Construction and Materials Regional Consortium (CMRC)

Railroad Crossties Containing Recycled Wood or Recycled Plastic

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16. Abstract

This report provides information related to the potential of using either recycled wood or recycled plastic to produce railroad crossties. The objective of this report is to document the viability of railroad crossties containing recycled wood and/or recycled plastic for military applications. Recycled wood focused on the use of composite wraps and rehabilitation through injection of filler materials, and recycled plastic focused on ties made fully of plastic. It was concluded that recycled plastic railroad ties can be used within military railroad infrastructure and could be part of responsible recycling to address the plastic crisis, pending proper standards. Without proper standards, recycled plastic railroad ties are a questionable form of recycling. A second conclusion was that glass fiber reinforced polymer wraps over wooden cores have been demonstrated to produce ties with suitable performance characteristics and life expectancy in the range of 75 years. Research targeting performance specifications for recycled plastic ties could identify the key parameters that are most effective at predicting tie performance and is recommended. Installation procedures for recycled plastic ties should also be developed in an effort to mitigate specific poor performance characteristics of the material itself like splitting and breaking upon cut spike installation.

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Recycled Plastic, Crosstie, Railroad Tie, Recycled Wood

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LIST OF SYMBOLS AND ACRONYMS

AREMA	American Railway Engineering and Maintenance-of-Way Association
A-State	Arkansas State University
CFRP	Carbon Fiber Reinforced Polymer
CLT	Cross-Laminated Timber
CTE	Coefficient of Thermal Expansion
E	Modulus of Elasticity
EPA	Environmental Protection Agency
EPC	Engineered Polymer Composite
ERDC	Engineer Research and Development Center
FAST	Facility for Accelerated Service Testing
FRA	Federal Railroad Administration
FRP	Fiber Reinforced Polymer
GFRP	Glass Fiber Reinforced Polymer
HDPE	High-Density Polyethylene
HSRM	High Strength Reduced Modulus
MGT	Million Gross Tons
MSU	Mississippi State University
PSI	Pounds Per Square Inch
PTLF	Portable Track Loading Fixture
RPL	Recycled Plastic
SBVR	South Branch Valley Railroad
TR	Technical Report
TTCI	Transportation Technology Center, Inc.
U.S.	United States of America
UFC	Unified Facilities Criteria
UFGS	Unified Facilities Guide Specifications
USACE	United States Army Corps of Engineers
WVDOT	West Virginia Department of Transportation
WVRA	West Virginia State Rail Authority
WVU	West Virginia University

CHAPTER 1-INTRODUCTION

Railroad ties can be manufactured from different materials including concrete, wood, steel, and polymeric materials such as recycled plastic or glass fiber reinforced polymer composites of varying types. Historically wood has been the most prevalently used material for manufacturing railroad ties. Construction of the railroad network occurred during a time (late 1800s) in the U.S. when trees with higher mechanical properties were more available than they are in present day. In present day, there are more materials options than in the early development of the railroad network, and there is also more attention given to making productive use of post-consumer materials by way of recycling or re-purposing. Worldwide, recycling plastic is a matter of first order importance, and as shown in this report, producing railroad ties from post-consumer plastics does occur and is being considered for military railroads. This need to recycle plastic, however, should not overshadow the need for railroad performance, nor should the need for railroad performance overshadow the need to be environmentally conscious.

Composite materials and post-consumer plastics are finding their way into a variety of civilian and military applications. Railroad ties are a military application where post-consumer plastic has been used for a significant number of railroad track miles over the past few years. Lampo (2014) documented use of plastic ties in elevated and ballasted track and also in a railroad bridge at Fort Eustis, VA. As of the date of this report, AREMA (American Railway Engineering and Maintenance-of-Way Association) chapter 30 includes a section for engineered composite ties, and this annually updated Manual for Railway Engineering provides load, design, and testing guidance for all crossties (AREMA 2022). Work to advance the use of composites and/or post-consumer plastic is very timely and is the focus of this report for railroad crossties.

Lampo (2014) reported the following factors for investigating alternatives (e.g. recycled plastic, or RPL, ties) to wood crossties: wheel loads increasing from 32 to 39 tons; changing environmental regulations for chemically treated wood (new products and disposal of old products); concerns of present-day wood producing lower quality crossties; rising wood costs; wood rotting and insect attack; and the need for large numbers of trees to meet crosstie replacement demands.

Traditionally speaking, fiber reinforced polymer (FRP) composite systems consist of fibers and a cured resin matrix that encapsulates the fibers. Glass and carbon fibers have historically been the most common for construction or infrastructure applications, often in conjunction with polyester or vinylester resins. Qiao et al. (1998) developed and tested a glass fiber-reinforced plastic (GFRP) composite wrap for application to wooden ties with positive results relative to tie performance and service life. Vijay et al. (2010) also explored GFRP composite shells over discarded wood and rubber cores with good results relative to strength, stiffness, resistance to cracking, and spike pull-out.

Lampo (2014) reported that demand for composite ties was in excess of capacity and that international composite railroad tie sales were rising. In the U.S. market, the Railway Tie Association (2022) reports less than 1% of tie sales are steel or composite with wood making up over 93% of the market of approximately 19 million ties. Concrete makes up the difference. It is noteworthy to mention that the term “composite” is not universally defined across literature sources relevant to the rail industry, and this report addresses this issue for contextual clarity.

According to Lampo (2014), there are roughly 175,000 miles of railroad track in the U.S. Every year, millions of wooden ties are discarded in the US after their initial service life is complete. According to a survey by the Railway Tie Association (2015) representing roughly 80% of Class 1 railroad mileage in the U.S. and Canada, 81.3% of ties removed from service were recycled as fuel sources for energy conversion while 17.5% were recycled for landscape-related applications. 0.9% of the ties were reused by the railroads themselves. EPA regulations regarding air pollution and waste and/or hazardous material disposal impact the percentage of ties recycled in cogeneration facilities, so the percentages are likely to vary over time.

1.1 Objective and Scope

The objective of this report is to document the viability and in some cases challenges of railroad crossties containing recycled wood and/or recycled plastic for military applications. Recycled wood focused on the use of composite wraps and rehabilitation through injection of filler materials, and recycled plastic focused on ties made fully of plastic.

ERDC has had an active railroad inspection program for many years, but rail research by ERDC has been limited over the past ± 10 years. This report documents one of the first ERDC railroad research efforts in the past several years. This report relies primarily upon existing literature and publicly available information to evaluate the use of recycled materials and their application(s) in military rails. Stewart (2024) wrote a PhD dissertation with some overlap to this report that is a more comprehensive assessment of the plastic crisis that uses relevant portions of this report as needed given these two documents were largely developed in parallel. This document and Stewart (2024) each contain some unique content. This effort only considers railroad ties in open air and on grade applications and does not consider confined spaces such as tunnels or elevated cases such as bridges.

1.2 Terminology

This report usually refers to a railroad crosstie as a “tie”. Another term for a tie from literature is “sleeper”. This report does not intend to take firm positions on terminology relative to the re-purposing of materials for use as railroad ties. The report does, however, desire to provide information that can help future discussions in this arena be more productive. The review of literature and practice documented in this report identified a few areas where some terminology clarification might be useful for future endeavors. The remainder of this section provides terminology as used in this report which isn’t always fully consistent with these same terms when used in some other documents.

Plastic refers to a wide range of synthetic or semi-synthetic materials where the primary ingredients are polymers. Polymeric describes materials of or relating to polymers. Polymers are substances containing very large molecules that are comprised of repeating simpler chemical units.

By most definitions, composites contain two or more materials with different properties. These two materials are usually not dissolved or blended into each other, and often one material (matrix) is reinforced by a smaller amount of the other material. Fiber Reinforced Polymer (FRP) would fit a more traditional composites definition as the material consists of a polymer resin (e.g. vinyl ester) that is reinforced with fiber (e.g. glass). The two materials are intended to complement one another and are fundamentally different.

In a very loose sense, building materials manufactured from recycled plastic, or RPL, are a composite of different plastics, but this phrasing does not fit the spirit of more traditional composites definitions. This terminology usage is noted because some (if not most) of the "composite" railroad ties in the current market are not reinforced by a material dissimilar to post-consumer and/or post-industrial plastic. This report often refers to these types of materials as RPL ties rather than composite ties. A complete list of symbols and acronyms used in this report can be found in the front matter, page vii.

CHAPTER 2-RAILROAD FUNDAMENTALS

AREMA track design standards were summarized by Al-Chaar et al. (2019). Details include common tie failure modes as well as overall design specifications for railroad track and foundations. Components of railroad track construction include rails, tie plates, spikes, ties, and ballast. Other methods and details of rail connections to ties were not discussed including various clips, rail anchors, hooks, track bolts, and other assorted pieces of "track jewelry" as they are informally known.

Figure 2.1 shows a typical rail installation with key components identified. As shown, ties are typically spaced 19.5 inches apart on center. Ties are placed within a bed of ballast material to provide vertical and horizontal support while preventing water ponding and providing an area where vegetation can be efficiently prevented from growing. Figure 2.1 also includes rail anchors which are not always utilized but are designed to prevent longitudinal movement of the rails and attach to the underside of the rails such that they will bear along the side of the tie. The rails themselves are generally identified by their specific weight. For example, 115 pound rail weighs 115 pounds per yard of length.

Rails are seated on tie plates which attach to ties. The tie plate is designed with a slight cant (elevation difference between rail heads) such that the rails tilt slightly toward one another. The cant gives a better contact surface between the wheel and rail to improve safety, reduce rail rollover, and reduce wear on the wheels of the rail cars. The tie plates are attached to wooden ties with spikes (cut or screw type), and the rail is secured to the tie plate with spikes (as shown in Figure 2.1). According to Lampo et al. (2001), cut spikes were the most commonly used fasteners by U.S. railroads (military rail included) in the early 2000's time frame. Cut spikes are typically used for railroads with wooden ties. They are named cut spikes because they are made to cut wood fibers and not split wood – they are driven in a specific orientation in order to perform as cut spikes. Concrete ties require the use of rail clips of various designs to secure the rails to the tie plates.

Placement of tie plates on a tie dictates the gage or spacing between the rails themselves. Nominal rail gage is 56.5 inches. Tie plates serve to not only maintain rail spacing and cant, but they serve as bearing plates to help protect ties from vibrations (Agico Group, 2022).

Anywhere from 15 to 20 million ties are replaced annually (Bolin and Smith 2013). Lampo (2014) reported an annual average of 10 to 15 million railroad tie replacements. Up to 3% of these replacement ties were composites and 90 to 95 percent were wood as of roughly ten years ago (McConnell 2009) though RTA (2022) reports a lower composite percentage of less than 1%.

2.1 Typical Railroad Tie Specifications

RTA (2014) published a set of specifications for timber ties that includes the kinds of wood from which ties can be produced as well as dimensional specs. The dimensional specs essentially identify two grades of crossties (7-in. and 6-in.) which correspond to the height of the ties. 7-in. grade ties are more common with a nominal cross section of 7-in. x 9-in. (height x width). 6-in. grade ties have a nominal cross section of 6-in. x 8-in. Nominal lengths for either grade are specified by the customer and are normally 8-ft. 0-in., 8-ft. 6-in., or 9-ft. 0-in.

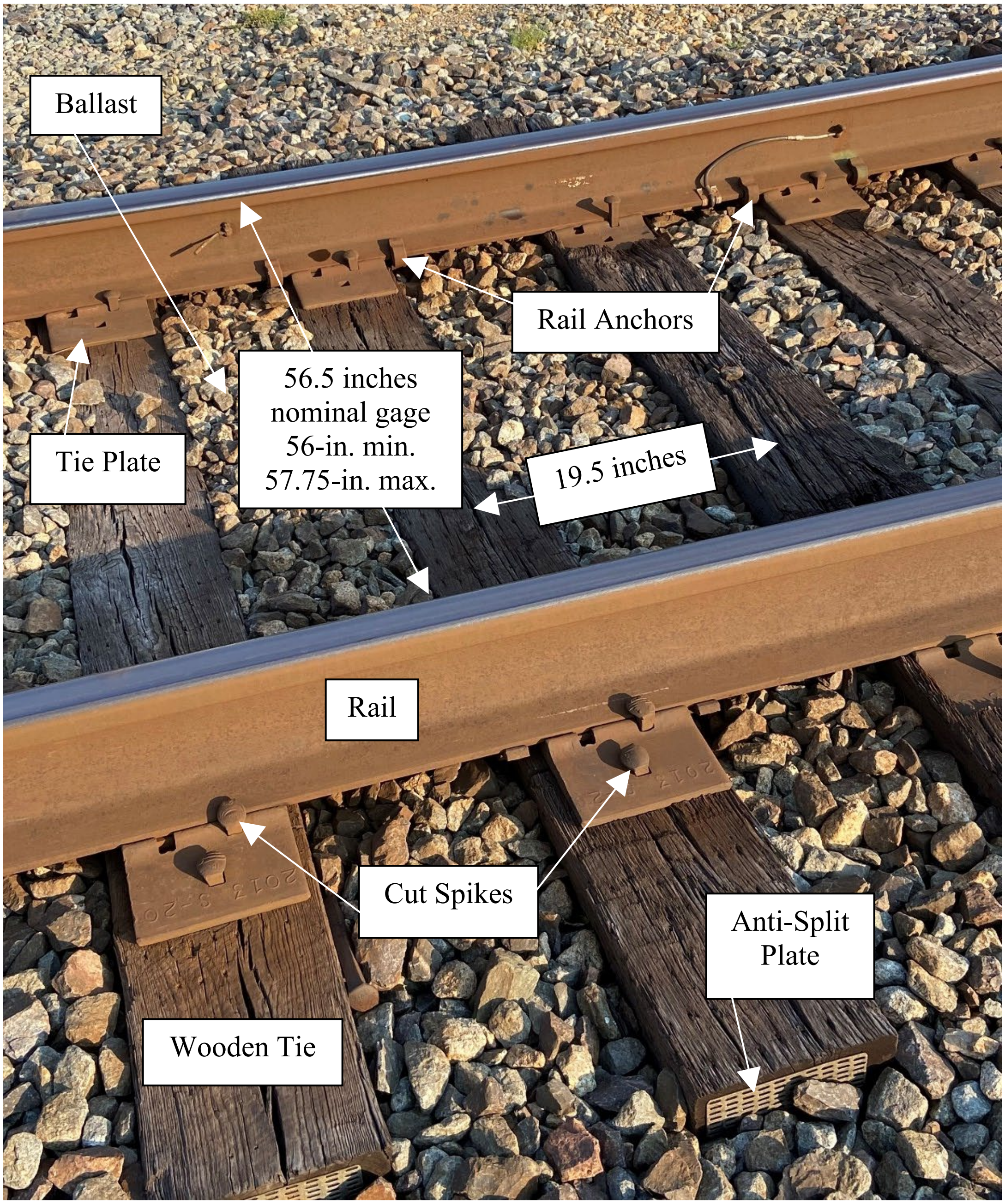


Figure 2.1. Typical rail installation

AREMA's *2022 Manual for Railway Engineering* (chapter 30) provides several tests commonly performed such as rail/plate area compression, fastener wear, electrical impedance, and single tie lateral push testing.

Lampo et al. (2001) provided the following performance target goals for RPL and/or composite ties.

- *Dimensions:* Cross section of 7 by 9 inch and peak-to-peak surface flatness within 0.0625 inches under the tie plate.

- *Mechanical:* Maintain gage within 0.125-in. (+) under a lateral load of 24,000 lb, a static vertical load of 39,000 lb, and a dynamic vertical load of 140,000 lb and have a modulus of elasticity (E) over 170,000 psi.
- *General:* Have less than 5% water absorption, resist diesel and grease to a level that properties don't change more than 10% in their presence, be electrically non-conductive, surface degradation due to ultraviolet light be less than 0.003-in. per year, be installed with standard equipment and be compatible with standard fastening hardware.

2.2 Railway Groups

The following groups provide guidance, design standards, and testing procedures for railroad components and construction. This is not an exhaustive list.

Association of American Railroads
https://www.aar.org/

Railway Tie Association
https://www.rta.org/

American Railway Engineering and Maintenance-of-Way Association
https://www.arema.org/

National Institute of Building Sciences
https://www.nibs.org

Federal Highway Administration (FHWA)
https://highways.dot.gov

American Wood Protection Association
https://awpa.com

2.3 Military to Commercial Rail Comparisons

Military rail loads are typically much higher than commercial loads, and military rail speeds are typically slower than commercial rail speeds. Both of these factors increase durability demands on railroad ties. Military rail usually travels in the 10 to 35 mph range, whereas commercial rail typically travels closer to 60 mph. Military rail is often less maintained than commercial rail. More specific details on military rail loads and speeds is not for public dissemination.

The Unites States Department of Defense approved for public release the Unified Facilities Criteria (UFC) Railroad Track Maintenance & Safety Standards (Maintenance, 2008). This document details military rail inspection procedures for all parts of the rail transport system from roadway and ballast to track geometry and clearances. Many of these standards refer to AREMA standards and are identical to them. The use of plastic or RPL ties is also mentioned in this document (section 5-4) with reference to the Unified Facilities Guide

Specifications (UFGS) document on Railroad Track and Accessories (UFGS, 2008) for material requirements. The UFGS document instructs users to refer to the tie manufacturer's recommendations for installation details while acknowledging that these ties represent relatively new technology.

2.4 Railroad Crosstie Types and Materials

2.4.1 Wooden or Timber Crossties

Wood tie properties are presented first so that properties of other tie materials can be benchmarked to wood.

Chapter 30 of the AREMA Manual for Railway Engineering (2022) provides details on the complete specifications for wood ties. It details inspection procedures, specific details of defects that may exist, and even specific species of wood from which wood ties may be sawn. Geometric properties of ties are also specified in chapter 30. Standard tie lengths (given as ft'-in") are specified as 8'-0", 8'-6", or 9'-0" and are to be specified by the customer. All specified dimensions are green dimensions with an expected shrinkage of ¼-in. on any dimension for dry or treated ties. The rail bearing areas of all ties (between 20-in. and 40-in. from tie center) shall measure as described herein. 6-in. grade ties shall have a cross section of 6-in.x8-in. (height x width) with a maximum of 1-in. of wane in the top rail-bearing area. Wane is defined as a defect characterized by bark or insufficient wood at a corner or along an edge due to the curvature of the log (see Figure 2.2). 7-in. grade ties shall measure 7-in. x 9-in. (cross section) with a 1-in. maximum wane in the top rail-bearing areas. Wane along the bottom face up to 1-in. at any given point is permitted in both 6-in. and 7-in. grade ties.

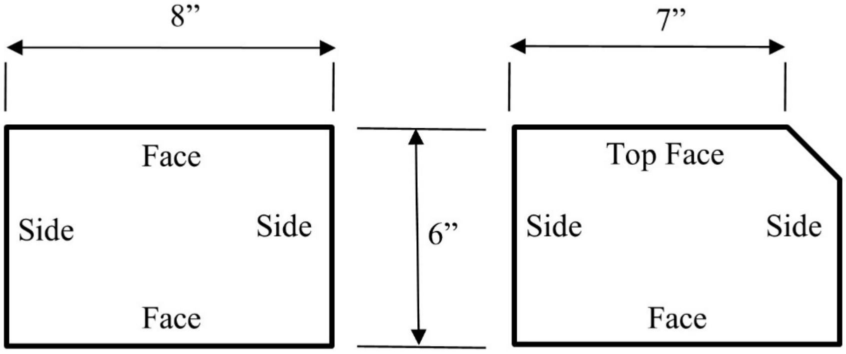


Figure 2.2. Cross section view of 6-inch grade tie without and with wane

Chapter 30 of the AREMA Manual for Railway Engineering (2022) specifies numerous items which are to be inspected upon delivery of wooden ties. Items which are detailed for inspection include decay, holes, knots, shake, splits, checks, slope of grain, bark seams, and manufacturing defects. Because wooden ties are cut from trees, each tie is necessarily unique. Therefore, inspection procedures are intended to quantify the presence of potential defects in such a way as to provide an indication of suitability to perform as a tie in rail service. Ties aren't expected to be free of holes or knots or splits or other defects completely, but such natural characteristics of wood ties must be within acceptable limits with regard to size or frequency or other defined criteria. The Railway Tie Association (2014) summarizes the AREMA specifications.

Modulus values are dependent upon wood type. Modulus of elasticity (E) values typically range between 0.86 and 1.44 million psi for commonly used wood in the U.S. Modulus of rupture values range from 5.0 to 7.4 thousand psi (Webb et al. 1998).

Wood generally expands upon heating and contracts on cooling. According to the Wood Handbook (Forest Products Laboratory, 2010), the coefficient of thermal expansion (CTE) for oven-dry wood parallel to the grain is independent of wood species and specific gravity and ranges from about 1.7 to 2.5 $\times 10^{-6}$ / °F with dimensional units of strain (in/in). Coefficients of thermal expansion in the radial and tangential directions (across the grain) are proportional to specific gravity and range from 5 to over 10 times greater than the parallel-to-grain coefficients (Forest Products Laboratory, 2010). The handbook notes that wood containing moisture will react differently than oven-dry wood when exposed to varying temperature and will generally shrink due to moisture loss more than it will expand due to heating for a net negative dimensional change upon heating in moisture contents above 4%.

Wood ties are susceptible to rotting and insect attack, and warm and moist environmental conditions increase their susceptibility. Wood ties are pressure-treated with creosote to lessen environmental degradation, and creosote treatment extends tie service life by 5 to 8 times (Webb et al. 1998). Bolin and Smith (2013) report expected life values of 35 years for properly treated wooden ties under ideal conditions. Bowyer et al. (2007) report that temperatures in the 500 to 680°F range cause wood Pyrolysis to accelerate to a level that flammable gases are evolved that can ignite from a flame.

Installation of new wood ties sometimes results in reduced train speeds until the ties are firmly seated into underlying ballast. This temporary speed reduction provides sufficient time for the tie/ballast interface to lock together to prevent relative tie movement which could be hazardous to rail traffic and general rail safety. The lateral push-out values can increase by 2.5 times or more during this period of time as the track sees 15-20 MGT (million gross tons) of traffic (Lampo et al., 2003).

2.4.2 Concrete Crossties

Concrete ties are generally made by casting concrete around pretensioned steel running longitudinally through the tie (Yu et al. 2015). Steel tie plates are cast into concrete which facilitate rail fastening and preset gage between the rails. Yu et al. (2015) identified seven primary failure modes of concrete ties; chemical degradation, prestress cracks, rail seat cracks, center negative cracks, rail seat deterioration, freeze-thaw cracks, and shoulder/fastener wear or fatigue. Concrete ties are generally spaced 24-inches apart on center (may be up to 30 in.), weigh between 600 and 700 pounds each, and have a life expectancy of 50 years (L.B. Foster Company 2022). Concrete ties require additional or new ballast for installation.

Concrete ties depend on a lower life-cycle cost and high load-carrying capacity for market share. However, premature cracking can shorten their life expectancy. A common problem for concrete ties is cracking when the ballast is pulverized beneath the tie or otherwise able to work itself out from under the tie ends over time (Zeitouni et al., 2018). This center binding condition results in cracking due to the rigidity of the concrete ties which are normally constructed with high strength concrete (compressive strength greater than 7000 psi). The high strength concrete normally has a high modulus of elasticity (4.4 to 7.3 million psi), but one remedy for such cracking has been the development of high strength reduced modulus (HSRM) concrete. According to Zeitouni et al. (2018), the HSRM concrete used in pre-stressed concrete ties can delay crack initiation and withstand higher ultimate loads.

Mechanical properties of concrete are somewhat variable and have accepted value ranges. The modulus of elasticity for concrete is the ratio of the applied stress to the corresponding strain and generally falls in the range of 4.4 to 7.3 million psi. That value is typically a calculated value from the tested compressive strength rather than a material property (as with many metals – tabulated and used frequently by engineers). The modulus of rupture for concrete is generally accepted to be in the range of 10 to 20% of the compressive strength. The coefficient of thermal expansion (CTE) for concrete is quite variable. A primary source of variation is the coarse aggregate itself used in the concrete. Mallela et al. (2005) report that the coefficient of thermal expansion for concrete is generally between 4 and 8 x 10^{-6} / °F. A common design value used is 5.5 x 10^{-6} / °F with dimensional units of strain (in/in). CTE variability is most often associated with aggregate type, so high strength concrete would share this nominal design value with standard concrete. This fundamental property of concrete is associated with crack propagation and expansion as well as general thermal expansion behavior.

2.4.3 Steel Crossties

Steel ties are formed with a trough-style cross-section and installed with the trough opening down such that ballast is effectively tamped under and beneath the tie. Recommended ballast depth is at least 10 inches beneath the ties, and tie spacing is nominally 24 inches on center. Ties weigh between 125 and 240 pounds depending upon material thickness and tie length. The expected life of steel ties is 50 years, and they are 100% recyclable at the end of their useful life. Primary failure concerns include corrosion and fatigue cracking (Ferdous and Manalo 2014). The yield strength of steel ties was reported by Narstco (2021) as 50 thousand psi.

Certain material properties common to steel are equally valid for steel ties. The modulus of elasticity is approximately 29 million psi, and the coefficient of thermal expansion is 6.5 x 10^{-6} / °F.

Steel ties have some advantages when compared to wooden, concrete, or RPL ties. Steel ties can stack for efficient transport, and their overall shape causes them to have a natural resistance to lateral movement. The lateral movement resistance is due to the spade-shaped ends of the ties that effectively “dig in” to the ballast. Some steel ties are manufactured with open ends and lose that lateral movement resistance, but those ties have inspection holes and the ability to have concrete poured through them and vibrated into place to preserve track gauge integrity (Progressive Railroading 2021). Steel ties are generally considered easy to handle for installation activities.

Steel ties have a disadvantage for use in the United States of America. Some of the track signaling systems require insulation between the railroad track and the ties, and that insulation must be maintained at all times. Systems have been designed to provide the necessary insulation and track signaling capabilities, but it is still challenging for rail operators to fully trust those systems with steel ties in some situations.

2.4.4 Recycled Materials Crossties

Crossties can be made from many different recycled materials including plastic, rubber, wood, and steel. For the purposes of this report, however, steel will not be included in further discussions of ties from recycled materials. Wooden ties can be recycled back into rail service if appropriately reinforced, and post-consumer plastics can be utilized as a raw material source for tie manufacturing. The following two chapters separately address two materials for ties – plastic and wood. Ties with both plastic and wood cores have been developed, and wood ties both with and without a wrapping or layer of some sort to improve performance are discussed. Ties with an external wrap/layer over a core of a different material (such as plastic, rubber, or discarded wood tie) are referred to as composite ties.

CHAPTER 3-RAILROAD CROSSTIES CONTAINING RECYCLED PLASTIC

Lampo et al. (2001) discussed several critical issues related to crossties made from polymeric materials from a perspective of roughly two decades ago. At that time, several thousands of plastic composite ties had been installed in track of varying types. Increased axle loads (39 tons versus 36 tons) were stated as a factor for investigating composite ties since they were accelerating wear of wood ties. Environmental concerns with creosote treatment were also listed as a factor.

According to Lampo et al. (2001), plastic "lumber" materials made from recycled products began in the U.S. One of the first documented plastic ties was made from high-density polyethylene (HDPE) by an Illinois-based company and placed on short line in the Chicago area (the test was "not completely successful" due to inadequate mechanical properties of unreinforced HDPE). After this initial experiment, a variety of manufacturers entered the ties market with a variety of reinforced plastic ties (reinforcement included glass fibers, polymer fibers, mineral byproducts, and steel).

Zureick (2001) conducted an investigation of fiber reinforced recycled plastic / composite railroad ties. The work included numerous tests on material samples as well as full-sized ties. Both external fabrics and internal reinforcing bars were tested to determine their impact on the flexural behavior of RPL beams. The experiments were largely targeted at comparing theoretical modulus and stiffness values to experimental results. The work revealed increased modulus and stiffness from the reinforced specimens when compared to the unreinforced ones.

Vijay et al. (2010) reported that plastic railroad ties were evolving and being field implemented as alternatives to wood and concrete in the USA in the 2010 time frame. It was reported that most of these ties were made of recycled polymers such as high density polyethylene (HDPE), polypropylene (PP), polycarbonate (PC) or polyethylene (PE) derived from bags, bottles, cups, and other sources and there was only a small percentage (<10%) of chopped strand mats included. These products were reported to have satisfactory behavior under laboratory conditions, but under field conditions they exhibited cracking during and after field installation near to and away from areas where tie plates and spiking are present.

Lampo (2014) reported on a cooperative effort in 1998 to evaluate plastic-composite railroad ties. Participants were the Construction Engineering Research Laboratory (CERL), the Crane Naval Surface Warfare Center (NSWC), and the Crane Army Ammunition Activity (CAAA). Their #10 turnout on mainline track was chosen for a demonstration with plastic ties. A second turnout was completed with plastic ties in 2002.

A railroad tie test section was designed by USACE-ERDC and created at the McAlester Army Ammunition Plant (MCAAP) in McAlester, OK. One primary purpose for the test section creation was to evaluate commercially available RPL ties in military rail applications. Construction began in 2019, and this test section is further detailed in section 3.6 of this document.

3.1 Specifications

Railroad ties can be evaluated via multiple ASTM standards: bending (D6109); density (D6111); compression (D6108); spike pullout (D6117); thermal expansion (D6341); and resistance to slip (F609). As of Lampo et al. (2001), pullout forces for cut or screw spikes into composite ties was an area in need of additional investigation. Cases of plastic composite ties cracking (to varying degrees) or fracturing during fastener installation were also reported and were noted to be related to installation method.

The AREMA Railroad Manual is a commonly utilized resource; Section 5 on Engineered Composite Ties – Chapter 30 – was first released in the 2003 edition of the manual. According to Lampo (2014), the following properties were provided in the original AREMA manual for plastic composite crossties.

- Modulus of Elasticity: 170,000 psi (minimum)
- Modulus of Rupture: 2,000 psi (minimum)
- Rail Seat Compression: 900 psi (minimum)
- Single Tie Lateral Push: 2,000 lb (minimum)
- Spike Pullout: 1,900 lb (minimum)
- Screw Pullout: 5,000 lb (minimum)
- Thermal Expansion: 7.5 x 10^{-5} in/in/°F (maximum)

3.2 RPL and/or Composite Tie Manufacturers

The following manufacturers were known as of January 2024, but other manufacturers may exist. No manufacturers were intentionally omitted.

Axion Structural Innovations https://axionsi.com/
IntegriCo Composites https://www.integrico.com/
Atlas Ties http://www.atlasties.com/Products_Plastic.php
Evertrak https://evertrak.com/
TieTek https://tietekglobal.com/
Agico Group https://railroadrails.com/otm/composite-railroad-ties/

Axion Structural Innovations (https://axionsi.com/), as of January 2024, advertises its tie product as a composite railroad tie, ECOTRAX®. According to their company website, their ties exceed all AREMA standards and utilize the strictest quality control in the category. They state that their ties are manufactured from 100% recycled material and are unaffected by the natural environment. Specific qualities they claim include no plate cutting, never abrades, holds spikes and screws, never rots, never absorbs moisture, and is impervious to chemicals. The manufacturer states that their ties will not rot, warp, splinter, crumble, rust, absorb moisture, or leach toxic chemicals into the environment (Axion Structural Innovations 2023). Specific information about manufacturing is not provided though it is stated that they use a proprietary formula to create an industrial-grade structural composite.

IntegriCo (https://www.integrico.com/), as of January 2024, markets its ties as composite ties, IntegriTies®. According to their company website, their ties exceed all applicable AREMA standards. They state that their ties are made from 100% recycled plastics which would otherwise be destined for landfills or incinerators due to their “hard-to-recycle” nature. Their manufacturing process isn’t detailed, but they do indicate that it is a mold process rather than extrusion and that it is low-heat. The plastics they utilize (cross-linked plastic) do not require processing or washing, and their products are claimed to be 100% recyclable at the end of their use. They list numerous properties on their website to demonstrate why their product is better than wood ties or composite ties from other manufacturers. Some such claims include longer life in harsh climates, immunity to insect infestation, high electrical impedance, resistance to rail cutting, vibration and noise attenuation, excellent gauge retention across the life of the tie, and resistance to damage from caustic and corrosive environments (IntegriCo Composites, Inc. 2023).

Atlas Ties (http://www.atlasties.com/Products_Plastic.php), as of January 2024, markets its ties as composite ties, and their website contains wording identical to IntegriCo with a link sharing a wheel drop test with the IntegriCo brand from YouTube®. The website claims that their plastic is never heated to liquid form, and they claim to cool their products in molds, but other details are not clear about their tie manufacturing process (Atlas Trading International 2023). The contact section of the website lists Mexico, Central America, and South America as potential service areas for their company though the parent company address is in Beaverton, Oregon.

Evertrak (https://evertrak.com/), as of January 2024, advertises its composite ties under the name Evertrak 7000. Their website claims that the ties are manufactured from glass fiber reinforced 100% recycled polyolefin plastic. The website also identifies numerous tested properties of their ties along with the comparable AREMA standards for composite ties. Their ties exceed AREMA standards in each category shown. Additional details about their manufacturing processes are not provided by their website.

TieTek (https://tietekglobal.com/), as of January 2024, manufactures crossties which are advertised as engineered polymer composite ties. The website says that their ties are manufactured with recycled, non-toxic materials and are 100% recyclable. Specific materials used in their manufacturing process include plastic bottles, plastic bags, waste fiberglass, and used tires. They claim a life span of 50 years with resistance to fungi, moisture, rail-seat abrasion, insect damage, chemicals, and harsh environmental conditions (TieTek Global 2023). As with other RPL and/or composite ties, TieTek claims that their ties can be installed with existing equipment used for wood ties and can be interspersed with wood ties. The TieTek website also states that their ties meet or exceed performance recommendations from AREMA, and they utilize X-ray technology for testing every tie. Regarding their manufacturing processes, the website indicates that raw materials are mixed by melting and compounding, then ties are shaped with molds and cooled, then they are textured and examined for quality assurance.

Agico Group (https://railroadrails.com/otm/composite-railroad-ties/), as of January 2024, markets two types of ties through its website – composite and plastic. Their composite ties are said to have been developed in Japan and are made from fiber-reinforced foamed urethane. The primary materials contain continuous glass fiber, polyether polyol, isocyanate and related components (Agico Group 2023). Composite tie properties are provided on their website with comparisons to standards which aren't AREMA standards (it was unclear which standards are being used for the comparison). The Agico Group plastic sleeper is made from ultra high molecular weight polyethylene. The website states that the sleepers are "polymer of plastic with waste and rubber" (Agico Group 2023). Polystyrene is also mentioned as a material component. Some properties of the plastic sleepers are provided, but they aren't referenced to AREMA standards. Manufacturing details are not provided for their composite or plastic ties. It is also not clear how much recycled material is used in the manufacture of any of the Agico ties.

Chada (2012) identified four manufacturers, two of which were listed in this section (TieTek and IntegriCo). The two manufacturers not listed in this section were Dynamic Composite Ties and ForcePro Composite ties. Dynamic Composite ties were reported to be manufactured from recycled high density polyethylene, recycled rubber, steel, and concrete. These ties were rectangular in shape. ForcePro Composite ties were manufactured with I-beam designs in portions of the cross section and were made from plastics and molded metal parts and cavities.

3.3 Issues with RPL and Composite Ties in Military Rail

Over a few year period prior to 2017, the Army installed a considerable number of one producer's RPL ties, a process that continued until late in the 2017 calendar year. Changes in material proportions and/or manufacturing seemed to have led to stiffer and more brittle ties which experienced a level of failures during installation that led the Army to re-evaluate their recommendation for future use. Changed manufacturing processes were noted around 1 year prior to the increased brittleness of these ties (cracking, breaking, and handling).

These ties were installed at an Air Force Base (AFB) in late 2017 and ended up with longitudinal cracks from 0.5 to 5 inches long. In some cases, these ties broke all the way through. A recommendation was made by the manufacturer to predrill a 5/8-in. hole and drive a 5/8-in. cut spike, and this recommendation was questioned. Without predrilling, around 50% of the ties were cracking. Hole sizes of 8/16, 9/16, and 10/16-in. were attempted. Ties did not crack with 10/16-in. holes, but there was concern of spike pullout. Individuals involved with this work indicated they had tested 5/8-in. spike pullout and that it met AREMA standards (1,900 lb. minimum). Past recommendations were to predrill a 3/8-in. hole. Note that typical pullout from RPL tie manufacturers was noted at around 3,200 lb., and wooden ties have pullout values of around 4,000 lb. Prior to these pre-drilling activities, it was noted they had not pre-drilled every past tie and had had very few issues with cracking.

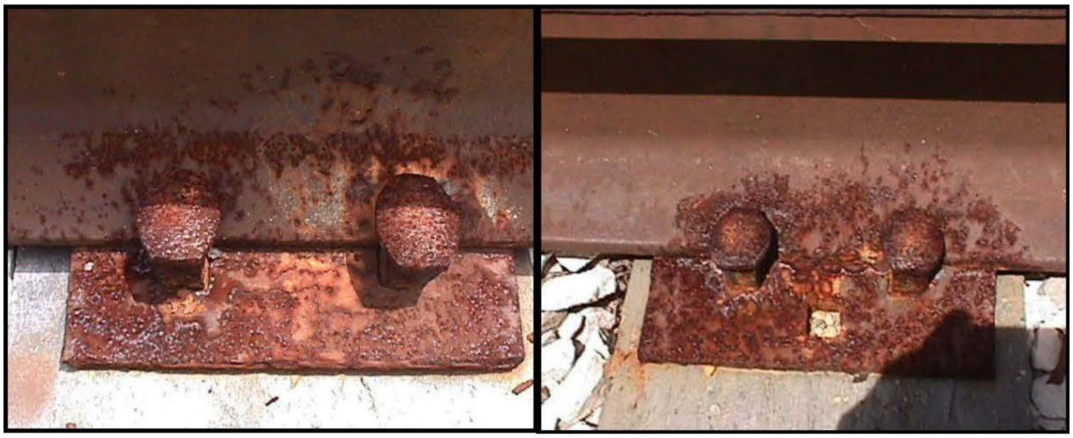
Recycled plastic (RPL) railroad ties have recently been used in Department of Defense (DoD) railroads on a trial basis. Despite their potential, there have been significant issues from implementation of RPL ties (see Figures 3.1 and 3.2). Specific issues observed include gage problems, general tie deterioration, tie damage such as splitting during installation, accelerated plate/spike/rail corrosion, and in-service deformations and failures.

In the summer of 2018, a crosstie replacement project totaling approximately $3.4M was completed strictly using RPL and composite crossties. In the fall of 2019, ERDC personnel performing an inspection identified numerous areas of tight gage measuring 55.5 inches on the majority of tracks. The track network had not seen any traffic in the year and a half since the crosstie replacement project was complete. Of note, the crosstie replacement was completed during 2018, and all tracks were regulated and aligned to standard gage (56.5 inches) during the hottest part of the summer.

It is commonly seen during summer months that typical lengths of RPL crossties are 2-4 inches longer than their starting dimensions of 102-inches. Given these conditions, the tight gage might be attributable to the contraction of the ties in the cooler fall and winter months. Another possible cause for the tight gage is that the track could have been spiked a little tight from the beginning. It is common practice for wood ties to be spiked just under the

(a) Thermal effects cause tight gage (b) Warped headblocks

(c) Installation damage (d) Surface flaking



(e) Plate/spike/rail corrosion (f) Severe plate/spike/rail corrosion

Figure 3.1. RPL and/or composite tie sample issues after installation

ideal 56.5-inch gage due to the slight stretch often caused by the lateral forces induced from train movements. While this stretch is traditionally seen with wood ties, it is not seen with

(a) Steel and recycled plastic ties **(b) Damaged recycled plastic tie**

(c) Deteriorated recycled plastic tie **(d) Longitudinal cracking**

(e) Sunken middle of recycled plastic tie **(f) Installation damage**

Figure 3.2. RPL and composite tie implementation issues

RPL ties. Because there is no guidance between the installation of different types of ties, common wood tie installation procedures can actually further exacerbate issues seen with RPL crossties.

Due to highly variable and proprietary construction methods and materials, one supplier's RPL or composite crosstie may behave very differently from another. The latest AREMA guidelines from Chapter 30 part 5 state that if designing with an engineered polymer composite (EPC, plastic or composite crossties), the design engineer of record should provide significant research and justification that the EPC will behave as expected. However, Class 1 Railroads have not adopted mass integration of RPL or composite crossties into new construction or maintenance. Until these standards are uniform and there is mass adoption from Class 1 Railroads, the DoD is not able to benefit from suppliers conforming to meet Class 1 material specifications and standards. Up to this point, the DoD has benefited from industry standard practices which ensure that crossties, rails, and fasteners and other materials (F&OTM) meet minimal standards allowing the UFC to lack specific project specifications (I-Gram Army Dams & Transportation Program 2021). Unfortunately, UFC standards have not been updated to effectively govern the use of RPL and composite crossties. There have been issues ranging from splitting crossties during installation to gage problems in track. Figures 3.1 and 3.2 show photographic records that first appeared in Stewart et al. (2023). Figure 3.3 shows additional implementation issues associated with the RPL ties.

(a) Broken-off chunk from installation **(b) Additional installation damage**

(c) Center crack (broken crosstie) **(d) Surface flaking**

Figure 3.3. Additional installation & performance issues - RPL and composite ties

3.4 Performance Comparisons to Other Crosstie Materials

Allen (2008) documented tie plate failures in wood and plastic ties installed in a 6-degree curve that showed plastic ties permitted more flexure than wooden ties that lead to fatigue stress failures at a higher rate. These observations occurred on the high tonnage loop at the Facility for Accelerated Service Testing (FAST).

Bolin and Smith (2013) compared life-cycle costs for wooden ties treated with creosote, concrete, and composite ties. Several of the most meaningful composites' inputs were assumed or estimated, highlighting life-cycle comparison challenges. Their results indicated that creosote-treated wooden ties had lower fossil fuel and water use as well as a lower environmental impact than the concrete or plastic/composite ties evaluated.

A test track was created by USACE-ERDC to compare the performance of ties from 6 different sources – wood, steel, and 4 different manufacturers of recycled plastic (RPL) ties. The results of the test track and associated lab experiments revealed variability in mechanical properties of the plastic and composite ties with temperature. In particular high temperatures led to insufficient lateral stability, vertical stiffness, and ductility. These material issues led to gage problems and tie deformation in the test track sections (Stewart et al. 2023). Additional information is found in section 3.6 of this document.

Lampo et al. (2001) reported that screw spike holding power was comparable in plastic composite ties and wooden ties. Testing with cut spikes showed plastic ties to have significantly less holding power in new materials (3,500 lb versus 8,000 lb in wood); note that wood's holding power reduces over time.

3.5 Properties of RPL and Composite Ties

Lampo (2014) described initial development of recycled plastic (RPL) and composite railroad ties. Development began in the mid-1990's with two independent groups working on composite ties with glass-fiber reinforced high-density polyethylene (HDPE). This effort was performed with the following performance targets: minimum flexural modulus of 170,000 psi; gage maintained within +0.25 in. under a 39,000 lb. static vertical load and a lateral load of 24,000 lb.; installation with standard techniques, equipment, and fasteners; and similar weight and dimensions relative to wood (roughly 190 to 220 lb. for a tie of 7 x 9 x 102-in. dimensions).

Most polymeric ties are constructed primarily of high-density polyethylene (HDPE) and usually contain 85%(+) recycled plastic materials such as grocery sacks, tires, plastic bottles, milk jugs, and similar. RPL ties utilize the same installation equipment and processes as wooden ties.Literature reports achievement of minimum AREMA properties by commercially available composite tie products (Ferdous et al. 2015). Many of these tie products have been placed into service for testing by various groups to better understand their durability and long-term usability.

Resistance to creep and deformation in the lateral direction are a potential concern for some RPL and/or composite ties (Lampo 2003). Modulus values in the lateral direction may not be adequate to maintain gage over time. Some have reported that spikes are hard to place into composite ties. Composite ties in railroad crossings can crack if they are too close to the edge.

Lampo (2014) reported on testing of composite ties that were ten years old and had been in high tonnage loading conditions that showed no signs of property deterioration.

Lampo (2014) identified eight possible failure modes including: minimum performance requirements; fracture/cracking; tie plate cutting; fire; low tie/ballast interaction; creep (gage increase); stress-relaxation (loosening of fasteners); and environmental exposure deterioration.

3.6 McAlester, Oklahoma Test Sections

McAlester Army Ammunition Plant (MCAAP) is located in McAlester, OK, and houses the Army Mobile Rail Repair Team. MCAAP encompasses approximately 45,000 acres and employs several hundred people. MCAAP houses roughly 230 miles of rail which is a considerable portion of the roughly 2,500 miles of rail owned by the Army.

An instrumented experiment was planned at this location, and test section construction began in the fall of 2019. A site visit was made in November of 2019. Figure 3.4 shows representative photos of the activities that were occurring during the site visit.

The test section is roughly 900 ft long with six test sections that are each 150 ft long. During instrumentation installation in this area, an underlying layer of what appeared to be chemically stabilized soil/rock was identified. The six test sections were: 1-wood; 2-Manufacturer 1 composite; 3-Manufacturer 2 composite; 4-Manufacturer 3 composite; 5-Manufacturer 4 composite; and 6-steel. Note that all of these composite ties are best defined as RPL ties. To protect instrumentation, tamping was suspended within a few ties of instrumented locations, and instrumented locations were the center of each test section. Instrumented areas were tamped manually and repeatedly marked with orange paint.

RocTest equipment was a key feature that allowed dynamic reading via vibrating wire gages in this experiment. Historically, vibrating wire gages were used for continual data collection.

Ballast spreading and shaping occurred the same as if there was no instrumentation. Cases where there was ballast only in the middle of the track were observed and normal since remnant ballast is often dumped only between the tracks for logistical ease to fully empty rail cars. All items were constructed using fresh angular ballast, a 21-in. tie spacing, and predrilled screw spikes with the exception of the steel crosstie sections which used traditional steel rail clips. The beginning and end of the test track was placed over 50-ft from the turnout and road crossing to eliminate any influence. A schematic of the test section is shown in Figure 3.5.

Laboratory testing was also completed as part of the test program implemented at MCAAP. The experimental work was undertaken to gain a better understanding of the mechanical properties of and thermal effects on RPL ties. COVID-19 led to considerable delays in data collection and in some cases altered research plans.

Testing methodology and some results from the MCAAP facility are reported in the following subsections of this document. Much of this information was previously documented by Stewart et al. (2023) and is included here in abbreviated form for simplicity and continuity. Additional data has been collected at, and associated with, MCAAP that is not documented in this section.

3.6.1 MCAAP Testing Methodology

This test track was built to determine the long-term performance of different RPL and composite crossties and the influence of temperature on this performance. To capture these

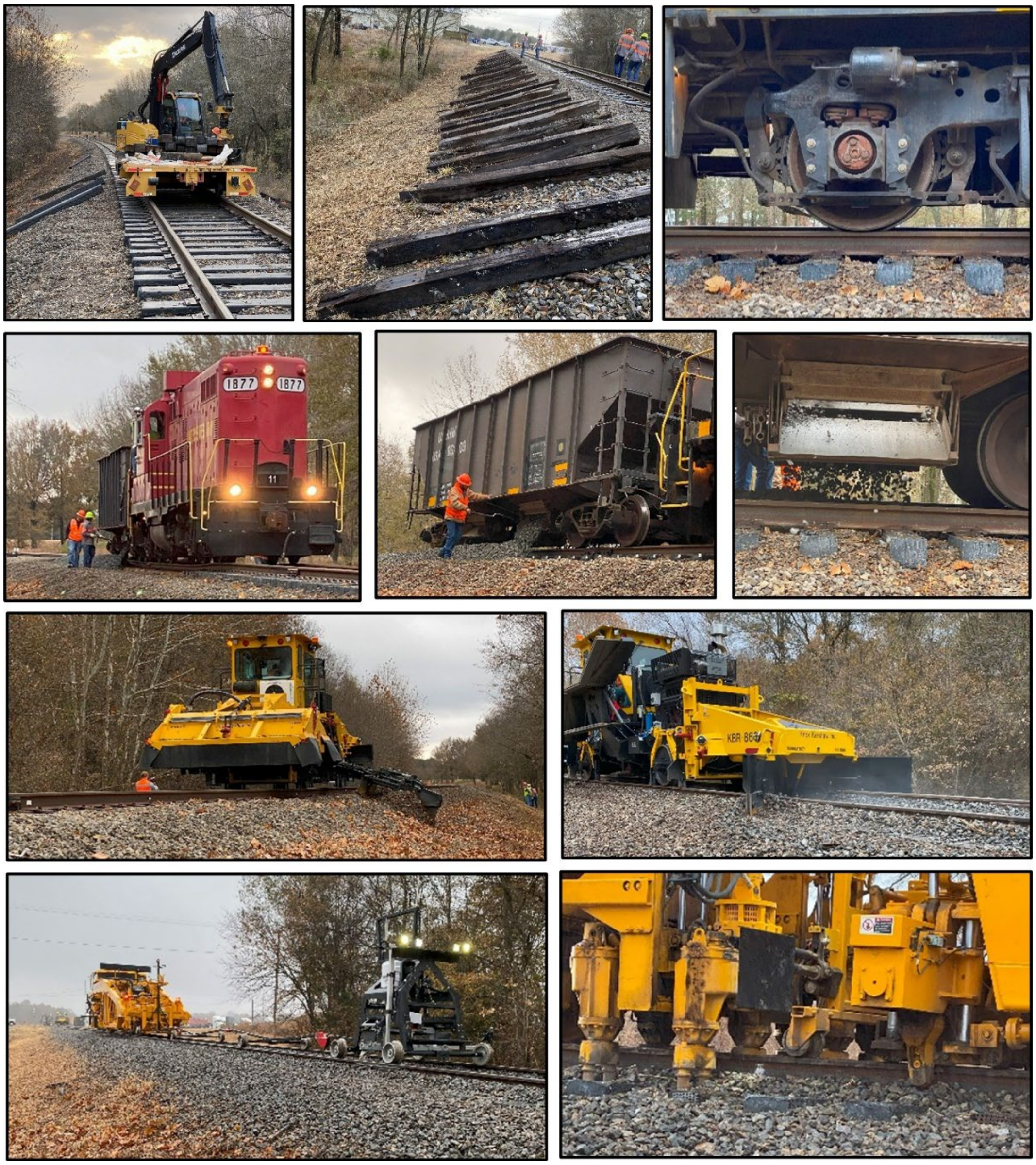


Figure 3.4. Photos of McAlester test sections under construction

factors, different testing was performed on the 900-ft section over three years. Weekly gage measurements were taken every 50-ft along the test track in the morning and afternoon. In addition to gage measurements, the outside temperature and weather conditions were also recorded. Gage is measured between the heads of the rails at right-angles to the rails in a plane five-eighths of an inch below the top of the rail head (CFR Title 49 2019). Note that standard gage for railroad tracks is nominally 56.5-in. with an acceptable lower limit spacing of 56-in. and an upper limit spacing of 57.75-in. for Class 2 and 3 track (Figure 2.1). If track gage exceeds these limits, rail lines become restricted or unusable. Crosstie surface temperatures were also taken along the track. An OMEGA™ HH501DK K type thermocouple probe was used, and wires were taped to the surface of the crosstie. A minimum of 30 seconds was given to allow temperature probes to stabilize before any readings were taken.

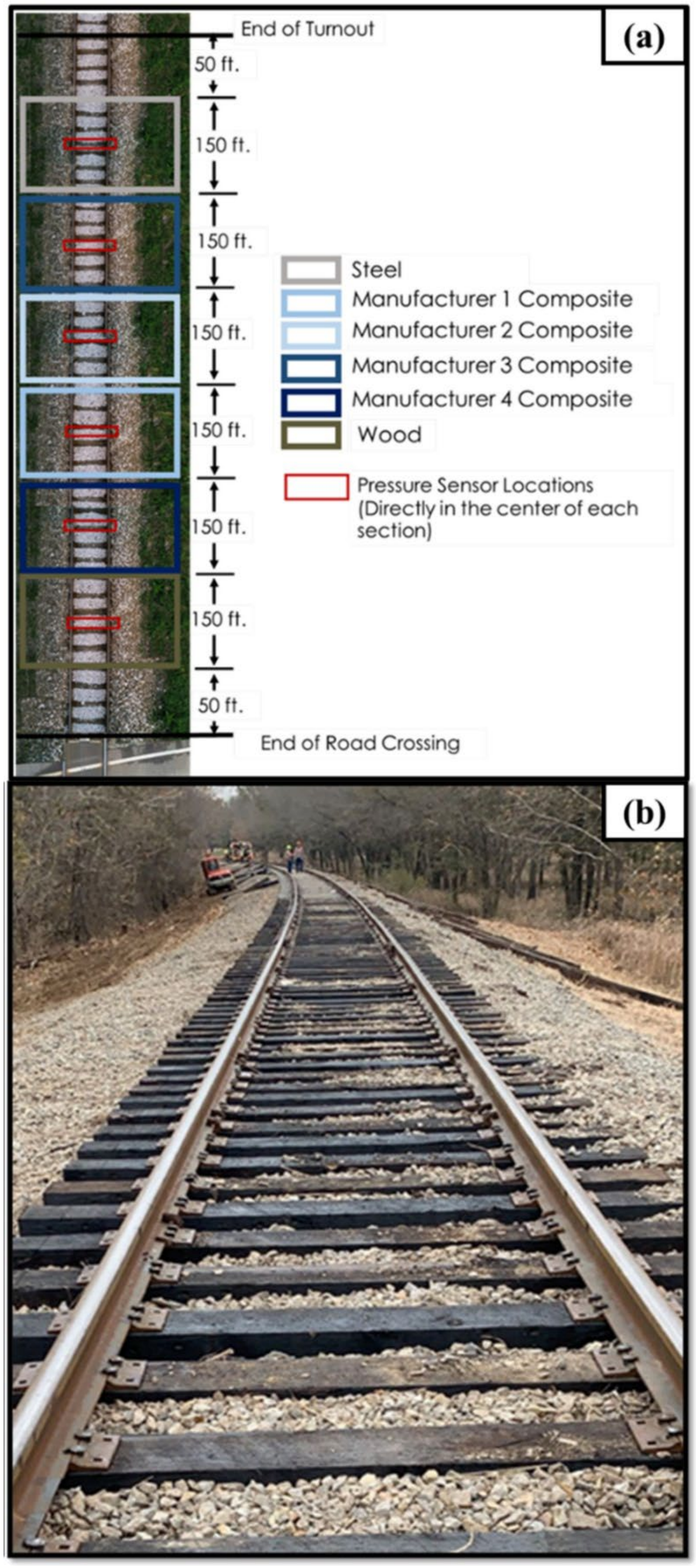


Figure 3.5. Schematic of MCAAP test track and MCAAP test track

The material properties of RPL and composite crossties are a concern in their ability to maintain track gage over long periods of time. Polymers are generally considered viscoelastic,a mechanical characteristic causing stress response to be time dependent and exhibit both viscous and elastic characteristics. A train can cause lateral loads of over 20,000 lbf while moving along a rail system. Crossties' viscoelastic properties and the long-term creep performance due to cyclic loading caused by train movement can lead to "stretching" of crossties and impact a crosstie's ability to maintain proper gage. To determine a track's lateral strength, ENSCO developed a manually operated, nondestructive Portable Track Loading Fixture (PTLF) that measures gage strength per Federal Railroad Administration's (FRA) Track Safety Standards (TSS) 49 CFR §213.110 (2019). PTLF deflection measurements were taken at the center of each test section under a 4000-lbf lateral load applied near the rail shear center.

Raw materials were prepared from commercially available crossties from three RPL crosstie manufacturers, one wood tie manufacturer, and one steel tie manufacturer. Two of each type of RPL crosstie were purchased and cut into 4 sections. The specimens for tensile testing were prepared by machining samples according to the ASTM D638 standard method of test for tensile properties of plastics.

Samples were randomly selected from the 8 different sections of each RPL crosstie type to capture variability. To evaluate the anisotropy occurring throughout the tie, tensile load testing was performed in both the perpendicular and transverse directions. Uniaxial monotonic tensile tests were conducted using an MTS servo-hydraulic load frame in ambient laboratory conditions with a hydraulically actuated self-aligning gripping system. To ensure the specimen's vertical alignment, specially machined inserts were used during the tests. Each typical tensile dog-bone shaped specimen was gripped at its ends and pulled to elongate at 0.025 mm/s to its breakpoint as shown in Stewart et al. (2023). At least three specimens were tested for each condition.

Temperature influence on mechanical properties was determined by performing tensile tests on crosstie samples after exposing them to hot and cold temperatures. For elevated temperatures, specimens were tested after oven heating for 24 hours at 120°F. Specimens were placed in a freezer at 0°F before testing to determine the influence of colder temperatures. Temperature settings and exposure times were carefully monitored to attain equal heating history for all specimens. This temperature range incorporates typical temperatures seen for crossties located in standard climates across the United States. It is important to note that these temperature ranges do not include extreme temperatures seen in some areas. After removal from the elevated or lowered temperature exposures, specimens were immediately measured for dimensional changes and placed for tensile testing.

To test and evaluate the flexural rigidity, three-point bend testing was performed on full sized RPL and composite and wood ties at 56.5-in. spacing as described in Stewart et al. (2023).

3.6.2 MCAAP Field and Laboratory Test Results

RPL and composite crossties have exhibited property variation that appears to be highly influenced by temperature and/or sun exposure. The dark color of these ties only exacerbates temperature effects. Temperatures were taken when outside air was 94°F and in locations that were exposed to direct sunlight. Temperature on the direct surface of the rail on the inside polished and outside corroded areas of the rail were 129°F and 120°F, respectively. In comparison, one crosstie surface temperature was measured at 145°F. Darker crossties exhibit higher temperatures than lighter crossties in the same daytime conditions. Surface temperatures on crossties exceeding 50°F higher than outside air temperatures further explain the gage issues that are being seen throughout DoD railroad track. The RPL and composite tie data from USACE-ERDC showed both dimensional and material property changes with temperature for RPL and composite railroad ties.

Figure 3.6 shows changes in gage over the 2020 calendar year for test track sections constructed with ties from multiple manufacturers as well as data from standard wood and steel ties. Graph spacing is evenly spread across the 12 months of 2020. Graphs in Figure 3.6 show two different gage measurements for each test item in their 150 ft. section. The green line represents gage at a location 50 ft. into the section, and the black line represents 100 ft. into the section. In order to give a reference, the red line along each graph shows the ideal gage of 56.5 inches. The wood and steel sections show very little variation of gage in each point of measurement. While the wood section does have a difference in gage between the two points where measurements were taken, this difference is not related to any temperature issues. The difference is likely due to installation variation or specific track changes at that spot. In contrast, all RPL/composite ties show up and down gage variation trends due to expansion and contraction throughout the year. Additionally, Manufacturers 1,2, and 3 show an average drop in gage during the end of the year due to lower temperatures typically associated with the months October to December. Manufacturer 4 shows the least amount of gage changes throughout the year compared to the other RPL crosstie manufacturers. The data reported in Figure 3.6 was also reported in Stewart et al. (2023), but there was an error in the Manufacturer

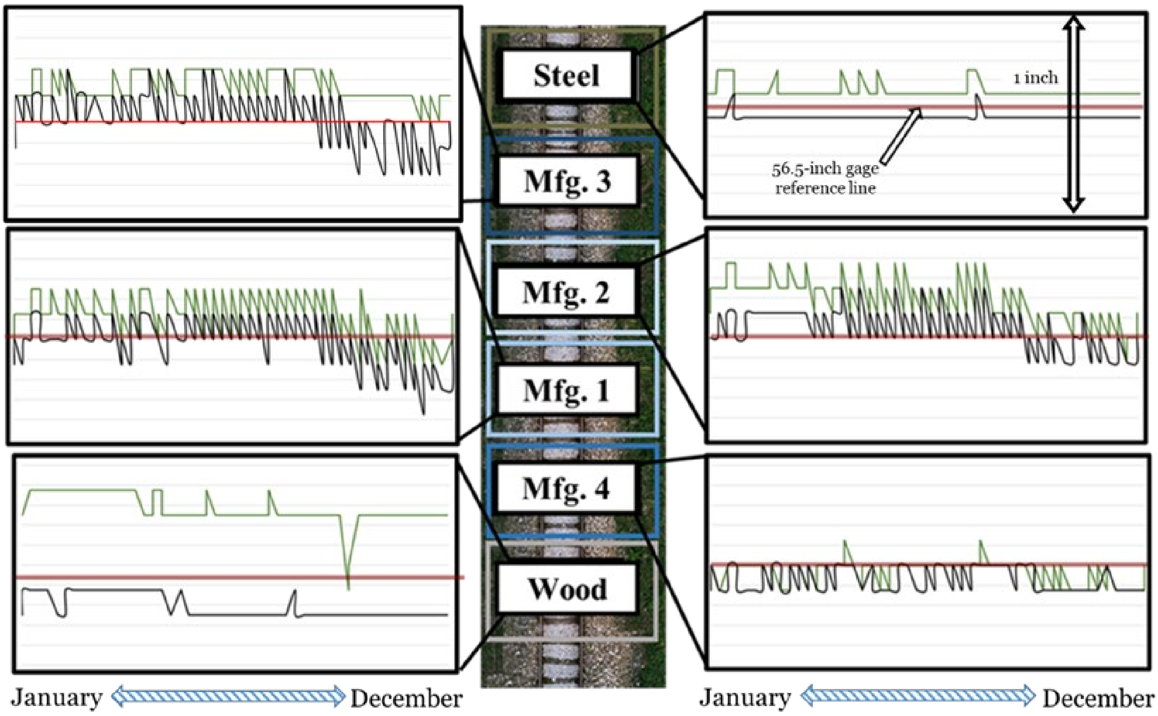


Figure 3.6. 12-month period (2020 calendar year) gage change on the MCAAP test track. Red line is 56.5-in. gage and vertical scale is 1-in.

3 portion of Figure 3.6 which was only found after publication of Stewart et al. (2023). The error did not change the overall conclusions from the data and was corrected in this document.

Field data demonstrated cyclical gage changes throughout the year for at least three of the RPL ties tested. Lateral force application combined with such thermal cycling can cause significant reduction in mechanical properties. The testing regimen discussed was designed to help determine suitability of RPL ties for military rail use. A more extensive examination of all test data was created by Stewart et al. (2023).

The lab and field testing results revealed numerous points of interest. Manufacturer 4's tie had the best gage stability under load and temperature effects among the RPL ties. Lab results from two of three specimens from Manufacturer 3 indicated that its tie would shrink outside allowable gage limits under extreme cold conditions (tested at 0°F). Manufacturer 3 also showed the least amount of overall gage stability. Manufacturers 2, 3, and 4 all showed significant decreases in ultimate strength when exposed to high temperatures (tested at 120°F), so concerns exist for those ties if exposed to lateral loading in a hot environment. Three-point bending tests were performed on an RPL tie from Manufacturer 1, and the results indicated significant bending under lower loads as compared to a tested wood tie (see Table 3.1). The testing regimen revealed that properties of different ties from the same source were variable beyond expectations in both ultimate strength and ductility, and such variation might be explained by waste stream purity/consistency or manufacturing process quality assurance practices or something completely unknown at this time.

Table 3.1. Test results from three-point bending

Tie Material	Weight (lbf)	Max Load (lbf)	Max Deflection (inches)
Wood	181	19475	3.82
Manufacturer 1	255	8318	5.15

3.6.3 MCAAP Discussion

Based upon purchase history in early 2022, the McAlester Army Ammunition Railroad Track Repair Team reported traditional prices of wood, plastic, steel and concrete ties to be approximately $102, $179, $188, and $175, respectively. Wood, plastic and steel tie spacing results in around 3,200 ties per mile, but concrete ties can be spaced at larger distances such that only 2700 ties are used per mile. Cost per mile of track, using tie material and a one-time replacement of all crossties, is $326,400 for wood, $572,800 for plastic, $601,600 for steel, and $472,500 for concrete. Note that the life expectancy of these ties is not uniform, so the replacement expense would be incurred at different times in the future. It should also be noted that the concrete tie cost does not include the rail fastener assemblies, and concrete ties are not recommended for jointed track which is the most common type of track seen on DoD installations.

Strengths of RPL ties include long service life, resistance to fungal and insect attack, market size, non-biodegradable behavior, low electrical conductivity, and the ability to be incorporated into existing track with wooden crossties. The biggest weaknesses of RPL ties are their insufficient high temperature lateral stability, vertical stiffness, and inherent ductility. Noted problems with maintaining gage and deformation of the recycled plastic ties are manifestations of these weaknesses, and overloading of ballast and subgrade materials could result from their installation. A key concern to the adoption of RPL ties would be to ignore the test data (e.g. Stewart et al. 2023) and continue to use existing products without addressing the temperature-dependent material behavior characteristics and overall product variability. Consistent and predictable performance characteristics are a significant hurdle which the RPL tie industry must clear prior to widespread industry or military acceptance. Design specifications based on sound engineering principles can provide a pathway for responsible plastic recycling within railway infrastructure in the U.S.

CHAPTER 4-RAILROAD CROSSTIES CONTAINING RECYCLED WOOD

Wooden ties make up over 90% of the new ties used in the United States in present day (Railway Tie Association 2022). Wood ties have a life expectancy between 33 and 42 years, and around 3% of wood ties are replaced annually. Approximately 20 million wood ties are expected to be replaced each year. Many of the removed ties are recycled in some form (landscape timbers and fuel for co-generation facilities are two common recycling methods), and around 4 million are disposed of in landfills in a typical year. Research has revealed ways for wood ties to be recycled back into service following rehabilitation. Methods include reinforcing with CFRP or GFRP sheets in various arrangements as well as injecting with filler materials. This chapter explores these options from literature and identifies some specific projects where such methodologies for wood tie rehabilitation have been utilized. This chapter was included to benchmark RPL ties against an alternative that makes use of recycled wood ties, to show more than one alternative to recycle by way of railroad ties.

4.1 Literature Review of Wood Rehabilitation with Composites

CFRP and GFRP have been used to improve performance characteristics of timber structural elements. Saad and Lengyel (2022) performed a literature review of methodologies and results of both types of reinforcement to establish the state-of-the-art. Their work summarized the effectiveness of multiple ways of creating composite structural elements, and they also discussed challenges associated with the different forms of FRP reinforcement. Roughly 25 years ago, Laosiriphong (2000) studied wrapping ties only in the region of rails and steel plates using thermoplastic GFRP.

Corradi and Borri (2007) documented increased strength, ductility, and especially flexural stiffness with the application of GFRP pultruded elements (H and I shapes) to both hardwood and softwood timber structural elements. The GFRP reinforcements were bonded with epoxy to the wooden beams and then attached with screws. Corradi et al. (2018) documented the use of GFRP plates as reinforcement on timber structural elements. The plates were mechanically attached to the tension side of the members tested, and increases in bending capacity (75%) and stiffness (50%) were reported.

GFRP sheets have been used to reinforce timber beams in many applications. Gomez and Svecova (2008) documented research targeted toward improving shear performance for beams with visible splits, and the GFRP sheets were able to improve stiffness by approximately 5 to 50%. Al-Fasih et al. (2021) demonstrated performance improvements with the addition of both strips and complete wrappings of GFRP to timber elements in shear testing. Rostampour Haftkhani et al. (2022) documented lateral resistance improvements in double shear lap joints when GFRP sheets were incorporated into cross-laminated timber (CLT) sheets.

Lokuge et al. (2021) reported on the effectiveness of GFRP wraps for timber pile rehabilitation. Restored axial capacity and energy absorption were observed by the researchers. They filled splits and other gaps in the original timber piles with underwater cementitious grout or crane rail epoxy prior to applying the GFRP jackets. Negrao et al. (2011) reported strength increases in timber beams from CFRP laminates as passive reinforcement elements. Dewey et al. (2018) documented successful rehabilitation efforts for timber bridge girders using CFRP sheets and GFRP rods and dowels. Cost savings were noted as motivation to adopt similar approaches to rehabilitation as part of ongoing maintenance efforts.

Qiao et al. (1998) and Davalos et al. (1999) explored the possibility of using glass fiber-reinforced plastic (GFRP) composites with wooden railroad ties. Their experiments were conducted on wooden core samples wrapped with a (0.07 in.) thick layer of composite; meaningful increases in strength (28% for dry and 70% for wet) and stiffness (21% for dry and 25% for wet) were obtained. Davalos et al. (1999) recommended increasing the GFRP composite thickness in the vicinity of the rail seat to improve the performance of the composite tie overall. Figure 4.1 is an example of a cross-section of a GFRP wrapped crosstie sawn in half.

Figure 4.1. Example GFRP-wrapped wooden railroad tie cross section

Vijay et al. (2010) explored similar applications with ties made with GFRP shells over wooden cores. The shell thickness tested was 0.5 inches, and the shell was wrapped on all sides of the wooden cores. The results of their testing showed high strength/stiffness under static loads, excellent strength retention under millions of fatigue cycles, and negligible localized cracking from spikes. The wooden tie cores used were planed-down discarded wooden ties. Additional work from this research group from West Virginia University (WVU) is detailed elsewhere in this chapter.

Polyethylene foam with glass fiber reinforcement has been documented as tie material for service life applications of up to 60 years (Manalo et al. 2010). Other reports state composite ties have been manufactured from composite plastics and oak as well as glass fiber composite skins and modified phenolic foam (Ferdous and Manalo 2014).

Wooden railroad ties have been experimentally rehabilitated in place (Al-Chaar et al., 2019). The process utilized a cementitious geopolymer material that was injected into the split and/or otherwise damaged ties. Results of this research are explored later in this chapter.

Railroad ties that have reached the end of their useful life can be rehabilitated with composite wraps. This possibility increases the value to the rail industry of otherwise discarded ties. It also presents opportunities to apply this technology prior to the initial installation of wooden ties to extend their useful lives and improve their overall durability. Details of composite ties containing recycled wood are further explored in this chapter.

4.2 Wooden Tie Rehabilitation

Wooden tie rehabilitation has been examined with at least two separate methodologies. One methodology allows the ties to be repaired in-situ by injecting a flowable material into the tie itself (Al-Chaar et al., 2019). Another methodology involves wrapping damaged ties with a composite material (Chada, 2012; Bharil and GangaRao, 2020).

Al-Chaar et al. (2019) described a wooden tie rehabilitation process in ERDC/CERL TR-19-15 by which ties could potentially be repaired in situ. The process involves injecting damaged ties with a flowable cementitious geopolymer material. Damaged ties must first be cleaned; pressurized water and air were utilized in this process as part of the research. Mechanical means might also be needed to remove rotted portions of the wooden ties, and enlargement of damaged portions might be necessary to accomplish the desired removal of damaged wood. Once the ties are suitably prepared, the flowable material can be inserted into the tie to essentially fill the voids and restore load-carrying capability and service life to the damaged wooden tie. After a period of time for curing under appropriate conditions to include maintenance of appropriate moisture content, the rehabilitated ties would be ready for rail traffic. Testing of repaired ties in the research showed promising performance characteristics. A primary advantage of this process is the lack of removal of the tie from its service location. The research completed was performed on ties that had been removed from rail service, though, so procedures to actually accomplish the in-situ repairs would still need to be developed and proven. Curing time and conditions on active rails for the geopolymer material are major points of interest for future applications and implementation.

WVU has been involved with research into GFRP wraps over wooden cores to rehabilitate wooden ties and timber bridge elements. Abhari (2007) documented timber railroad bridge rehabilitation with GFRP composite wraps to improve strain response and shear modulus. Liang and GangaRao (2013) documented numerous environmental engineering applications of FRP composites including railroad ties. Vijay et al. (2010), Chada (2012), and Bharil and GangaRao (2020) reported results from the railroad tie work. The fundamental idea is to remove damaged wooden ties from service, plane them down to permit the addition of a GFRP wrap on all sides and ends, apply the GFRP wrap to the wooden cores, and then place the composite ties back into service. The performance of these composite ties was superior to wooden ties. The expected service life of these ties is predicted to be 75 years under normal environmental conditions while withstanding 100 million gross tons annually (Bharil and GangaRao, 2020). Fatigue, aging, and environmental considerations were critical points of the research, and equations were developed to assist in the design of the composite ties to attain superior life expectancy compared to plain wooden ties while accounting for these specific factors. Bharil and GangaRao (2020) emphasized that current AREMA standards for tie performance are met by basically all commercially available ties regardless of their makeup, but the standards focus on the tie's properties at the time of purchase and installation and don't reflect any long-term performance matrix with regard to design life or tonnage. The research group also explored and documented a nondestructive methodology to inspect the rehabilitation efforts through infrared thermography (Halabe et al, 2012).

Moore (2019) mostly focused on retaining walls but also evaluated a few railroad ties. Used wooden ties were planed to reduce their thickness by roughly 30 mils on each face, and the edges were rounded to reduce stress concentrations and improve corner bonding. Seven layers of GFRP were used to wrap these ties with a total thickness of roughly 0.16 inches. Table 4.1 summarizes the findings of Moore (2019) that are pertinent to this report.

Table 4.1. GFRP-wrapped wooden tie test results from Moore (2019)

GFRP Description	Static Bending Test Method	Elastic Modulus (E) – 10^6 psi	Peak Bending Stress (psi)
Wood Only - Control	3 point	0.55	275
Hand Lay-Up – Vinyl Ester	3 point	1.42	267 to 340
Resin Infusion – Polyester	3 point	0.98	367
Resin Infusion – Vinyl Ester	4 point	1.67 to 1.75	177 to 333

-- A 7 ft clear span was used for testing, and in 4-point bending, loads were at third points

4.3 Moorefield, West Virginia Test Sections

An active railroad site in Moorefield, West Virginia (WV), was visited in August of 2019. This railroad site is a part of the West Virginia Department of Transportation (WVDOT), is owned and operated by the West Virginia State Rail Authority (WVRA), and is part of the South Branch Valley Railroad (SBVR). The rail line visited is a feeder line and isn't on a main rail line. According to WVDOT in August of 2019, total carloadings of 3,800 to 4,000 per year are typical, and primary freight categories are grain, lumber, polymers, and aggregates (https://transportation.wv.gov/rail/SBVR/Pages/default.aspx).

The Moorefield site is not a specific research site, but they do perform periodic experiments of interest on their active rail line, and they have done so for the past several years. During the project team's visit, their two active composite railroad tie experiments were visited, largely for the purpose of viewing recycled wood ties by way of GFRP on active rail. Figures 4.2 and 4.3 show representative photographs of this site visit, including wooden and GFRP wrapped ties interspersed within the rail line. The remainder of this section summarizes pertinent work at the Moorefield test site that has been previously documented in literature.

Some of the ties at this location in August of 2019 had end wraps with gang nails at the end (e.g. Figure 4.4), while others did not. The composite ties at this location had been there for roughly two years, and they were not at the Transportation Technology Center, Inc. (TTCI) prior to their deployment near Moorefield. The area where these ties were placed is a fairly wet area. There were 25 to 30 wooden ties rehabilitated with glass fabric in a vinylester resin. Several of the ties at this location had visible damage to the composite wrapping. Rail representatives indicated this damage occurred when driving them laterally under the rail as they drug on the rail. Overall, these ties were reported to be performing well.

Prior to the August 2019 visit, GFRP research on discarded wooden ties was performed at Moorefield and is summarized in the remainder of this section. The works of Vijay et al. (2010), Vijay et al. (2012), and Chada (2012) were summarized collectively in the following paragraphs.

Figure 4.2. August 2019 Moorefield Experiment 1

Figure 4.3. August 2019 Moorefield Experiment 2

Wooden tie shown in center
Composite wrap shown surrounding tie
Gang nails shown in green on sides of figure

Figure 4.4. Rehabilitated wooden tie schematic with gang nails

Vijay et al. (2010) documented field testing of seven GFRP reinforced wooden oak ties where discarded ties were planed to obtain all around dimensions of approximately 1 inch less than final tie sizes (7 inch by 9 inch by 102 inch). During installation, the GFRP shell provided slightly higher resistance to driving the spike as compared to wooden oak ties. A standard 256-kip locomotive traveling at speeds up to 15 mph was used to load test these GFRP ties and compare them to traditional wooden ties. In straight line portions of the track, strains in the GFRP recycled ties were on the order of 15% less than wooden ties where measured strains in all cases were between 400 to 500 microstrains (με). Strains increased with curvature and locomotive speed and were recorded as high as 1,070 με in sharp curves, but this was reported to be 12 to 15 times lower than the GFRP failure strain. Vijay et al. (2012) reported the ties with lower fiber/fabric contents of the seven ties evaluated showed localized horizontal cracking or some transverse cracks, while the remaining ties showed excellent field performance.

Chada (2012) further described experiments conducted at SVBR on the aforementioned seven GFRP wrapped ties. Gage change was measured by LVDT's between rails. Maximum gage change was due to dynamic loading and was 0.09 to 0.34 inches for GFRP composites depending on track location. There were five ties with a 0.38-inch thick GFRP wrapping made from 15 layers with a 17% fiber volume fraction, and there were two ties with a 0.50-inch thick GFRP wrapping made from 19 layers with a 15% volume fraction. After three months of service, three ties with low fiber/fabric content showed localized horizontal cracking or some transverse cracks and the remaining four ties showed good field performance (this observation was the same as made by Vijay et al. 2012).

Chada (2012) reported on red oak wood ties that were GFRP wrapped. These ties were laboratory produced from discarded red oak tie cores. Six ties were produced with elastic modulus (E) values of 1.2 to 1.5 (10^6) psi. Average dimensions of these ties were lengths of 102 in, widths of 8.8 in, and thicknesses of 6.9 in. Chada (2012) also compared a new white oak wooden tie to a GFRP wrapped discarded tie in three-point bending with a 60-inch clear span. The GFRP tie made use of 20 layers of wrapping. Elastic modulus of both the white oak and GFRP tie were 1.3 (10^6) psi, whereas the modulus of rupture of the GFRP tie was modestly higher than the white oak tie (9,200 psi versus 8,700 psi).

The work in the 2010 to 2012 time frame at the South Branch Valley Railroad (SBVR) in Moorefield, WV, was the basis of the work at TTCI in Pueblo, CO, that is documented in the next section. The best performing ties at SBVR were re-designed and sent to Pueblo, CO (the thermoset GFRP ties discussed in Section 4.4 were based on the SBVR work).

4.4 Pueblo, Colorado Test Sections

The Transportation Technology Center, Inc. (TTCI) in Pueblo, CO has also evaluated used wooden ties that have been GFRP wrapped. These test sections were not visited as were

McAlester and Moorefield, but relevant findings from these test sections (either from literature or reported by either WVU or TTCI) are reported in the remainder of this section.

Lampo (2014) reported on two plastic ties that were installed in a 5-degree curve in the FAST at TTCI (Transportation Technology Center, Inc.), Pueblo, CO, in 1996; in 1997 there were 24 additional ties installed, and in 1998 a third group was installed (some having cut spikes, some with embossing for increased lateral stability). Lampo (2014) reported that the oldest ties have received over a billion gross tons of traffic (in MGT units). Data from these experiments identified a need for increased lateral stability. Lampo et al. (2001) had noted this same need along with the ability for manufacturers to impact the lateral stability. Data indicated an increase in push-out value from 700 lb (smooth) to 6,000 lb (textured) along with the elimination of the need to initially reduce train speeds as is typically needed for new wooden tie installations. In 2014, Lampo reported that a newly installed wood or RPL tie had a push-out force of approximately 1,000 lb., but with 15 million gross tons of traffic, a wood tie increased to 2.500-3,000 lb. while a plastic tie was still at roughly 1,000 lb. It was noted, however, that newly installed RPL ties with embossed/modified sides had push-out values of 4,000 to 6,000 lb.

Vijay et al. (2012) documented properties of the ties evaluated in the Pueblo test sections; GFRP with thermoset resin was used throughout the investigation with oak wooden cores. Manufacturing processes are described in detail in Vijay et al. (2012), and this work would be a continuation of the efforts documented at Moorefield.

Chapter 2 of Vijay et al. (2012) described 15 rehabilitated ties from WVU that made use of thermoplastic resin where 13 were placed in the field in Pueblo, and 2 were tested in the laboratory. These ties were referred to in some documents as the composites 1 site. The two tested in the laboratory were previously reported by Chada (2012). Figure 4.5 shows representative photos of these field test sections. Field testing indicated good performance up to 16 MGT of load by a 39-ton axle load train on the TTCI tracks; cracks were noted under the tie-seat area. Fatigue wise, these thermoplastic ties performed well in the laboratory, withstanding up to 2.5 million cycles while cracking from the field was not observed in laboratory conditions. The completed composite ties weighed roughly 225 lb. each.

a) Tie positioning during installation b) Completed ties installation

Figure 4.5. Composite tie installation at Pueblo, CO

Chapter 3 of Vijay et al. (2012) considered 16 ties with thermoset resin, of which 14 were evaluated in the field at TTCI and 2 were tested in the laboratory. Houshmandyar (2013) provided a comprehensive background of testing and development of the rehabilitation efforts for these 16 thermoset GFRP composite ties as well as performance characteristics associated with them. The 14 ties evaluated in the field at TTCI have been referred to in some locations as composites site 2. Field testing showed successful performance of the thermoset resin GFRP ties up to 63 MGT by a 39-ton axle load train. At roughly 28 MGT of loading, some spike/plate cutting and end-splitting was observed in a few ties, and around 37 MGT there was some uplifting of outer spikes. After 63 MGT of loading, the ties were removed and examined visually. There were some ballast imprints that were supported by improved push tests. Overall, the key observation was that these ties successfully carried 63 MGT; additional testing was halted for funding and not performance reasons. For reference, there were 22 layers of GFRP wrapping the wooden cores. Single tie push test (STPT) values were 1100 to 1400 lb at 0 MGT but increased to 1900 to 2500 lb at 11 MGT which was attributed to the aforementioned indentions. STPT testing was conducted under heavy axle loading for maximum loading and displacement assessment. The GFRP thermoset ties reinforcing a discarded wooden core were found to have successfully overcome limitations exhibited by the thermoplastic GFRP ties.

Laboratory three point bending tests were performed on the thermoset resin GFRP rehabilitated ties (Table 4.2). All sixteen thermoset ties were tested, but only flexural rigidity was reported for each tie, which averaged 750 x 10^6 lb-in^2 and ranged from 430 to 1140 x 10^6 lb-in^2.

Table 4.2. Properties of thermoset ties compared to their wooden core

Property	GFRP-Wrapped Composite Ties[1]	Planed Wooden Tie Core
Width (in)	9.8, 9.2	8.6
Thickness (in)	7.8, 7.3	6.7
Moment of Inertia - I (in^4)	438, 365	221
Elastic Modulus - E (millions of psi)	2.4, 1.4	1.3
EI (millions of lb-in^2)	1073, 526	280
Failure Load – 60 in span (kips)	62, 43	22
Failure deflection – 60 in span (in)	1.13, 1.22	1.08
Modulus of rupture - MOR (psi)	8300, 6400	3300

1: Two ties were tested, and the properties of both are shown where values of each tie are separated by a comma.

The 14 ties at composites site 2 experienced 100 million tons worth of freight cycles at the Pueblo, CO, FRA test track. These ties do not have end caps; i.e. no composite material covered the ends of the wood ties. These ties were not continuously used along the rail line (e.g. the composite wrapped wooden ties were every 10th tie along the rail line). These ties were installed in the same manner as the composites site 1 but were noticeably less distressed from installation. The freight tonnage at the composites site 2 was stated to be roughly 20% of that at the composites site 1. A center to center spacing of 19.5 inches is typical for railroad ties. Site 2 typically used 100-lb. rail.

4.5 Wooden Tie Rehabilitation Discussion

Wooden tie rehabilitation provides a sustainable option for the approximately 20 million ties that are replaced in the railroad industry annually. Research has shown that a wooden core from a wooden tie that requires replacement can be rehabilitated with a GFRP wrap for installation with an expected life of up to 75 years (Bharil and GangaRao, 2020). In situ rehabilitation has been explored as well by Al-Chaar et al. (2019) with the injection of flowable materials to restore load-carrying capability.

Some questions remain with the "repair in place" wooden tie rehabilitation process. Quality control on the pre-repair condition of the wooden tie is critical to rehabilitation success. Factors such as deteriorated wood removal, debris removal, and moisture content are important. Curing time for the injected material along with the environmental conditions during that curing time are also critical. Equipment required to prepare the wood ties and inject the material would also have to be obtained. The impact of these factors could limit the incorporation of this in-situ rehabilitation technique on a broad basis.

The GFRP wrap process doesn't change normal operating parameters for current wooden tie replacement. The wooden ties would be rehabilitated after removal from service, so new or rehabilitated ties would have to be on-hand for installation as damaged ties were being removed from service. The rehabilitated wooden ties are installed in the same manner and with the same equipment as new wooden ties, but some damage due to installation has been noted, so some adjustments to those processes or equipment might be necessary. Electrical conductivity (impedance) testing of composite ties (wooden core with either thermoset or thermoplastic shell) by TTCI, Pueblo, CO, verified their suitability for installation in U.S. railroad track networks (Houshmandyar, 2013). Cost of rehabilitation compared to new wooden tie purchase will also be a factor of significant importance with regard to implementation of GFRP-wrapped composite ties.

CHAPTER 5-SUMMARY, CONCLUSIONS, AND PATH FORWARD

5.1 Summary

Railroad ties can be constructed from materials other than wood. RPL and wood-based composite ties have been studied for effectiveness and improved performance characteristics compared to traditional treated wood ties. When properly designed and fabricated, there are potential options to provide longer service lives compared to wood. RPL ties are inherently resistant to many forms of environmental degradation such as rot and insect attack, and wrapped composite ties seem to have similar characteristics. It is somewhat unclear how the wooden ties repaired in situ will respond to long-term environmental exposure, and that answer may vary with the amount of original material replacement that is done through the rehabilitation process.

Changes in installation methods may be required if wooden ties are to be replaced with RPL or wrapped composite ties. Tie damage has been documented due to installation with both types of ties. RPL ties have experienced gage problems at installations that were completed during the summer months, so tie plate spacing guidelines during installation may need to be determined based on temperature or season or tie manufacturer or perhaps even based on specific manufacturing runs from a given manufacturer. Damage during installation to the GFRP wrapping could cause premature damage to the wooden core of rehabilitated composite ties. Some RPL ties have shown a need for pre-drilling for screw spike usage rather than cut spike usage, and such parameters may impact the usability of the ties if suitable installation procedures can’t be followed for any reason.

5.2 Conclusions

RPL railroad ties can be used within military railroad infrastructure and could be part of responsible recycling to address the plastic crisis, pending proper standards. Without proper standards, RPL railroad ties are a questionable form of recycling. A SWOT analysis through literature review revealed strengths of RPL ties and successful installations. However, data collected through USACE-ERDC from both test track and material testing revealed variability in RPL and composite tie performance. Specific testing targeted the capability of ties to maintain track gage and support anticipated loads. General trends in tie performance were noted which included seasonal variation in gage, temperature-dependent ductility, and lower load-carrying capacity than wooden ties. This data indicates a need for clear performance specifications to prevent post-installation track usage problems which can impact military readiness and response times and therefore national security. Incorporation of RPL ties tested herein wouldn’t reduce maintenance or increase reliability of military railway infrastructure, but opportunities have been identified to accomplish those goals while also making an impact on the plastic crisis.

Wooden tie rehabilitation procedures have been identified and tested. Rehabilitation in situ is possible with an experimental procedure documented by Al-Chaar et al. (2019). The procedure hasn’t been scaled to field use, but it certainly shows promising potential. GFRP wraps over discarded wooden cores have been demonstrated to produce ties with suitable performance characteristics and life expectancy in the range of 75 years (Bharil and GangaRao, 2020). Lab-scale wrapping has been utilized already, but it is believed that the procedures could be scaled up effectively to manufacturing-scale speed and output.

5.3 Path Forward

Research targeting performance specifications for RPL ties could identify the key parameters that are most effective at predicting tie performance and is recommended. Installation procedures for RPL ties should also be developed in an effort to mitigate specific poor performance characteristics of the material itself like splitting and breaking upon cut spike installation. RPL ties which cannot be supplied with sufficiently consistent performance characteristics must be identified and kept out of the supply chain. A pre-installation testing methodology for new RPL ties should be considered to ensure performance. Novel considerations for installations such as specific inter-mixing with wooden or composite ties might also be considered so that the final result is a reliable track for military rail applications. An example of such an installation methodology would be to replace every third tie in an installation of RPL ties with a wooden or composite tie.

Additional research into the use of fiber reinforced polymer composite material for remanufacturing discarded wooden ties should be conducted. Some initial estimates are that these remanufactured ties might be able to have 75-year service lives. Remanufacturing investigations should consider the economics of performing local (perhaps on-site) remanufacturing versus building centralized facilities that could perform activities in a mass production environment. Non-destructive quality control protocols like infrared thermography also need to be developed or employed to ensure acceptable properties of the remanufactured ties. Remanufacturing should also consider use of wooden chips or sawdust that could serve as core material that could be compression molded to re-produce the proper shape of tie that would be subsequently GFRP wrapped. Resin and filler options should also be explored (e.g. phenol RF, polyurethane, epoxy and primer).

Research into adding GFRP wraps to new wooden or RPL ties might also have merit. If recycled ties can benefit from GFRP wraps to improve performance and extend life, similar or perhaps better performance gains could be made with new ties. Timber resources could produce more ties if the overall tie size was reduced to accommodate GFRP wraps. If original service life from GFRP-wrapped ties could be extended by 25 or 50 or more years, it might be worthwhile to invest in the wrapping before the tie is put into service rather than utilizing it only after an initial service life has been exhausted. Perhaps the GFRP wrap could completely replace creosote treatment and result in a more environmentally friendly wooden tie. With regard to wraps on RPL ties, composite ties of this nature might prove to be more durable and less susceptible to seasonal dimensional changes.

RPL crossties have not been fully evaluated by engineers with the United States Army Corps of Engineers (USACE), and at present it is recommended they not be used in any new construction or repair without updated standards. The United Facilities Criteria (UFC) does not have required specifications regarding properties of RPL or composite crossties. Due to the lack of clear specifications, effective assurance that DoD rail owners receive a high-quality crosstie that also protects the DoD’s investment into track assets is elusive. In addition to the test sections described earlier in this report, ERDC has built test sections at the station in Vicksburg, MS where experiments are also ongoing.

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