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Development of Laboratory Fatigue Tests for Engineered Polymer Composite Ties

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Key Findings:

- TTCI developed a new laboratory fatigue test for engineered polymer composite ties to address the center cracking issue. The test setup is a deflection-controlled four-point bending test. The test criterion is 1.5 million cycles, or tie failure; whichever comes first.
- Results showed that the new lab test method was capable of replicating the failure mode (center fatigue cracking) that has been observed in track.
- The method showed the potential in quantifying fatigue performance and indicating how EPC ties will perform in track.
- Further development of the center bending fatigue test will help to better understand and refine the test design, which would eventually result in better recommendations to the industry.

Transportation Technology Center, Inc. (TTCI) has been conducting research since early 2000s to evaluate the performance of engineered polymer composite (EPC) ties and improve design guidelines and recommendations. In-track observations in revenue service and at the Facility for Accelerated Service Testing (FAST), Pueblo, CO, have shown that the center fatigue cracking is one of the failure modes of EPC ties. This fatigue failure normally is associated with the large internal voids inside of the tie cross section according to visual observation. The recommended bending test in the American Railway Engineering and Maintenance-of-Way Association (AREMA) *Manual for Railway Engineering* could not address this failure mode. Thus, a new laboratory fatigue test was developed by TTCI to predict EPC tie performance under repeated train loads and to improve design, quality control, and fatigue performance criteria for EPC ties. The findings will be recommended to AREMA Committee 30-Ties.

Strain test data gathered at FAST and in revenue service was used as inputs for the laboratory test development. Since EPC ties have large performance variations, a load amplification factor was applied to the average in-track strain values for the design of laboratory test. A four-point bending setup was chosen for the ability to apply a constant, maximum bending moment to a 30-inch zone in the middle of a tie. This has the advantage of putting more cross-sectional material under the maximum testing moment. In several initial runs, EPC ties showed a creep behavior of increasing deflection under a constant actuator load. Therefore, the four supporting locations were rigidly fixed to the spreader bar and the support bases using four clamps to make sure the tie and the actuator have in-phase motion.

More than 90 percent of Class I railroad track miles use wood crossties. In areas prone to rot and decay, wood ties may not remain serviceable for 10 years before replacement is necessary. These types of environments present an opportunity for an alternative tie that may offer a longer life cycle with similar performance.

Through research sponsored by the Federal Railroad Administration (FRA), in collaboration with the Association of American Railroads' (AAR) Strategic Research Initiatives program, three types of EPC ties were installed and studied at FAST and in revenue service to improve design and testing recommendations. The in-track performance at FAST showed that 12 percent of the EPC ties experienced center cracking within 230 MGT, as shown in Figure 1. However, the in-track strain measurements suggested that the strain values at the tie center were far below the tie ultimate bending strength. Therefore, a fatigue failure is believed to be the failure mechanism. The existing AREMA recommended laboratory testing has not proven to be effective in identifying this fatigue failure prior to in-track installation, highlighting the needs for a new and more representative test.

Figure 1. Center cracking of EPC ties

To satisfy this research need, TTCI proposed a new laboratory center bending fatigue test to address this center cracking issue. In this *Technology Digest,* development considerations of this test, such as test setup and parameters are presented. The proposed test criterion is up to 1.5 million loading cycles, or tie failure; whichever comes first. The 1.5 million cycles are equivalent to more than 200 MGT of heavy axle load traffic.

Further development of this test is needed to better modify the test design and give better recommendations to AREMA.

IN-TRACK STRAIN MEASUREMENTS

To better understand the loading environment of EPC ties and develop a laboratory test, strain gages were installed at the center top and rail seat areas of the ties (Figure 2). Strain data was collected for different types of composite ties (Type A, B, C), various train speeds and loads, and at different times of day. Nine ties were selected at FAST (three consecutive ties in each of three test zones), and eight ties were selected at the western mega site on Union Pacific (UP) territory (four consecutive ties in each of two test zones). The ties in each zone were selected by the test engineer to ensure that no severely hanging ties or ties with loose plates were chosen. Overall, the ties chosen were representative of the ties in the test zones.

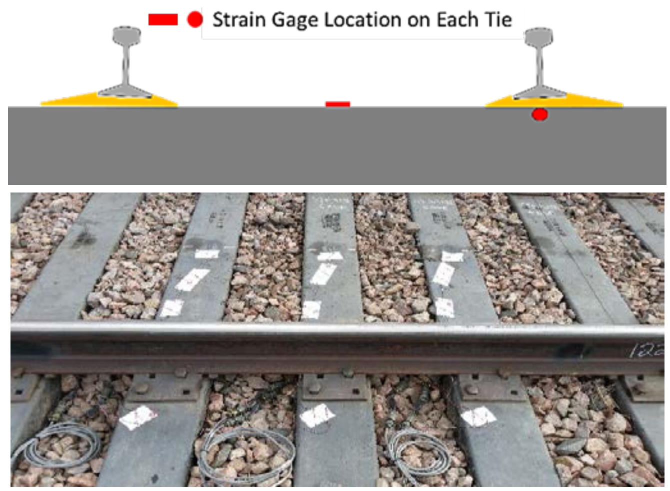

Figure 2. In-track bending strain test

Figure 3 shows a sample result of the center bending strain data collected at FAST for Type C ties. It is worth noting that each cycle of the strain data represents one car. The peak strain of each cycle was obtained for each strain gage measurement during the post-processing of the data. The EPC ties were installed at a 6-degree curve at FAST and FAST cars have higher axle loads than the cars in revenue service. Therefore, as expected, the strain values at FAST were higher than the values in revenue service, as shown in Tables 1 and 2. In addition, the center bending strains were generally higher than the rail seat bending strains. Therefore, only the center bending strain values of each tie type at FAST were used to develop the laboratory fatigue test.

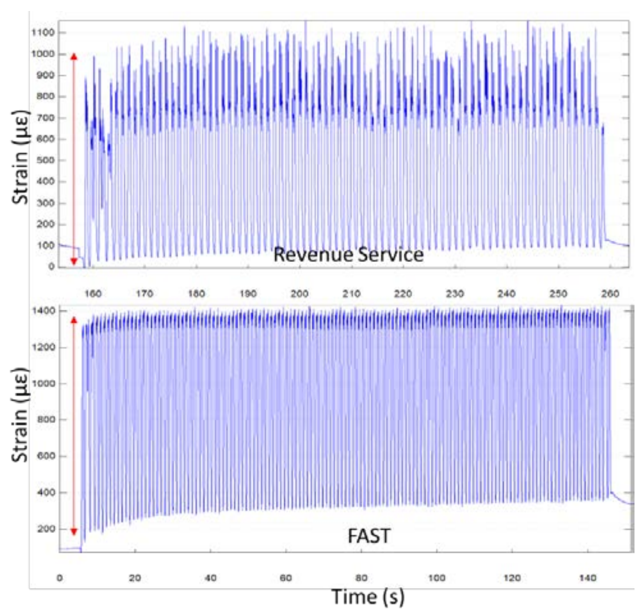

Figure 3. Strain measurements at FAST and revenue service

Table 1. Center bending strain at the UP site

Tie Name	Tie No.	Rail Seat Strain (με)		Center Strain (με)	
		Train 1	Train 2	Train 1	Train 2
Type A	1	522.15	41.22	1073.52	981.75
	2	532.86	550.87	993.08	897.52
	3			1078.98	982.53
	4	432.94	-241.21	939.65	851.17
Type C	1			987.67	920.64
	2	715.38	752.12	958.70	887.62
	3	698.68	713.75	1056.91	961.23
	4	619.51	632.24	907.13	834.26

Table 2. Center bending strain at FAST

Tie Name	Tie Number	Rail Seat Strain (με)	Center Strain (με)	Avg. Center Strain (με)
Type A	1	466.1	1718.1	1701.5
	2	286.6	1681.1	
	3	458.5	1705.4	
Type B	1	937.6	1718.8	1778.5
	2	1384.3	1780.6	
	3	1117.9	1836.1	
Type C	1	372.5	1011.7	1214.4
	2	547.4	1119.7	
	3	244.0	1511.7	

DEVELOPMENT ITERATIONS OF THE TIE FATIGUE TEST

This section presents the development considerations of the EPC tie bending fatigue test and how the proposed test setup was determined from the test iterations. The following parameters were considered in the development process and will be discussed individually in details.

Test setup: According to the in-track observation, the center cracking failure often is associated with the internal voids or defects in the tie center area. Therefore, a four-point bending test setup was designed to create a significant region of constant bending moment in the middle section of the tie, as opposed to only a single point of maximum bending in a three-point test.

Figure 4 shows the test setup. Section AD is the 60-inch outer span (support span), consistent with the AREMA three-point bending test. Section BC is the inner span (loading span) and needs to be determined in this test development. A longer inner span is favored because it can provide a longer constant moment area to have a longer tie section tested. However, a longer inner span reduces the length of Sections AB and CD, and thus increases the shear forces in those two sections resulting tie shear failure instead of bending failure. Loading span to support span is typically a ratio of 1:2 or 1:3 according to ASTM standards (D790, D6272, D7264). Therefore, 20-inch and 30-inch inner spans were used in the test. During tests, the 30-inch inner span was able to generate the tie center cracks without failure by shear, and most of the center cracking failure was found within the middle 30-inch tie section. Therefore, a 30-inch inner span setup is determined to be adequate for this test.

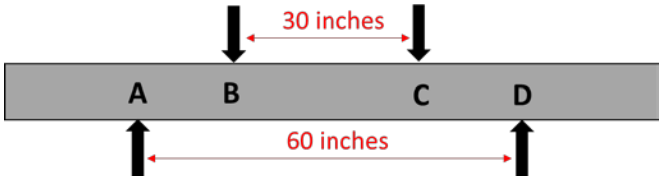

Figure 4. Four-point bending setup

Input load: The average center bending strain values for each type of EPC tie are presented in Table 2. Table 1 data was used as inputs in the fatigue test. Therefore, ties were initially loaded to a strain value corresponding to the strains collected during in-track testing. This amplification factor of two was used to increase the severity of the test. This setup has cracked some ties in the center, which is similar to the in-track failure mode, which proves the concept of this test. The next step will be to standardize the input load based on the in-track measurements and modeling effort.

Fixture modifications: With the test setup and the input load determined, several test runs were made. However, it was found across all tie types and all loading frequencies that the tie did not have enough time to rebound from the applied load. As a result, the desired strain range for fatiguing could not be achieved (see Figure 5).

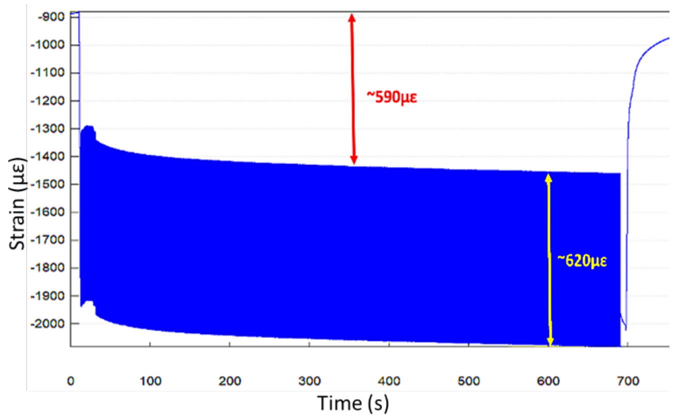

Figure 5. The strain data in the force-controlled test

To obtain the desired strain range, fixtures were used to clamp the tie at the four supporting locations (shown in Figure 7). The purpose of this design was to force the tie back to a near-zero strain value at minimum stroke to more accurately represent what the strain responses were in track (shown in Figure 3). The fixture is pulling the tie back to its initial strain value by attaching the tie to the actuator arm. On its return stroke, the actuator would pull up on the tie; thereby resetting its strain values. The tie was able to be loaded at the desired strain values after adding the fixture as shown in Figure 6.

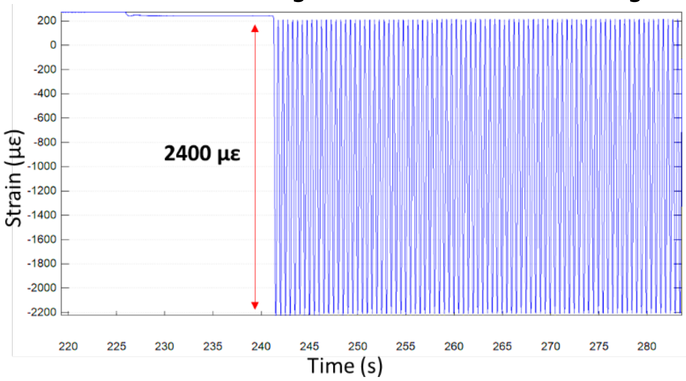

Figure 6. The strain data after adding the fixture

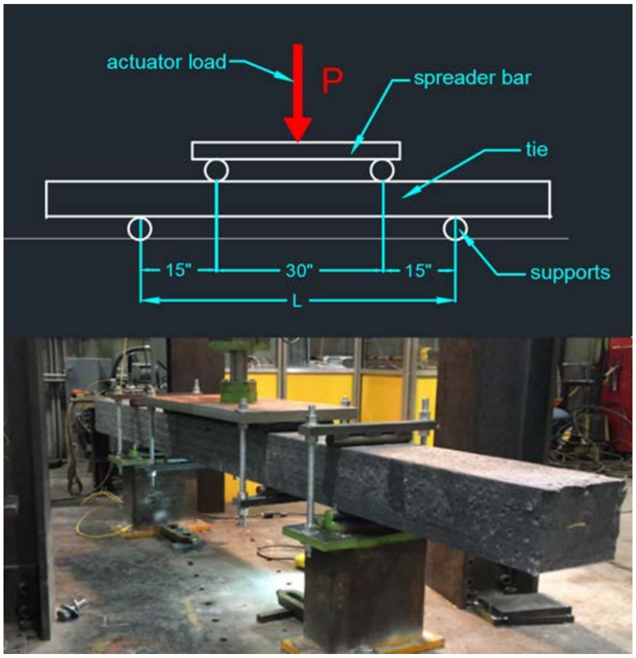

Figure 7. Proposed EPC tie fatigue test setup

Loading Frequency: During testing iterations, three types of ties were cycled at various loading frequencies. Each tie type was cycled from 1 to 10 Hz. This was done in order to determine if loading frequency could be adjusted to maximize stress/strain range for fatigue cycling. The test cycled the tie at 1 through 10 Hz. The tie was able to maintain the desired strain range at all frequencies. However, running at the higher frequencies were pushing the limit on the test machine, causing a potential reliability issue. In addition, running higher frequencies may increase the tie temperature and affect the tie performance. Running at lower frequencies, however, is not efficient for the fatigue test. Therefore, the fatigue test was determined to run at 5 Hz. But this test can be run at other frequencies if the test machine allows and the tie temperature does not change significantly.

CONCLUSION

This report presents how a laboratory center bending fatigue test for EPC ties was developed. Figure 7 shows the test setup.

The current proposed test criterion is up to 1.5 million loading cycles (equivalent >200 MGT of HAL traffic) or tie failure; whichever comes first. A few ties have been tested and broken in a similar fashion to what was observed at FAST and in revenue service. Therefore, the test showed its capabilities in quantifying fatigue performance and being indicative of how EPC ties will perform in track. More test runs using this setup will be conducted.

ACKOWLEDGEMENT

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