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Evaluation of Engineered Polymer Composite Tie Bending Properties

Mike McHenry and Brach Prough

Summary

Transportation Technology Center, Inc. (TTCI) is currently conducting research to evaluate the performance of engineered polymer composite (EPC) ties and improve design guidelines and industry recommended practices. Composite ties offer a potential alternative to creosote treated wood ties, particularly in areas of high rot or high decay.

This report presents results from center bending testing conducted on a variety of EPC ties. EPC ties from three major suppliers (Axion, American TieTek, and IntegriCo) were randomly selected from railroad and supplier inventory for testing. Additionally, samples from two types of EPC ties that had accumulated tonnage at FAST since 2000 and 2004 were tested. Bending test results thus far indicate:

- Axion ties are significantly stiffer (higher modulus of elasticity) than ties from IntegriCo. American TieTek ties were the least stiff, with an average modulus of elasticity below the current American Railway Engineering and Maintenance of Way Association (AREMA) recommended minimum.
- The two sets of EPC ties from previous FAST testing did not experience any failures and many of these ties have an MOE below the AREMA recommended minimum.
- Almost all individual composite ties tested had MOR values above the current AREMA recommended minimum of 2,000 psi.

Bending properties were compared with in-track loading simulations and tie handling and installation stresses previously measured and reported by Reiff (2014).[1] Key recommendations include:

- Tie unloading, tie insertion, and nipping/spiking procedures may generate high enough loads to exceed the current AREMA recommended minimum ultimate bending strength (MOR) for composite ties. An increase to this recommended criteria is warranted.
- Static bending tests, and particularly the MOR parameter, are recommended as an indicator of performance during installation and handling.
- In-track loading (assuming well supported conditions) does not generate high enough stresses to exceed the ultimate bending strength (MOR) for EPC ties.
- There is a need for a composite tie bending fatigue test that may better address observed in-track craking failures. EPC ties with high stiffnesses have been observed to crack at higher rates under repeated in-track loading. These cracks may initiate at voids or other stress concentrators. Future work will focus on further understanding EPC tie fatigue.

EPC tie performance is being assessed with in-track testing conducted at FAST and in revenue service on a Class I railroad. TTCI is working closely with AREMA Committee 30 to implement recommendations and improved design guidelines in AREMA's *Manual for Railway Engineering*.

Please contact **Mike McHenry (719) 584-0605** with questions or concerns regarding this *Technology Digest.* E-mail: mike_mchenry@aar.com.

INTRODUCTION

TTCI is conducting research to enhance the design and testing guidelines in the AREMA *Manual for Railway Engineering* for EPC ties as an alternative for wood crossties. This digest presents results from an analysis of bending properties of EPC ties and a comparison with loading environments experienced during tie installation and in-track. This work is part of an ongoing AAR Strategic Research Initiatives project to improve the design and testing guidelines for composite ties in Chapter 30 – Ties. Improved recommendations for the industry will target specific characteristics of EPC ties and relate laboratory testing with in-track performance.

Ties and fasteners act together as a system to transfer vertical and lateral load applied at the wheel-rail interface into the ballast, and to maintain sufficient track geometry. Over 90 percent of Class I railroad track miles utilize wood crossties. In areas prone to rot and decay, wood ties may remain serviceable for less than 10 years before replacement is necessary often due to plate cutting and loss of gage strength. These types of environments present an opportunity for an alternative tie that may offer a longer lifecycle with similar performance. The railroad industry seeks to further the development of EPC ties as a one-for-one alternative for wood crossties – that is, a tie that can be integrated into existing tie handling and installation practices and provide compatibility with wood tie fastening systems and maintenance activities.

BACKGROUND

EPC ties are the most common type of composite ties in the industry, but account for less than 1 percent of the total crosstie market. EPC ties are generally composed of post-consumer recycled plastic. Additives or fillers and fiber or particle reinforcement may be added to enhance properties.[2] EPC ties have been in development in the United States since the mid-1990s.[3] One Class I railroad has reported over 1 million composite ties installed on its system, with a history of inconsistent performance. Railroads have observed center cracking, rail seat cracking, and spike hole cracking on EPC ties in service, and cracking of ties during unloading and installation. However, a select set of composite tie test zones have performed well in revenue service and at FAST.[4] Given their mixed performance history, uncertainty persists on how best to assess performance through qualification laboratory testing.

TEST SETUP

EPC ties from three major suppliers – Axion, American TieTek, and IntegriCo were selected from railroad and supplier inventory for inclusion in this study. Samples were composed of ties randomly selected by TTCI test engineers to provide a representative sample of ties produced over at least three different months of production. As ties were selected from inventory, all had passed through their respective suppliers' quality control procedures in place at the time. From each sample, 25 ties were randomly selected for laboratory center bending tests.

Used EPC ties from two previous FAST test zones were also incorporated into this study, TieTek ties, installed in 2000, and RTI ties, installed in 2004. These ties had accumulated 2,155 and 1,690 MGT respectively before being removed in 2015. In both zones, no tie structural cracking was observed. Raised cut spikes and spike kill were the ultimate failure modes that necessitated removal. Including these ties in the study allowed properties to be determined for ties with proven in-track performance and no history of center cracking at FAST.[4] Mixed hardwood ties were also tested for comparison. All ties had 9-inch by 7-inch cross sections. Table 1 shows the six tie types considered in this study.

Table 1. Tie types tested for the center bending study

Tie Type	Notes
New Axion	Random selection of production between 2014 and 2015
New American TieTek	Random selection of production between 2014 and 2015
New IntegriCo	Random selection of production between Dec. 2015 & Feb. 2016*
Used TieTek	Installed in 2000 at FAST, accumulated 2155 MGT before removal in 2015
Used RTI	Installed in 2004 at FAST, accumulated 1,690 MGT before removal in 2015

**From new IntegriCo plant – Spring Hill, LA*

CENTER BENDING TESTING

Center negative bending tests were conducted on 25 ties of each of the six types following AREMA Test 1C, shown in Figure 1. Load was applied at a deflection rate of 5 inches per minute, recommended practice for composite ties.[2]

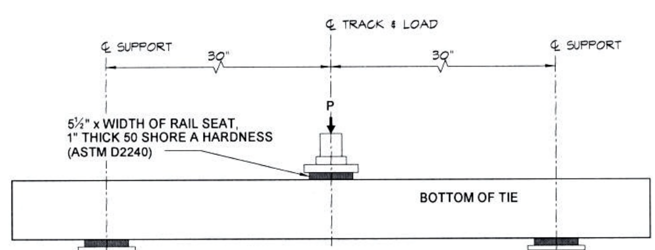

Figure 1. Test setup for AREMA Test 1C – Bending – Center Negative, showing the support conditions and 60-inch span.[2]

Load and deflection were recorded until the tie reached ultimate failure, or the stroke of the actuator (equal to ~6 inches) was reached. Modulus of Elasticity (MOE) and

Modulus of Rupture (MOR) were calculated for each test. The applied load at maximum actuator stroke was used to compute MOR for ties that exhibited load-deflection curve plateuing. Figure 2 shows MOR plotted against MOE for all 25 center bending tests for each of the five EPC tie types tested.

Generally, data points for each tie type fall within a grouping (circled), some more consistent than others.

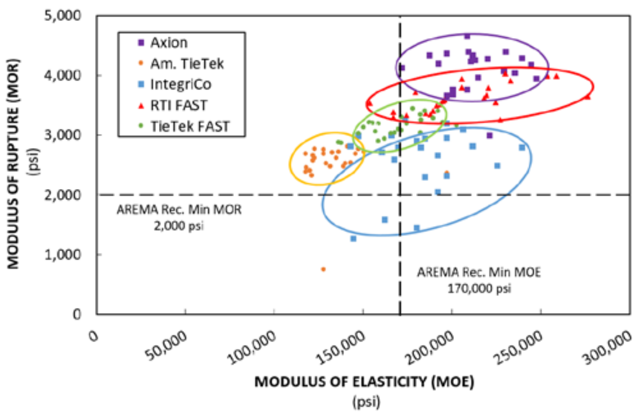

Figure 2. MOR plotted against MOE for 25 Bending Tests conducted on each of the Five EPC Tie Types

The new Axion ties had the highest average MOE and MOR. Both the new American TieTek and TieTek ties from the FAST test zone had average MOEs below the current AREMA recommended minimum. The AREMA recommended minimum MOR of 2,000 psi was exceeded for all but four individual ties. Figure 2 shows a fairly wide range of composite tie performance properties.The MOE and MOR for the mixed hardwood control ties ranged from 211,000 psi to 775,000 psi and from 6,100 psi to 9,200 psi, respectively, indicating the inherent variability in wood properties.

EPC TIE LOADING ENVIRONMENT

A tie will experience bending in service caused by installation and handling procedures and from passing axle loads once installed. The bending moments that are generated in-track increase somewhat with higher axle loads. But they increase more significantly with undesirable support conditions (tie center binding or reduced support beneath the rail). Two key bending moments are typically used to characterize bending stresses placed on a tie – the center negative bending moment and the rail seat positive bending moment. As the EPC ties tested have the same cross-section throughout their length, it is rational to compare the center negative bending moments generated in Test 1C with rail seat positive bending moments.

GEOTRACK™ (a 3-D elastic multi-layer track structure model)[5] was used to simulate the bending moments that could be expected for a variety of composite tie stiffnesses and applied wheel loads. EPC tie stiffnesses were varied from 120,000 psi to 220,000 psi, using the AREMA recommended minimum of 170,000 psi as the base case. Wheel loads of 20 kips, 50 kips, and 80 kips were used to generalize loads from empty car, loaded car, and peak dynamic wheel load cases respectively. Representative stress-dependent ballast stiffness and "medium" subgrade stiffness (q_u = 1.0-2.0 kips/ft^2) were used.[5] For comparison, cases were simulated for a stiff wood tie with an MOE of 1,300,000 psi.

Bending moments at the tie center and at the rail seat of the tie were estimated for the tie directly below the applied wheel load for each combination of tie stiffness and wheel load magnitudes.

Figure 3 shows that the equivalent center bending loads required to produce this range of bending moments for composite ties were all below 5 kips. As expected, stiffer ties carried higher bending moments. Additionally, tie deflections beneath the loaded rail seat were estimated to be less than 0.20 inch. The GEOTRACK analysis simulated uniform, nominal support conditions. It is recognized that more severe bending moments could easily be generated with center bound support conditions (center negative moments) or reduced support beneath the rail (rail seat positive moments). These severe conditions, however, generally develop over time after installation when fatigue becomes a greater influence. The effect of support conditions on composite tie bending is continuing to be studied.

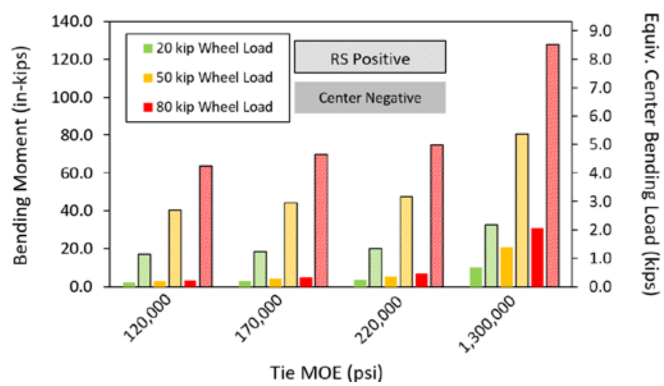

Figure 3. Center and Rail Seat Bending Moments from GEOTRACK Simulations

It is also desirable to understand the loads applied to the tie during handling and installation. Reiff measured the bending stresses in EPC ties during a typical installation process – insertion, nipping, and spiking and in drop tests to simulate severe tie unloading situations.[1] Table 2 summarizes the peak bending moments and equivalent center bending loads (in Test 1C) reported from this study.

Table 2. Peak Bending Moments and Equivalent Center Bending Loads for Installation and Handling Events (Reiff)

Event	Equiv. Center Bending Load in AREMA Test 1C (kips)	Equiv. Center Bending Moment (in-kip)
Insertion*	11.8	177
Nipping/spiking	10.6	159
Drop Test**	16.5	247
AREMA Min. MOR (2,000 psi)	9.8	147

Figure 4 shows representative load versus deflection curves (from regression analysis) for the five EPC ties from the laboratory center bending tests and how they compare with equivalent center bending loads simulated in the GEOTRACK analysis and equivalent center bending loads in Table 3. The equivalent center bending load resulting in the AREMA minimum recommended MOR of 2,000 psi is also shown for comparison.

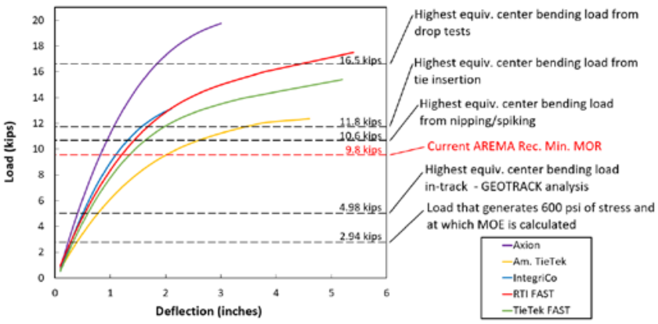

Figure 4. Load-deflection curves for the five EPC tie types compared to simulated in-track and handling/install loads[1]

CONCLUSIONS

The AREMA center bending test represents a worst case support condition and acts to apply a severe bending moment to the center of the tie. MOR, or the ultimate strength of the tie in bending, determined from this test, should be used to provide an indication of the tie's performance in singular one-time bending situations at high deflections such as those observed during installation, nipping/spiking procedures and drops during unloading. Peak loads observed during simulated drop tests are likely to exceed the ultimate strength of EPC ties. Previously measured insertion and nipping/spiking stresses exceed the current AREMA recommended minimum MOR (2,000 psi), suggesting an increase of this criteria may be warranted. Additionally, ongoing work seeks to provide "best practices" for the handling of EPC ties.

There is little evidence to suggest that higher stiffness (MOE) is indicative of how an EPC tie may perform in-track under repeated, but much lower bending moments than applied in the AREMA center bending test. In fact, the TieTek ties installed at FAST between 2000 and 2015 have an MOE slightly lower than the AREMA recommended minimum and remained serviceable without any cracking for 2,155 MGT. Very stiff composite ties have been observed to have higher rates of cracking on one Class I railroad. However, lower MOE may increase tie plate bending stresses and plate fatigue cracking.[6] The effect of tie stiffness on in-track performance continues to be studied.

A NOTE ON FATIGUE

Figure 3 indicates that the realistic range of bending moments in-track from an applied axle loads likely do not approach the ultimate strengths of EPC ties. Observations of cracked ties in-track at FAST and in revenue service post-installation suggest that fatigue failures can initiate at internal voids or stress concentrations inside of the tie cross section. It is clear that fatigue criteria should be established for composite ties. Ongoing and future work will consider the fatigue characteristics of EPC ties and life cycle testing.

ACKNOWLEDGEMENT

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