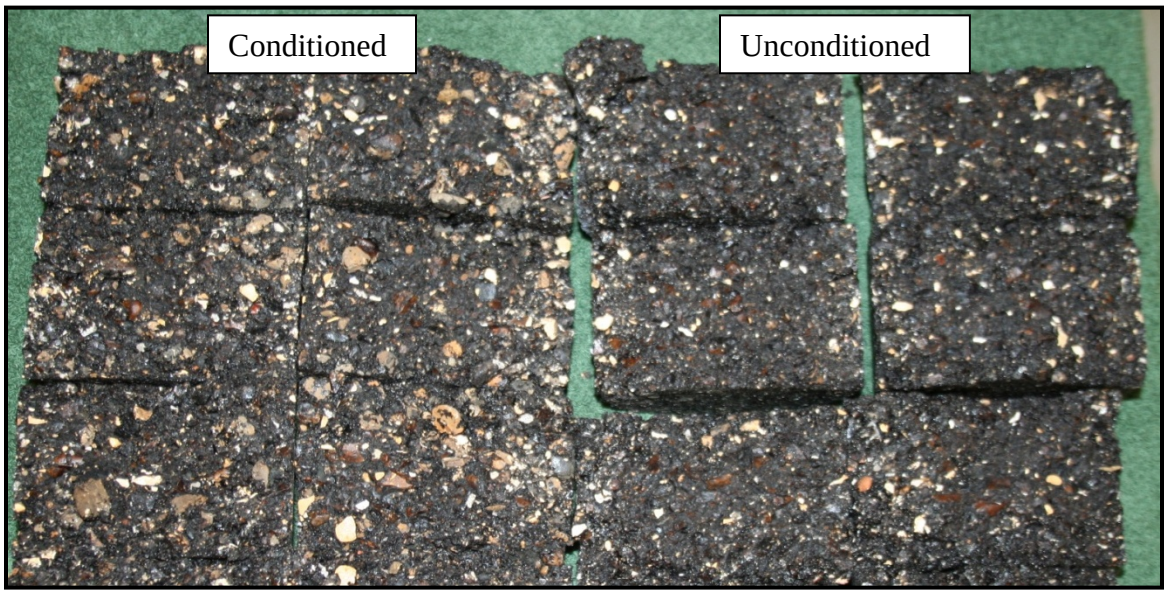


Figure F.3 Tested *TSR* Specimens for Mixture *9.5-25/RM-2*

Table F.4 *TSR* Test Results for Mixture *9.5-50/RM-1*

Type	Rep	V_a (%)	Initial Saturation (%)	S_t (kPa)	Agg. Visual Assessment Stripped (%)	Agg. Visual Assessment Broken (%)
Conditioned	1	7.2	66.3	2078.3	---	---
	2	7.2	61.1	1823.9	---	---
	3	7.3	63.9	2257.8	---	---
	Avg	**7.3**	**63.8**	**2053.3**	**13**	**15**
Unconditioned	1	7.1	---	2108.7	---	---
	2	7.1	---	2244.6	---	---
	3	7.4	---	1919.5	---	---
	Avg	**7.2**	---	**2090.9**	---	**12**
			***TSR* (%)**	**98.2**		

Note: Test was performed according to *ASTM D 4867*.
Visual assessment was performed by three examiners and averaged.

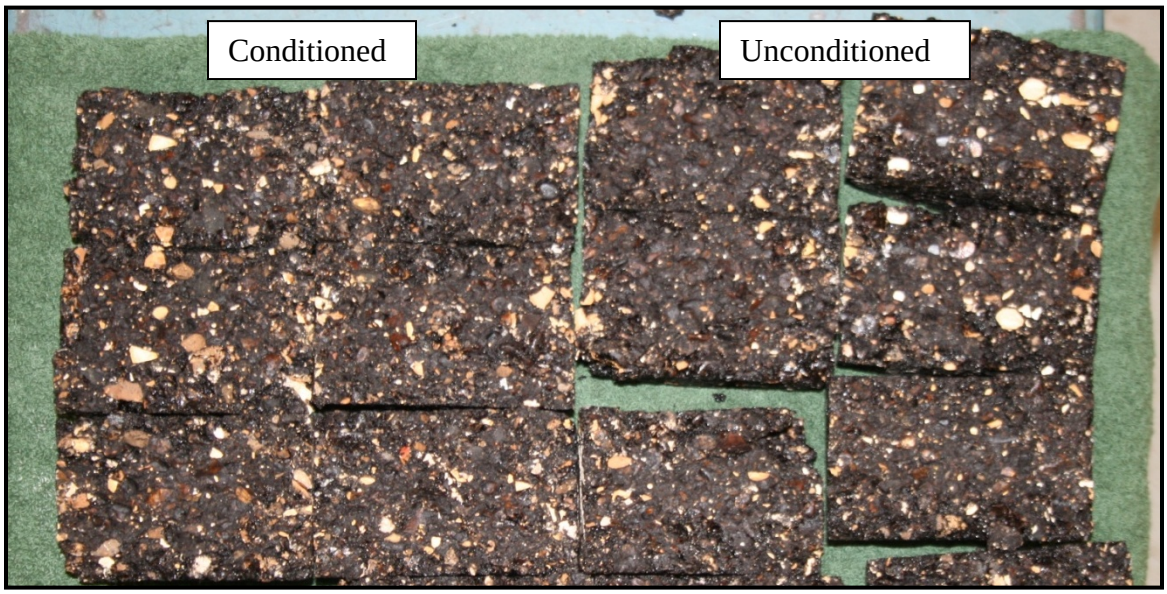


Figure F.4 Tested *TSR* Specimens for Mixture *9.5-50/RM-1*

Table F.5 *TSR* Test Results for Mixture *9.5-50/RM-2*

			Initial		Agg. Visual Assessment	
Type	**Rep**	**V_a (%)**	**Saturation (%)**	**S_t (kPa)**	**Stripped (%)**	**Broken (%)**
Conditioned	1	8.0	61.8	1833.9	---	---
	2	8.0	63.4	1702.2	---	---
	3	7.9	60.6	1858.2	---	---
	Avg	**8.0**	**61.9**	**1798.1**	**20**	**10**
Unconditioned	1	8.1	---	1928.1	---	---
	2	8.0	---	1895.4	---	---
	3	7.7	---	2001.7	---	---
	Avg	**8.0**	---	**1941.7**	---	**8**
			***TSR* (%)**	**92.6**		

Note: Test was performed according to *ASTM D 4867*.
Visual assessment was performed by three examiners and averaged.

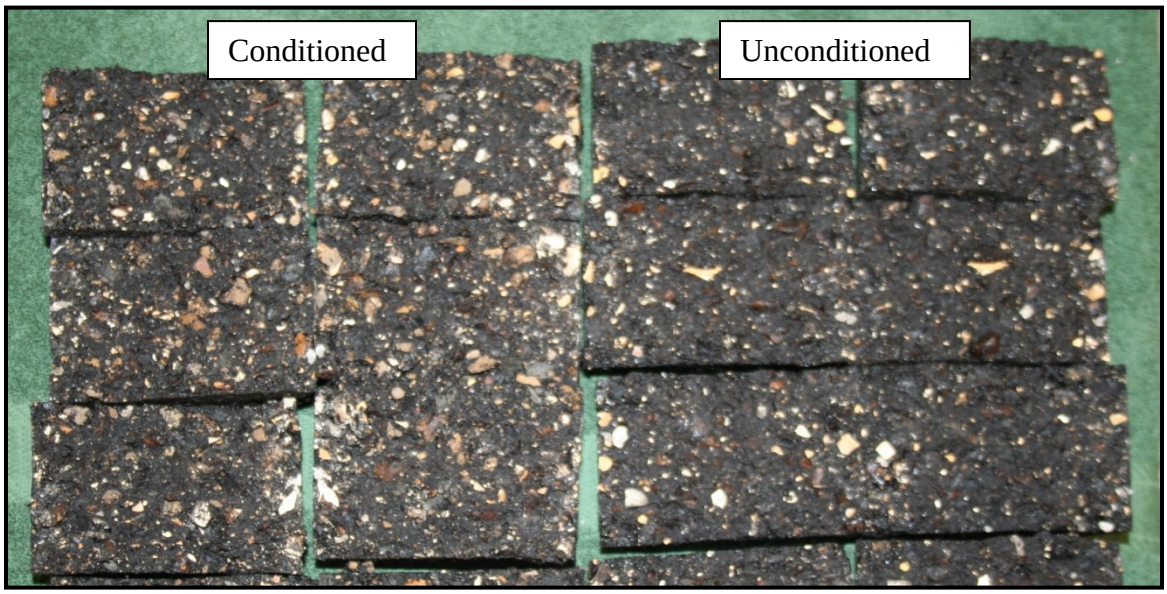


Figure F.5 Tested *TSR* Specimens for Mixture *9.5-50/RM-2*

Table F.6 *TSR* Test Results for Mixture *9.5-100/RM-1*

Type	Rep	V_a (%)	Initial Saturation (%)	S_t (kPa)	Agg. Visual Assessment Stripped (%)	Agg. Visual Assessment Broken (%)
Conditioned	1	6.7	63.8	1750.0	---	---
	2	6.4	69.0	2088.9	---	---
	3	6.3	71.4	2183.7	---	---
	Avg	**6.4**	**68.1**	**2007.5**	**8**	**12**
Unconditioned	1	6.9	---	2443.3	---	---
	2	6.2	---	1954.7	---	---
	3	6.3	---	2290.1	---	---
	Avg	**6.5**	---	**2229.4**	---	**13**
			***TSR* (%)**	**90.0**		

Note: Test was performed according to *ASTM D 4867*.
Visual assessment was performed by three examiners and averaged.

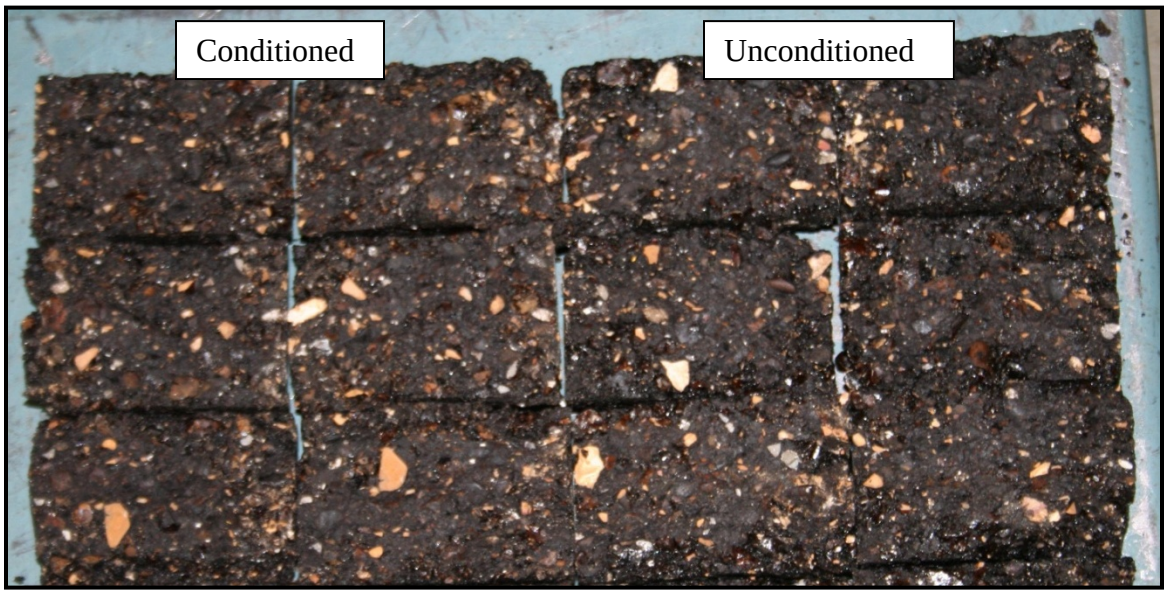


Figure F.6 Tested *TSR* Specimens for Mixture *9.5-100/RM-1*

Table F.7 *TSR* Test Results for Mixture *9.5-100/RM-2*

Type	Rep	V_a (%)	Initial Saturation (%)	S_t (kPa)	Agg. Visual Assessment Stripped (%)	Agg. Visual Assessment Broken (%)
Conditioned	1	8.4	64.6	1569.2	---	---
	2	8.4	59.8	1845.1	---	---
	3	8.5	61.5	1625.0	---	---
	Avg	**8.4**	**62.0**	**1679.8**	**20**	**7**
Unconditioned	1	8.4	---	2296.4	---	---
	2	8.4	---	2822.7	---	---
	3	8.4	---	2690.0	---	---
	Avg	**8.4**	---	**2603.0**	---	**8**
			***TSR* (%)**	**64.5**		

Note: Test was performed according to *ASTM D 4867*. The specification indicates air voids should be 6 to 8%, with the range given as whole numbers. The values shown are slightly out of the test specification when rounded to one decimal place, but conform when rounded to zero decimal places. The values are slightly high, but the test was not re-conducted.

Note: Visual assessment was performed by three examiners and averaged.

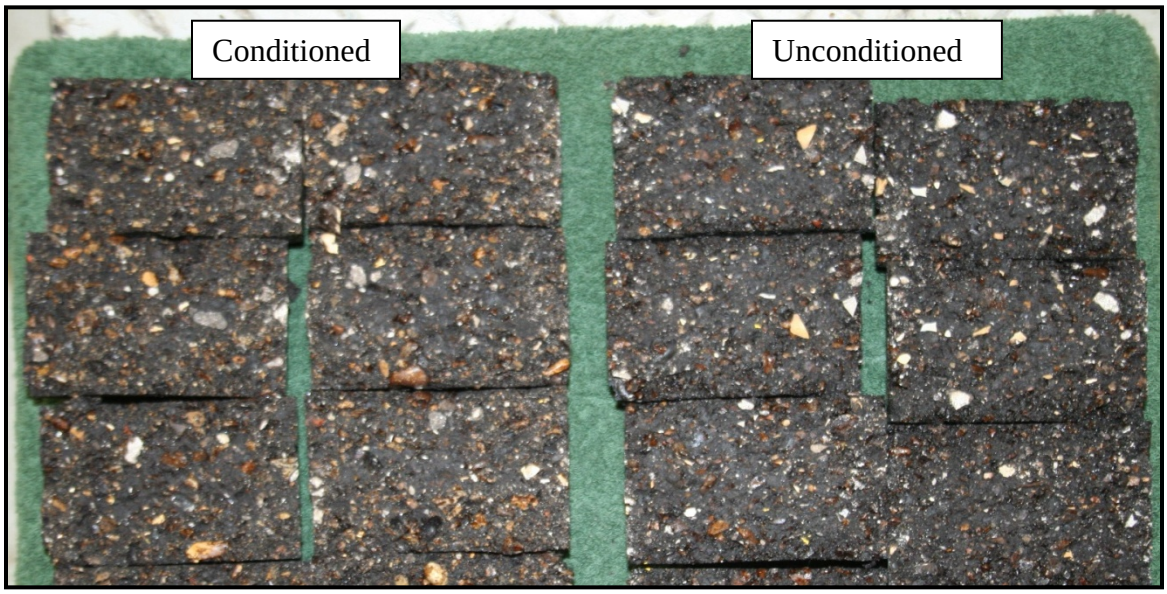


Figure F.7 Tested *TSR* Specimens for Mixture *9.5-100/RM-2*

Table F.8 *TSR* Test Results for Mixture 12.*5-100/RM-3*

Type	Rep	V_a (%)	Initial Saturation (%)	S_t (kPa)	Agg. Visual Assessment Stripped (%)	Agg. Visual Assessment Broken (%)
Conditioned	1	7.3	57.8	1522.1	---	---
	2	7.8	63.3	1248.2	---	---
	3	7.0	63.3	1380.1	---	---
	Avg	**7.4**	**61.5**	**1383.5**	**23**	**8**
Unconditioned	1	7.9	---	1803.4	---	---
	2	7.5	---	2060.4	---	---
	3	7.2	---	2014.1	---	---
	Avg	**7.5**	---	**1959.3**	---	**8**
			***TSR* (%)**	**70.6**		

Note: Test was performed according to *ASTM D 4867*.
Visual assessment was performed by three examiners and averaged.

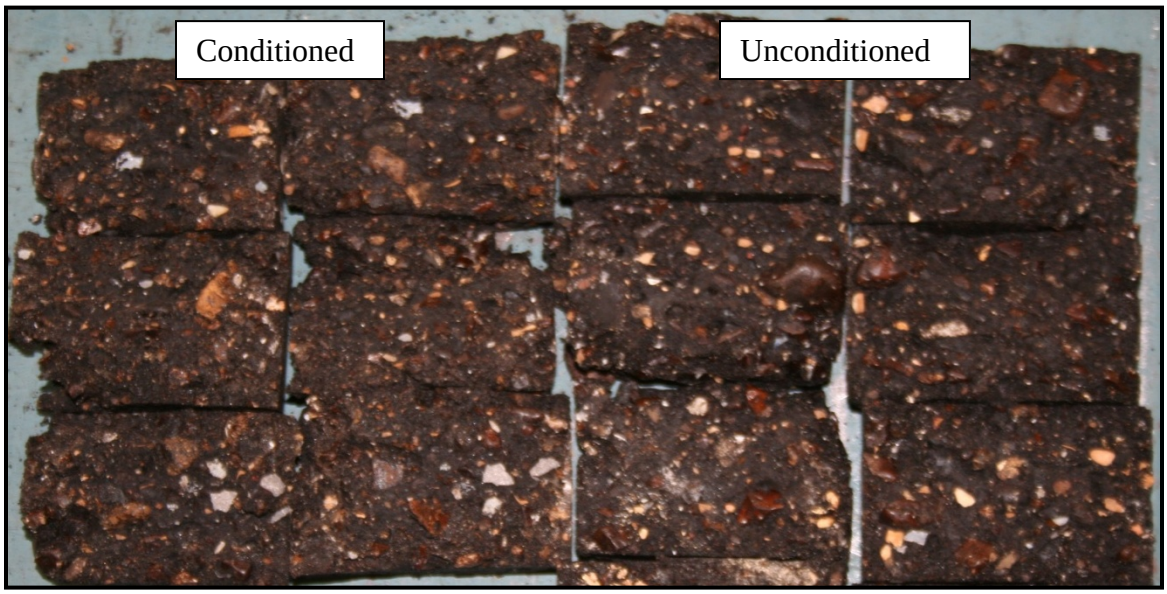


Figure F.8 Tested *TSR* Specimens for Mixture 12.*5-100/RM-3*

APPENDIX G – *MRTCR* DATA

Table G.1 *MRTCR* Data for *9.5-0/CM-1* Control Mixture

Stress (kPa)	*SGC* Specimen Replicate	V_a (%)	Test Specimen Replicate	$\varepsilon(5\%)_T$	$(\Delta\varepsilon/\Delta T)^{-1}$	*FN*	F_ε
68	1	4.2	**1**	1190	462	338	10.1
			2	930	298	226	9.91
			3*	1600	387	155	4.87
			Avg.	**1060**	**383**	**240**	**8.29**
			Std. Dev.	**184**	**116**	**79.2**	**0.13**
			COV	**17.4**	**30.3**	**33.0**	**1.6**
	2	3.8	**1**	680	235	180	10.2
			2	710	297	239	11.0
			3	1160	374	305	10.2
			Avg.	**850**	**302**	**241**	**10.5**
			Std. Dev.	**269**	**69.7**	**62.5**	**0.48**
			COV	**31.6**	**23.1**	**25.9**	**4.5**
	3	4.3	**1**	720	221	161	9.34
			2	680	210	144	8.89
			3	920	247	184	8.90
			Avg.	**773**	**226**	**163**	**9.04**
			Std. Dev.	**129**	**19.1**	**20.1**	**0.25**
			COV	**16.7**	**8.5**	**12.3**	**2.8**
	Avg.	**4.1**	**---**	**954**	**304**	**215**	**9.27**
	Std. Dev.	**---**	**---**	**313**	**87.2**	**68.6**	**1.79**
	COV	**---**	**---**	**32.8**	**28.7**	**31.9**	**19.3**
136	1	4.2	**1**	460	145	102	9.20
			2	210	65.8	48	9.64
			3	280	84.9	64	9.45
			Avg.	**317**	**98.6**	**71.3**	**9.43**
			Std. Dev.	**129**	**41.5**	**27.7**	**0.22**
			COV	**40.7**	**42.1**	**38.8**	**2.4**
	2	3.8	**1**	200	60.7	57	11.5
			2	230	62.7	38	7.56
			3	310	91.0	76	10.1
			Avg.	**247**	**71.5**	**57.0**	**9.72**
			Std. Dev.	**57**	**16.9**	**19.0**	**1.98**
			COV	**23.1**	**23.6**	**33.3**	**20.4**
	3	4.3	**1**	190	52.3	37	8.57
			2	300	73.9	36	6.01
			3	440	102	56	6.34
			Avg.	**310**	**76**	**43.0**	**6.97**
			Std. Dev.	**125**	**24.8**	**11.3**	**1.39**
			COV	**40.3**	**32.6**	**26.3**	**19.9**
	Avg.	**4.1**	**---**	**291**	**82**	**57.1**	**8.71**
	Std. Dev.	**---**	**---**	**100**	**28.6**	**21.6**	**1.79**
	COV	**---**	**---**	**34.4**	**34.9**	**37.8**	**20.6**

* Outlier that was omitted from analysis

Table G.2 *MRTCR* Data for *R-1* RAP Compacted at 116 C with 50 Gyrations

Stress (kPa)	Additives	P_{AC}	V_a (%)	Rep	$\varepsilon(5\%)_T$	$(\Delta\varepsilon/\Delta T)^{-1}$	FN	F_ε
272	None	High	2.5	**1**	140	33.3	15	5.47
				2	320	97.2	51	7.15
				3	150	36.1	14	4.79
				Avg.	**203**	**55.5**	**26.7**	**5.80**
				Std. Dev.	**101**	**36.1**	**21.1**	**1.21**
	Sasobit®	High	2.4	**1**	240	131	116	12.8
				2	160	68.6	49	10.5
				3	550	195	114	8.23
				4	160	75.5	80	14.3
				5	110	55.2	52	13.4
				6	260	90.0	55	8.47
				7	160	115	131	16.5
				8	170	74.4	66	12.3
				9	260	94.7	81	11.5
				Avg.	**230**	**100**	**82.7**	**12.0**
				Std. Dev.	**131**	**42.8**	**30.7**	**2.69**
	Evotherm 3G™	High	2.1	**1**	220	82.2	61	10.2
				2	290	134	121	12.7
				3	280	157	157	14.3
				4	250	200	246	17.7
				5	210	94.8	77	11.8
				6	320	201	248	16.9
				7	250	71.0	52	9.06
				8	390	190	126	10.3
				9	530	350	296	12.8
				Avg.	**304**	**164**	**154**	**12.9**
				Std. Dev.	**101**	**86.0**	**89.7**	**2.98**

Table G.3 *MRTCR* Data for *R-1* RAP Compacted at 116 C with 65 Gyrations

Stress (kPa)	Additives	P_{AC}	V_a (%)	Rep	$\varepsilon(5\%)_T$	$(\Delta\varepsilon/\Delta T)^{-1}$	FN	F_ε
272	None	High	1.6	**1**	280	162	106	10.6
				2	250	109	97	11.8
				3	230	75.2	49	8.70
				Avg.	**253**	**115**	**84.0**	**10.4**
				Std. Dev.	**25.2**	**44.0**	**30.6**	**1.54**
	Sasobit®	High	1.7	**1**	450	363	425	18.2
				2	310	191	198	15.4
				3	470	348	432	17.9
				4	150	110	106	15.0
				5	500	242	268	14.8
				6	270	128	140	14.9
				7	410	215	279	17.0
				8	70.0	72.4	79.0	17.9
				9	230	52.3	79.0	12.7
				Avg.	**318**	**191**	**223**	**16.0**
				Std. Dev.	**151**	**113**	**138**	**1.86**
	Evotherm 3G™	High	1.9	**1**	130	37.5	29	9.64
				2	230	99.3	99	13.0
				3	270	108	88	11.1
				Avg.	**210**	**81.6**	**72.0**	**11.3**
				Std. Dev.	**72.1**	**38.4**	**37.6**	**1.70**

Table G.4 *MRTCR* Data for *R-1* RAP Compacted at 116 C with 85 Gyrations

Stress (kPa)	Additives	P_{AC}	V_a (%)	Rep	$\varepsilon(5\%)_T$	$(\Delta\varepsilon/\Delta T)^{-1}$	FN	F_ε
272	None	High	1.2	**1**	240	126	135	15.5
				2	220	193	232	18.2
				3	250	106	75	10.0
				Avg.	**237**	**142**	**147**	**14.6**
				Std. Dev.	**15.3**	**45.4**	**79.2**	**4.18**
	Sasobit®	High	1.2	**1**	330	110	83	9.88
				2	290	157	128	11.9
				3	190	54.2	63	12.9
				Avg.	**270**	**107**	**91.3**	**11.6**
				Std. Dev.	**72.1**	**51.6**	**33.3**	**1.56**
	Evotherm 3G™	High	1.3	**1**	340	426	511	19.4
				2	260	131	120	12.6
				3	180	67.6	41	8.64
				4	140	81.2	91	15.7
				5	140	143	174	19.2
				6	140	93.0	130	19.1
				7	230	247	272	18.3
				8	230	125	86	10.7
				9	500	205	142	10.1
				Avg.	**240**	**169**	**174**	**14.8**
				Std. Dev.	**118**	**112**	**142**	**4.38**

Table G.5 *MRTCR* Data for *R-1* RAP Compacted at 138 C with 50 Gyrations

Stress (kPa)	Additives	P_{AC}	V_a (%)	Rep	$\varepsilon(5\%)_T$	$(\Delta\varepsilon/\Delta T)^{-1}$	FN	F_ε
272	None	High	1.0	**1**	90	181	113	14.3
				2	180	129	154	17.3
				3	140	121	161	20.2
				4	430	485	817	24.1
				5	290	147	113	11.4
				6	200	115	125	15.5
				7	710	377	369	13.6
				8	150	205	249	19.2
				9	360	272	254	14.8
				Avg.	**283**	**226**	**262**	**16.7**
				Std. Dev.	**195**	**129**	**225**	**3.89**
	Sasobit®	High	1.2	**1**	820	1134	990	15.3
				2	1350	88.9	990	15.9
				3	1220	995	990	13.8
				Avg.	**1130**	**740**	**990**	**15.0**
				Std. Dev.	**276**	**568**	**0**	**1.06**
	Evotherm 3G™	High	0.7	**1**	370	394	507	19.3
				2	1040	1013	990	15.2
				3	500	353	484	19.3
				4	280	123	107	11.6
				5	550	296	339	16.1
				6	660	246	131	7.82
				7	160	284	368	20.5
				8	330	188	178	13.7
				9	690	674	956	20.6
				Avg.	**509**	**397**	**451**	**16.1**
				Std. Dev.	**266**	**279**	**329**	**4.40**

Table G.6 *MRTCR* Data for *R-1* RAP Compacted at 138 C with 65 Gyrations

Stress (kPa)	Additives	P_{AC}	V_a (%)	Rep	$\varepsilon(5\%)_T$	$(\Delta\varepsilon/\Delta T)^{-1}$	*FN*	F_ε
272	None	High	1.0	**1**	230	145	213	19.0
				2	520	247	322	15.7
				3	560	298	266	13.1
				Avg.	**437**	**230**	**267**	**15.9**
				Std. Dev.	**180**	**77.7**	**54.5**	**2.95**
	Sasobit®	High	0.6	**1**	480	2645	295	16.1
				2	390	138	155	13.6
				3	380	143	175	14.8
				Avg.	**417**	**182**	**208**	**14.8**
				Std. Dev.	**55.1**	**72.0**	**75.7**	**1.26**
	Evotherm 3G™	High	0.7	**1**	650	459	496	15.7
				2	240	162	183	16.6
				3	410	170	132	10.9
				Avg.	**433**	**264**	**270**	**14.4**
				Std. Dev.	**206**	**169**	**197**	**3.07**

Table G.7 *MRTCR* Data for *R-1* RAP Compacted at 138 C with 85 Gyrations

Stress (kPa)	Additives	P_{AC}	V_a (%)	Rep	$\varepsilon(5\%)_T$	$(\Delta\varepsilon/\Delta T)^{-1}$	*FN*	F_ε
272	None	High	0.6	**1**	410	355	506	19.4
				2	1220	728	753	14.3
				3	290	149	160	14.4
				Avg.	**640**	**410**	**473**	**16.0**
				Std. Dev.	**506**	**293**	**298**	**2.87**
	Sasobit®	High	0.3	**1**	800	488	452	14.0
				2	410	294	441	19.3
				3	720	369	384	13.9
				Avg.	**643**	**384**	**426**	**15.7**
				Std. Dev.	**206**	**98.2**	**36.5**	**3.12**
	Evotherm 3G™	High	0.5	**1**	680	319	325	13.5
				2	490	239	217	12.8
				3	340	251	279	16.2
				Avg.	**503**	**270**	**274**	**14.2**
				Std. Dev.	**170**	**43.2**	**54.2**	**1.81**

Table G.8 *MRTCR* Data for *R-2* RAP Compacted at 138 C with 65 Gyrations

Stress (kPa)	Additives	P_{AC}	V_a (%)	Rep	$\varepsilon(5\%)_T$	$(\Delta\varepsilon/\Delta T)^{-1}$	*FN*	F_ε
272	None	High	1.6	**1**	30	71.5	82	23.9
				2	30	39.6	65	26.8
				3	40	94.8	155	28.8
				Avg.	**33**	**68.6**	**101**	**26.5**
				Std. Dev.	**5.8**	**27.7**	**47.8**	**2.46**
	Sasobit®	High	1.9	**1**	30	88.5	179	33.4
				2	30	72.4	152	34.9
				3	30	45.8	62	23.5
				Avg.	**30**	**68.9**	**131**	**30.6**
				Std. Dev.	**0**	**21.6**	**61.3**	**6.17**
	Evotherm 3G™	High	1.6	**1**	30	58.9	115	31.3
				2	30	71.4	151	34.1
				3	40	108	208	32.7
				Avg.	**33**	**79.4**	**158**	**32.7**
				Std. Dev.	**5.8**	**25.5**	**46.9**	**1.38**
544	None	Med	2.3	**1**	40	26.8	42	23.3
				2	40	24.1	29	17.7
				3	70	39.2	41	14.8
				Avg.	**50.0**	**30.0**	**37.3**	**18.6**
				Std. Dev.	**17.3**	**8.05**	**7.23**	**4.28**
	Sasobit®	Med	2.2	**1**	40	40.7	61	23.2
				2	40	14.5	17	15.4
				3	50	36.4	52	21.6
				Avg.	**43.3**	**30.5**	**43.3**	**20.1**
				Std. Dev.	**5.77**	**14.1**	**23.2**	**4.09**
	Evotherm 3G™	Med	2.4	**1**	70	55.6	106	25.9
				2	50	31.7	35	17.0
				3	80	79.7	113	21.6
				Avg.	**66.7**	**55.7**	**84.7**	**21.5**
				Std. Dev.	**15.3**	**24.0**	**43.2**	**4.48**

Table G.9 *MRTCR* Data for *R-3* RAP Compacted at 138 C with 65 Gyrations

Stress (kPa)	Additives	P_{AC}	V_a (%)	Rep	$\varepsilon(5\%)_T$	$(\Delta\varepsilon/\Delta T)^{-1}$	*FN*	F_ε
272	None	High	2.2	**1**	210	218	267	19.3
				2	140	141	226	24.0
				3	290	220	397	23.6
				Avg.	**213**	**193**	**297**	**22.3**
				Std. Dev.	**75.1**	**45.0**	**89.3**	**2.61**
	Sasobit®	High	2.2	**1**	150	178	365	29.1
				2	220	234	415	25.8
				3	160	147	249	25.0
				Avg.	**177**	**186**	**343**	**26.6**
				Std. Dev.	**37.9**	**44.2**	**85.2**	**2.16**
	Evotherm 3G™	High	2.2	**1**	170	190	410	28.2
				2	200	306	622	30.2
				3	140	277	601	34.0
				Avg.	**170**	**257.6**	**544**	**30.8**
				Std. Dev.	**30.0**	**60.21**	**117**	**2.92**
544	None	Med	3.5	**1**	390	112	68	7.77
				2	290	87.4	77	10.8
				3	350	124	110	11.4
				Avg.	**343**	**108**	**85.0**	**9.99**
				Std. Dev.	**50.3**	**18.4**	**22.1**	**1.95**
	Sasobit®	Med	3.1	**1**	340	96.3	58	7.59
				2	380	99.7	73	8.72
				3	260	86.8	66	9.97
				Avg.	**327**	**94.3**	**66**	**8.76**
				Std. Dev.	**61.1**	**6.69**	**7.5**	**1.19**
	Evotherm 3G™	Med	3.3	**1**	220	69.8	56	10.1
				2	320	104	80	9.90
				3	510	133	59	5.75
				Avg.	**350**	**102**	**65**	**8.58**
				Std. Dev.	**147**	**31.5**	**13**	**2.46**
544	None	Low	6.1	**1**	930	249	160	7.84
				2	680	154	63	4.67
				3	770	177	76	4.99
				Avg.	**793**	**193**	**99.7**	**5.83**
				Std. Dev.	**127**	**49.6**	**52.7**	**1.75**
	Sasobit®	Low	6.0	**1**	960	236	133	6.67
				2	670	213	38.0	2.10
				3	1360	345	183	6.49
				Avg.	**997**	**265**	**118**	**5.09**
				Std. Dev.	**347**	**70.5**	**73.7**	**2.59**
	Evotherm 3G™	Low	5.9	**1**	2440	598	284	5.77
				2	2020	484	196	4.87
				3	2220	539	189	4.20
				Avg.	**2227**	**540**	**223**	**4.95**
				Std. Dev.	**210**	**57.0**	**52.9**	**0.788**