

The research described was performed by Transportation Technology Center, Inc., a wholly owned subsidiary of the Association of American Railroads.

Key Findings:

- This study shows that the thermal effect on EPC ties can lead to an increase in track gage. The amount of gage widening did not move tracks out of class in the simulation cases; however, the allowable margin of gage widening from other causes (for example, vehicle dynamics, tie plate cutting, etc.) could be reduced.
- The model showed that the EPC ties bent if the heat source (simulated direct sunlight) was applied to the top surfaces of the ties.
- The gage widening was reduced when EPC ties with a higher thermal conductivity were used.

Thermal Effects on Track Gage of Engineered Polymer Composite Ties

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[TTCI](#) has been evaluating the performance of engineered polymer composite (EPC) ties and has been working to improve design guidelines and recommendations since the early 2000s. EPC ties, used in North American revenue service for over two decades, are the most common type of composite ties and offer a potential alternative to solid sawn timber ties. These materials are especially attractive for use in regions where wood is susceptible to degradation by moisture and decay organisms.

Recent research under the Association of American Railroads' (AAR) Strategic Research Initiatives Program found that track supported by EPC ties experienced more gage widening variations due to temperature changes than track supported by wood ties at the Facility for Accelerated Service Testing (FAST), Pueblo, CO. Specifically, the track gage was about 0.2 inch wider in the afternoon than in the morning for tracks with EPC ties. It is believed that the direct sunlight in the afternoon makes the top surface of the ties expand more than the other parts of the ties, thereby causing EPC ties to bend and widen the track gage. This *Technology Digest* presents field measurements documenting the track gage changes due to thermal influence and presents results of computer simulations that show how temperature affects EPC tie performance.

INTRODUCTION

Over 90 percent of Class I railroad track miles use wood ties. Wood ties may remain serviceable for less than 10 years in areas prone to decay before replacement is necessary, which is often due to plate cutting and loss of gage strength. The railroad industry seeks to further the development of EPC ties—generally composed of post-consumer recycled plastic additives, fillers, and fiber or particle reinforcements—as an alternative for wood ties as they may be used to enhance specific properties.¹ However, EPC ties have a higher thermal expansion coefficient than wood, concrete, or steel.¹ Theoretically, this means that EPC ties could grow longer or shorter with changes in temperature as compared to the other tie materials under the same temperature conditions, affecting track gage.¹ Moreover, recent in-track unloaded gage measurements at

FAST showed that track supported by EPC ties experienced 0.2 inch of gage widening due to temperature changes throughout one September day. The gage widening was consistent for all three types of EPC ties tested and was much higher than that for the wood tie zones.^{2,3} A preliminary numerical thermal analysis using finite element modeling is presented here to further understand how temperature affects the performance of track supported by EPC ties.

FIELD OBSERVATION

In the fall of 2016, track gage measurements at FAST were taken at different times throughout a single day using the Federal Railroad Administration’s (FRA) T-18 track geometry inspection vehicle. Unloaded gage measurements were taken on three EPC tie zones and wood/concrete tie zones in the same curve. At the time of each test run, tie temperatures were measured for one tie sample in each test zone. The tie temperatures at different locations on the ties’ tops and bottoms (measured from tie end and side) were measured. Ambient temperatures were also recorded. The gage measurement channel from the lowest tie temperatures was recorded at 7:30 am, and the measurement channel from the highest tie temperatures was recorded at 2:00 pm.

Figure 1 shows the ambient temperature and the temperatures recorded on different parts of a tie at the lowest and highest temperatures of the day.

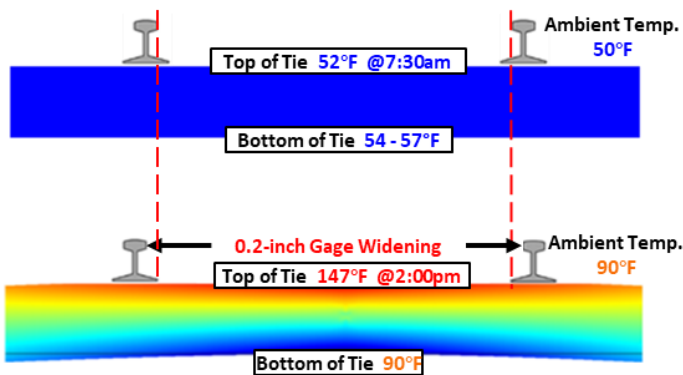


Figure 1. Temperature measurements and gage widening at FAST

The plot also depicts the general observation that the bottom of the tie tends to remain insulated by the tie itself and the crib ballast. This behavior creates a thermal gradient and generates center negative bending. Linear expansion of the tie coupled with this bending resulted in about 0.2 inch of gage widening, consistent between all three EPC tie zones.

No measurable gage increase was observed in the adjacent wood or concrete tie zones throughout the day.^{3,4}

MODEL DESCRIPTION

The in-track gage measurements suggested that EPC ties can thermally expand and generate measurable gage widening. To further investigate this issue, a finite element model was established to investigate the thermal effect on EPC ties. The model included two short pieces of rails, two American Railway Engineering and Maintenance-of-Way Association (AREMA) 14-inch tie plates, one EPC tie, and a supporting ballast layer (Figure 2). The steady-state thermal analysis was used to model the effects of steady thermal loads on the system and to quantify gage widening due to the temperature changes.

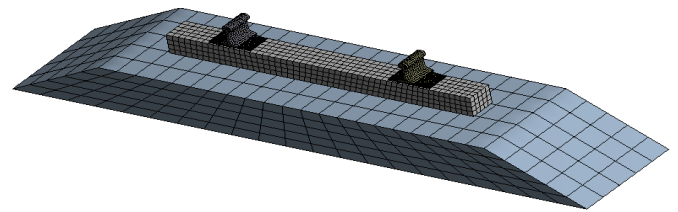


Figure 2. The schematic of the finite element model

As shown in Figure 3, heat sources were applied on the rails and the top surface of the EPC tie (red area) excluding the tie plate area. The convection areas were at all surfaces of all the components in the system. As this was a preliminary study on the thermal effect of EPC ties (not specific to any type of tie), the typical mechanical properties of each component were used in the model, as listed in Table 1.

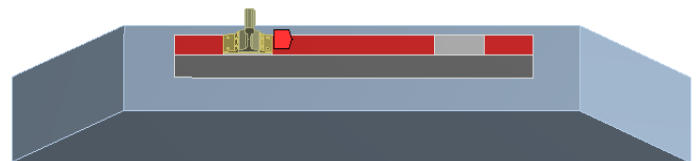


Figure 3. Simulation of direct sunlight on the track

Table 1. Model parameters

Parameter	Value
Wheel load (lbs.)	36,000
EPC Tie modulus (ksi)	200
EPC Tie Poisson’s ratio	0.45
EPC Tie coefficient of thermal expansion (in./in./°F)	Varied
EPC Tie thermal conductivity (W/(m·C))	Varied
Ballast modulus (ksi)	36
Ballast Poisson’s ratio	0.27
Ballast thermal conductivity (W/(m·C))	0.4 ⁵

MODELING RESULTS

Gage widening was calculated under eight simulation scenarios by changing three parameters: coefficient of thermal expansion (CTE), thermal conductivity (TC), and temperature condition, as listed in Table 2. The CTE of 3.5×10^{-5} in./in./°F is the lowest value of the three types of EPC ties on the FAST track; the CTE of 5×10^{-5} in./in./°F is the average value of the three types of EPC ties on the FAST track; and the CTE of 7.5×10^{-5} in./in./°F is the maximum allowable value in the AREMA *Manual for Railway Engineering*. The TC of 0.45 W/(m·C) is typical for high-density polyethylene⁶, which is the typical EPC tie material; 1 and 10 W/(m·C) are considered to be high but reasonable TC values for polymer compounds.⁷

Table 2. Modeling parameters in simulation cases

Case No.	CTE (in./in./°F)	TC (W/(m·C))	Ambient Temperature	Tie Top Surface Temperature
1	3.5×10^{-5}	0.45	90°F	147°F
2	5.0×10^{-5}	0.45	90°F	147°F
3	7.5×10^{-5}	0.45	90°F	147°F
4	3.5×10^{-5}	0.45	50°F	147°F
5	5.0×10^{-5}	0.45	50°F	147°F
6	7.5×10^{-5}	0.45	50°F	147°F
7	5.0×10^{-5}	1	90°F	147°F
8	5.0×10^{-5}	10	90°F	147°F

Cases 1, 2, and 3 were meant to simulate the actual in-track temperature conditions in the FAST test for EPC ties with different CTEs. Cases 4, 5, and 6 represented extreme differential temperatures between the top surface of a tie and the ambient temperature. Cases 7 and 8 increased the TC values using the parameters in Case 2 as a baseline.

The in-track temperature and gage widening measurements at FAST were used to verify the model. The CTE was assumed to be 5×10^{-5} in./in./°F for all three types since they showed a constant gage widening in the FAST test. The modeling results show a 0.19-inch-wide gage that was close to the in-track measured value of 0.20 inch (Figure 4). The resultant temperatures on the tie’s bottom (93°F) closely matched the actual measurements (90°F).

For each simulation case, track gage was first calculated at a low-temperature condition with ambient temperature

and all components at 50°F, and then at a high-temperature condition (simulated direct sunshine on the tie tops), which is listed in Table 2 for each case. The gage widening values for each simulation case was the difference between the two track gage values calculated above, as listed in Table 3.

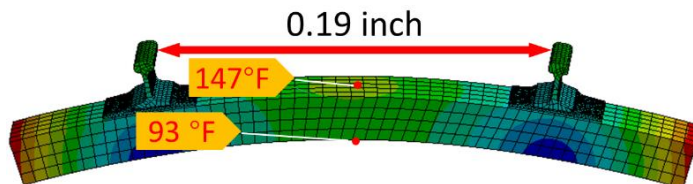


Figure 4. Simulation of the in-track results for model verification

Table 3. Gage widening in each case

Modeling Cases	Gage Widening (in.)
Case 1	0.10
Case 2	0.19
Case 3	0.26
Case 4	0.12
Case 5	0.21
Case 6	0.29
Case 7	0.18
Case 8	0.14

The allowable gage widening for different track classes by FRA Track Safety Standards is shown in Table 4 is a comparison. Based on the results, none of the gage widening caused by the thermal effect on EPC ties exceeded the FRA track safety standards. However, track gage widens due to many superimposed causes, including installation tolerances, loading over time, rail gage face wear, plate cutting/reverse rail cant, and spike kill.

Table 4. Allowable gage widening from FRA Standards § 213

Track Class	Gage Widening (in.)
Excepted track	1.75
Class 1	1.5
Class 2 and 3	1.25
Class 4 and 5	1.0
Class 6 and above	0.75

If a Class 4 or 5 track is built at a 56.5-inch track gage with EPC ties, the amount of class-specific gage widening may be reduced by at least 10 percent (Case 1) right after construction, and possibly even higher (29 percent in Case 6) for the tracks supported by EPC ties.

Comparing Case 1 to Case 6, two obvious and reasonable observations can be made: 1) track gage widened more as the CTE of EPC ties increased; and 2) track gage widened more as the differential temperature between the top surfaces of the ties and the ambient temperature increased. Moreover, Cases 2, 7, and 8 showed decreased gage widening with increased TC values. The temperature field was more uniform in ties with a higher TC, making the tie bend less. Therefore, a higher TC could reduce the gage widening effect of EPC ties.

CONCLUSIONS

A finite element model was built to investigate the thermal effect on the performance of EPC ties. The results from this modeling work showed:

- The track gage widening ranges from 0.10 inch to 0.29 inch in the eight simulation cases with changes in temperature conditions, the coefficient of thermal expansion, and the thermal conductivity of EPC ties.
- The magnitude of gage widening in the modeling did not exceed the FRA safety standards for any track class, but thermal gage widening could reduce the amount of gage widening from other causes without altering track class.
- The gage widening is predicted to be smaller with the use of EPC ties with a higher thermal conductivity.

Future work will continue to investigate thermal effects on the in-track performance of EPC ties and will provide test and simulation support to AREMA for improving recommendations for EPC ties as it relates to:

- Track safety and applicable track classes.
- Appropriate CTE and TC values based on track class/acceptable gage widening.
- Appropriate environment(s) to be installed.

The results of future work will continue to be shared and discussed within AREMA Subcommittee 6 – Composite Ties (under the parent Committee 30). Participation and leadership on Subcommittee 6 will continue to be an objective of this research project, supporting the ultimate goal of improved design and testing guidelines for EPC ties.

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