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## Evaluation of Tie Plate Cracking on Composite Ties

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### Summary

A study to determine the effect of tie stiffness on the durability of tie plates mounted on plastic and wood ties has been conducted by the Transportation Technology Center, Inc. (TTCI) at the Facility for Accelerated Service Testing (FAST).

Recently, several tie plates mounted to plastic ties have failed under normal operating conditions at FAST, while no tie plate failures have been observed in wood tie sections under the same conditions. A metallurgical analysis, a field test, and a laboratory test were completed to examine possible causes of the tie plate failures.

Three tie test zones were studied, two plastic tie zones and one wood tie zone, during testing on the High Tonnage Loop (HTL) at FAST. Two zones experienced over 900 million gross tons (MGT) of heavy axle load (HAL) traffic, while one zone had over 420 MGT of traffic. The work discussed here provides evidence that the lower stiffness of plastic/composite ties adversely affected the service life of the tie plates under the HAL loads applied at FAST.

Review of laboratory testing and testing at FAST shows that there is a direct relationship between tie stiffness and stress recorded in the tie plate. The test results suggest that plastic ties, which have a lower stiffness than timber ties, allow the tie plates to flex more than those mounted on timber ties, and therefore subject the plate to a higher stress environment. The high-stress, high-cycle load environment that the plates are exposed is causing early fatigue failure in plates supported by plastic ties.

A direct comparison of tie plate performance was made between wood ties and plastic ties in a 6-degree curve on the HTL using three separated 100-tie test zones. Approximately 16 percent of the tie plates mounted on one type of plastic tie on the high rail of the curve cracked on the field side of the rail under 39,000-pound wheel loads during 900 MGT of traffic. In a nearby plastic tie zone, with over 420 MGT, 3 percent of the high rail tie plates experienced identical failures. None of the tie plates on wood ties cracked during 900 MGT of traffic.

Because plastic ties are commonly being introduced as a direct substitution for wood ties, TTCI recommends continued investigation into the occurrences of broken plates in revenue service. Along with the fatigue analysis that is in progress and will be reported separately in another digest, it is recommended that a Finite Element Analysis be performed to determine the stress levels experienced at the crack initiation point. Understanding all of the factors contributing to the tie plate failure can help produce guidelines for preventative measures to eliminate the opportunity for tie plate cracking.



**INTRODUCTION**

As part of the program to enhance performance of railroad tie and fastener systems, TTCI is conducting experiments to demonstrate long-term performance of plastic crossties at FAST. Recently a number of broken tie plates have been observed on a segment of plastic ties that have seen over 900 MGT of HAL traffic, while a nearby section of hardwood ties with identical tie plates and nearly the same exposure to traffic is exhibiting no evidence of cracking plates. This digest reviews data collected to address differences in tie plate performance under wood and plastic ties that may have led to these failures.

**BACKGROUND**

Ties and fastening systems continue to evolve in today’s railroad industry. Ties and fastening systems must have the ability to support loads and train speeds that are continually increasing. In addition to increased loading criteria, ties and fastening systems are required to remain in place for longer periods of time due to improvements in rail durability. Further, increased costs of components and materials require that fastening system components and materials must be designed to last for extended periods.

Trends in the railroad industry show that plastic/composite crossties are frequently being used to replace or supplement wood ties in track. Composite ties are often favored because they offer superior resistance to insects and decay, when compared to conventional timber ties, and can be intermixed with wood ties when needed. Another appealing feature is that composite ties can utilize existing fasteners (cut spikes/tie plates or screw spikes with direct fixation clips), which allows for flexibility during installation.

Recently, a segment of plastic/composite ties installed on the HTL at FAST (Figure 1) and exposed to more than 900 MGT exhibited a higher rate of tie plate cracking in comparison to tie plates mounted on wood ties in a similar location. All fractures were on the high rail along the field side spike holes, as described below. Visual inspection of the fractured tie plates suggested fatigue was the major issue contributing to failures. Laboratory and field tests were conducted to determine if tie plate stress for plastic ties is significantly higher than stresses in wood ties under similar operating conditions.

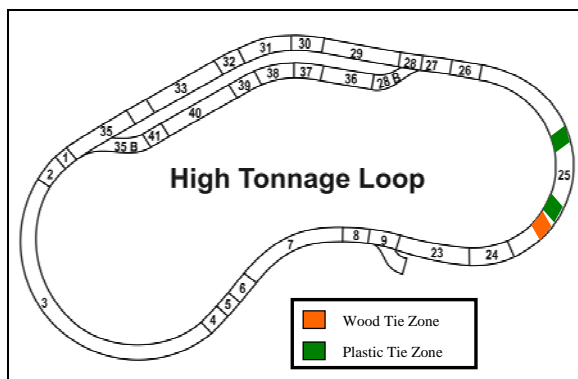


Figure 1. Test Tie Locations on HTL

Various types of plastic and wood ties are installed in Section 25 of the HTL. The section consists of a 6-degree curve that has experienced over 900 MGT of traffic since installation of wood ties and one section of the plastic ties. This test focused on three locations: two plastic tie locations (one with 900 MGT, the other with 420 MGT) and one wood tie location (Figure 1).

**METALLURGICAL EVALUATION**

After several of the tie plates installed on plastic ties began cracking, a metallurgical investigation was completed to determine crack initiation points and propose possible causes for the failures experienced at FAST. All three plates that experienced failures were from the high rail side of the curve in Section 25.

Three broken tie plates were studied. The fatigue crack initiated and propagated similarly for all three plates. Figure 2 shows one of the fractured plates and the corresponding crack initiation points. Evaluation of the fracture surface showed that all of the plates had multiple crack initiation sites on the base of the tie plate at the inner spike hole corners nearest to the rail seat. The crack then propagated along the field side shoulder of the tie plates until final fracture.

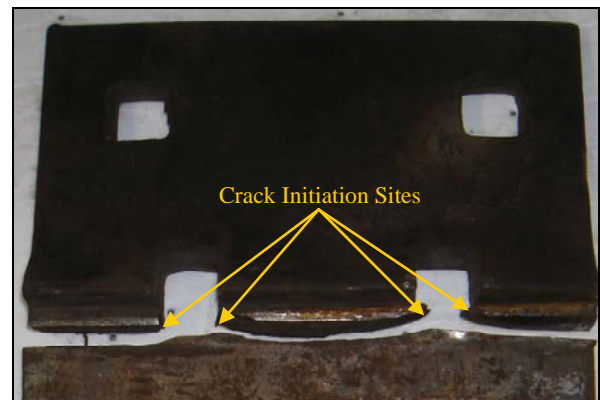


Figure 2. Broken Tie Plate showing Crack Initiation Locations

The fatigue cracks propagated parallel to the rolling direction of the train, which indicates that the plate experienced high tensile stresses oriented perpendicular to the rolling direction of traffic. Since the fatigue cracks propagated perpendicular to the rail base, the evaluation concluded that the failure of the plates was not caused by shear stresses in the plate.

In addition to the fatigue cracks in the shoulder of the plates, several other locations on the tie plate exhibited damage. Fretting occurred in the bearing seat and on the ridge between the bearing seat and the shoulder of the plate. Figure 3 shows the fretting on the ridge above the shoulder of the plate and in the bearing seat.

The fretting damage was observed on all three plates on the field side only. Little or no fretting damage was found on the gage side of the plate. The location of fretting is important because it helps to determine its affect on the fatigue damage in the plate. It is unlikely that the fretting caused the fatigue

initiation because of the crack initiation points. If fretting was the primary cause of the failures, the initiation points would be near the ridge of the plate (Figure 3(a)). The crack initiation and propagation, in this case, would be due to lateral loads imparted on the plate causing contact between the toe of the rail and the ridge of the plate. Since there is no evidence of crack initiation points in this area, the evaluation concluded that lateral forces alone, were not the cause of the failures. Although the fretting is not the primary cause of the fatigue failures, it can be used to understand the loading profile on the plates and its affect on the failures.

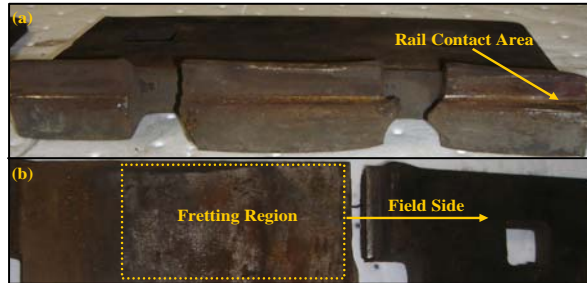


Figure 3. Rail Contact and Fretting Regions on Tie Plate

The prominent fretting toward the field side of the tie plate indicates that the field side of the plate supports the majority of the load. Studying the dynamic conditions in Section 25 shows that operations occur at overbalance speed, which may contribute to the field side fretting and cracking. Train operations at speeds above curve balance speed puts more vertical load on the high rail of the curve. At FAST, the average high rail vertical load is about 45,000 pounds.<sup>1</sup>

The spike holes near the shoulder of the tie plate are inherent stress risers and in overbalance situations, high levels of stress are expected on the field side of the plate.

### IN-TRACK TESTING AT FAST

Three tie plates from the plastic tie section experiencing failures on the HTL were selected for testing. Three plates were used to determine repeatability and variability for a single zone. Previous to any instrumentation or testing, the plates were inspected for any fatigue cracks using dye-penetrant testing. Although the plates showed fretting, none showed any signs of fatigue damage. Once the plates were nondestructively tested, each one was instrumented with four rosette strain gages. Figure 4 shows one of the instrumented plates with the gage placement and orientation.

The rosette was placed as close as practical to the corner of the spike holes. Only the spike holes under the shoulder of the plate were instrumented. All of the gages were covered in silicon in case of inclement weather. Thirty-six channels of data were collected at a sample rate of 1,024 samples per second with a 100-Hz filter.

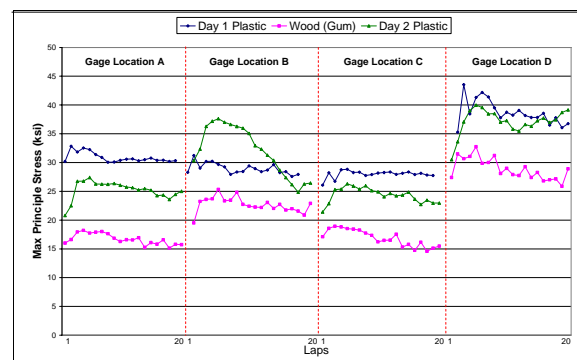
The three plates were installed consecutively in the center of each test section. Before the plates were installed, a small notch was removed from the tie so that the instrumentation would not be damaged. Data was collected over a 3-day period to reduce the number of instrumented tie plates needed.



Figure 4. Strain Gage Locations on Tie Plate

At the conclusion of one test, the tie plates were removed from one section and installed into the next section. The tests were run over consecutive days to reduce the chance of large temperature variations that could affect the tie stiffness. Since the tie plate test coincided with normal operations at FAST, the test train was used, which typically contains 80 loaded cars, each with a nominal weight of 315,000 pounds, traveling at approximately 40 mph. A minimum of 20 laps of data was collected for each zone. All runs were completed with the train being operated in the same direction around the HTL.

The first day of testing was conducted in a plastic tie section (Zone 10 in Section 25). The second day of testing was completed in the gumwood tie section (Zone 4), and the final day of testing occurred in a second plastic tie section (Zone 5). Figure 5 shows the maximum principal stress data collected using plate 1 for each of the three zones. The plot shows the maximum principal stress for each lap for all of the gages. The x-axis is the lap number, and the y-axis is the maximum principal stress.



values are reaching critical yield, the plates are still being affected by material fatigue. Figure 6 shows the average stress (all gages combined) values for all laps over each zone. In all cases, the stress in the plastic tie sections is higher than those in the wood tie zone. Again, none of the values exceed the yield strength of the material, but are still contributing to fatigue. The results from testing at FAST indicate that the plates mounted on plastic ties are experiencing higher stress than plates mounted on wood ties.

Although stress was measured near the spike hole location, it does not provide an accurate assessment of the stress at the crack initiation point. To completely understand the induced stress at the crack initiation point would require a complete Finite Element Analysis of the tie plate.

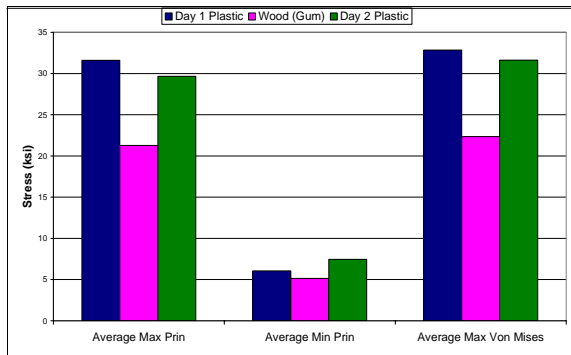


Figure 6. Average Stress for All Plates and All Gages

**Half-Tie Test**

In addition to the FAST testing, an instrumented tie plate was placed in the 1/2 tie rail seat bending configuration utilized by AREMA (Chapter 30) for evaluating tie performance. The setup, as Figure 7 shows, was used to determine the principal stress in the plate induced by a vertical load only.<sup>2</sup>

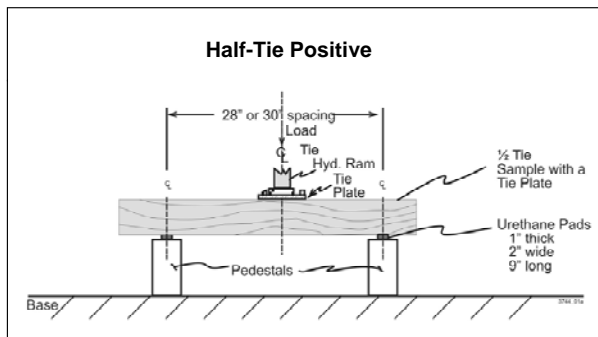


Figure 7. Half-Tie Configuration for Rail Seat Bending Test

The rail seat was loaded incrementally from 0 to 20,000 pounds in 2,000-pound increments. Data from all four rosettes was collected for a minimum of 30 seconds at each increment. The total deflection was also recorded during testing.

Figure 8 shows the maximum principal stress for gages A-D for a single tie plate. The plot compares data collected for both wood and plastic ties.

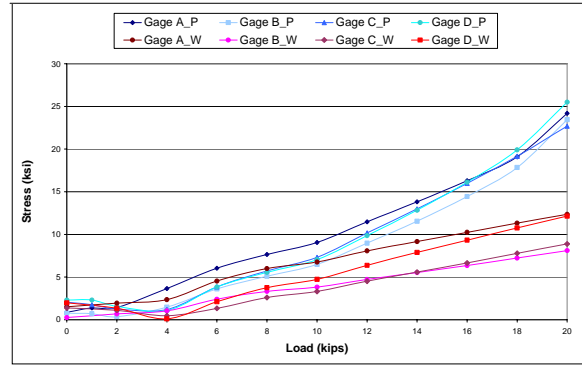


Figure 8. Maximum Principal Stress for Half-Tie Test

Once again, the stress for plastic ties (blue hues) is greater than the stress for wood ties (red hues). The maximum value of stress, 25.5 ksi, was recorded at Gage D for the plastic tie test, which is the same location that experienced the highest stress during field-testing.

In order to correlate the higher stress in the tie plate to the tie itself, the total deflection is shown in Figure 9. This figure represents the total deflection in the ties for loads ranging from 2,000 to 20,000 pounds. Figure 9 shows that the total deflection in the plastic tie condition is much greater than the wood-tie condition.

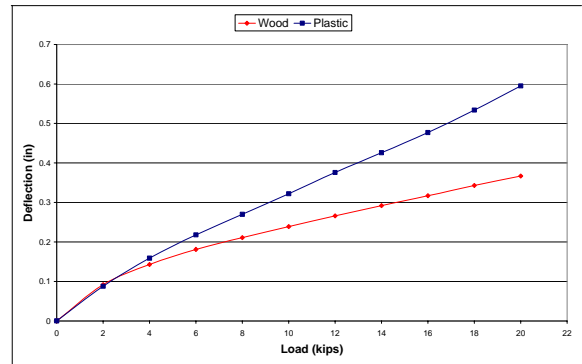


Figure 9. Total Deflection Recorded during Half-Tie Test

**CONCLUSION AND FUTURE WORK**

Combining the results from the metallurgical analysis, the field testing, and the half-tie laboratory testing, results show that there is a considerable difference in stress and stiffness when comparing plastic and wood ties. Additional analysis to predict fatigue life of the plates is being conducted and will be reported separately. In addition to the fatigue life study, TTCI recommends that a Finite Element Analysis be completed to better understand the stress levels at the crack initiation point and to continue observations at FAST and other in-service environments for occurrences of tie plate cracking.

**REFERENCES**

1. TPD measurements at FAST. May 2007 through August 2007.
2. *American Railway Engineering and Maintenance-of-Way Association Manual for Railway Engineering*. 2007. Chapter 30 -Ties, Landover, Maryland.

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