U.S. Department
Of Transportation

**Federal Railroad Administration**

# Research Results

**RR08-21**
**December 2008**

# Evaluation of Tie Plate Cracking on Composite Ties

## SUMMARY

Transportation Technology Center, Inc. (TTCI), in Pueblo, Colorado, conducted a study to determine the effect of tie stiffness on the durability of tie plates mounted on plastic and wood ties on the High Tonnage Loop (HTL) 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 were observed in wood tie sections in the same conditions. TTCI completed a metallurgical analysis, a field test, and a laboratory test to examine possible causes of the tie plate failures.

Three tie test zones were studied, two plastic tie zones and one wood tie zone. 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 loading conditions 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. Test results suggest that plastic ties allow the tie plates to flex more than those mounted on timber ties, which have a higher stiffness, and therefore subject the plate to a higher stress environment. This high-stress, high-cycle load environment caused 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 separate 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 (lb) 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 an alternative for wood ties, TTCI recommends continued investigation into broken plates in revenue service.

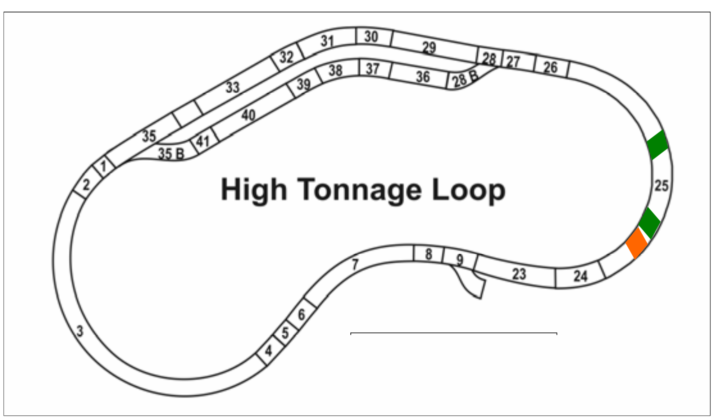


**Figure 1. Test Tie Locations on HTL.**

## 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 accumulated 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. Data was 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 with ties and fastening systems able to support loads and continually increasing train speeds. In addition to increased loading criteria, ties and fastening systems are required to remain in place longer due to improvements in rail durability. 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 sometimes replace or supplement wood ties in track. Composite ties offer superior resistance to insects and decay compared to conventional timber ties, and can be intermixed with wood ties. 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. 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 was significantly higher than stresses in wood ties under similar operating conditions.

Various types of plastic and wood ties are installed in Section 25 of the HTL. Section 25 consists of a 6-degree curve with over 900 MGT of traffic. Two plastic tie locations (one with 900 MGT, the other with 420 MGT) and one wood tie location were tested.

## METALLURGICAL EVALUATION

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

TTCI studied three broken tie plates. The fatigue crack initiated and propagated similarly for all three plates. 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 the final fracture.

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 2).

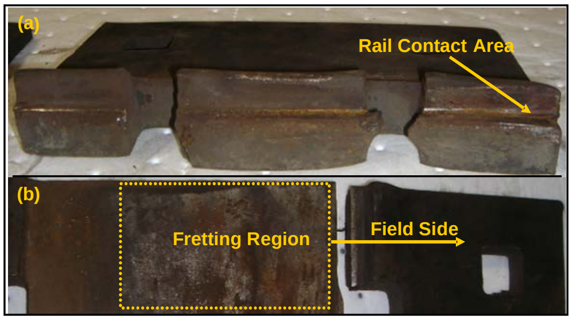


**Figure 2. Rail Contact and Tie Plate Fretting Regions**

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 helps to determine its effect 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 2a). 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 effect on the failures.

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. The study operations occur at overbalance speed, which may contribute to the field side fretting and cracking. Train operations above curve balance speed put more vertical load on the high rail of the curve. At FAST, the average high rail vertical load is about 45,000 lb [Ref. 1]. 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, TTCI inspected the plates 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.

The rosette was placed as close as practical to the corner of the spike holes. Only the spike holes under the plate shoulder were instrumented. All of the gages were covered with silicon in case of inclement weather. Thirty-six channels of data were collected at 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.

At the conclusion of one test, the tie plates were removed from one section and installed into the next section. The tests ran consecutive days to reduce the chance of large temperature variations that could affect tie stiffness. The 80-car test train at FAST was used traveling at approximately 40 mph in the counter clock-wise direction around the HTL. Each car had a nominal weight of 315,000 lb. A minimum of 20 laps of data was collected for each zone.

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 in a second plastic tie section (Zone 5). Figure 3 shows the maximum principal stress data collected for each lap for all of the gages using plate 1 for each zone. The x-axis is the lap number, and the y-axis is the maximum principal stress.

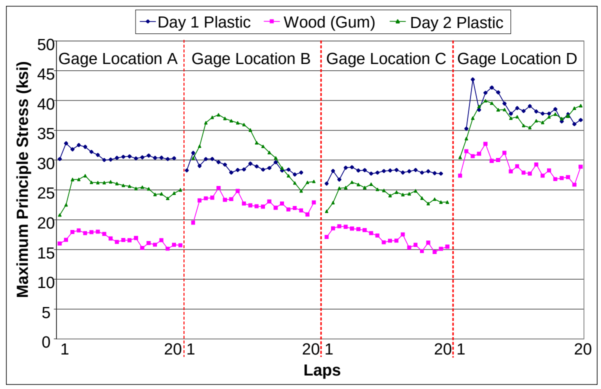


**Figure 3. Maximum Principal Stress for Plate 1.**

Figure 3 is typical of all three of the plates tested showing that both of the plastic tie zones show higher values of maximum principal stress at all four gage locations. Plate 2 had one exception at gage C, where the stress was similar for the first plastic tie zone and the wood tie zone.

The maximum stress for all laps and gage locations is 43.6 ksi, occurring at gage D. Compared to the yield strength of steel, approximately 60 ksi for medium carbon steel, the stress values were well below the yield strength of the tie plate. Although none of the principal stress values reached critical yield, the plates were affected by material fatigue. Figure 4 shows the average stress (all gages combined) values for all laps over each zone. In all cases, the stress in the plastic tie sections was higher than those in the wood tie zone. Again, none of the values exceed the yield strength of the material, but were still contributing to fatigue. Test results indicated that the plates mounted on plastic ties experienced 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, a complete Finite Element Analysis of the tie plate would be required.

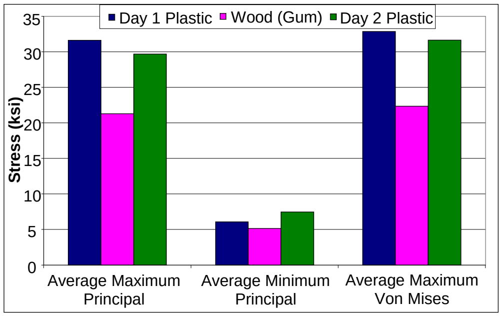


**Figure 4. Average Stress for All Plates and Gages.**

## Half-Tie Test

An instrumented tie plate was placed in the half-tie rail seat bending configuration utilized by **American Railway Engineering** and Maintenance-of-Way Association (Chapter 30) for evaluating tie performance. The setup for the rail seat bending test, as Figure 5 shows, determined the principal stress in the plate induced by a vertical load only [Ref. 2].

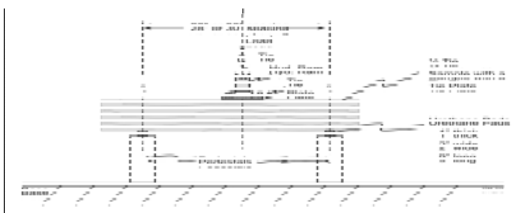

**Figure 5. Half-Tie Configuration.**

The rail seat was loaded from 0 to 20,000 lb in 2,000-lb increments. Data from all four rosettes was collected for a minimum of 30 seconds at each increment. Figure 6 shows the maximum principal stress for gages A through D for a single tie plate. TTCI collected data for wood and plastic ties.

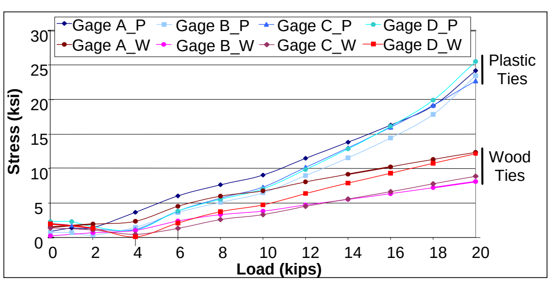


**Figure 6. Maximum Principal Stress for Half-Tie Test.**

The stress for plastic ties is greater than for wood ties. The maximum value of stress, 25.5 ksi, was recorded at gage D for the plastic tie test, at the same location with the highest stress during field-testing. Figure 7 correlates higher stress in the tie plate to the tie itself and represents the total deflection in the ties for 2,000- to 20,000-lb loads. Figure 7 shows that the plastic tie total deflection is much greater than the wood-tie deflection during the half-tie test.

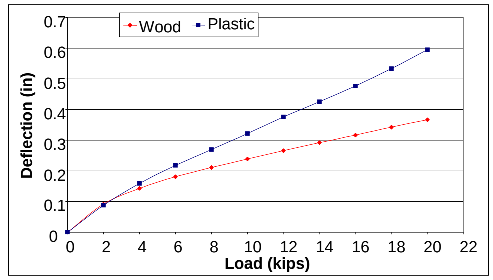


**Figure 7. Total Deflection Recorded.**

## CONCLUSIONS

The metallurgical analysis results, field testing, and half-tie laboratory testing results show that there is a considerable difference in stress and stiffness when comparing plastic and wood ties.

## ACKNOWLEDGEMENTS

This test was conducted through cooperative efforts by the program at FAST and the Tie/Fastener Association of American Railroads Strategic Research Initiatives Program. Special thanks to Dave Williams who installed and calibrated strain gages.

## 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, MD.

## CONTACT

Leonard Allen: Federal Railroad Administration
Office of Research and Development, RDV-31
1200 New Jersey Ave, SE
Washington, DC 20590
Tel: (202) 493-6329 Fax: (202) 493-6333
Email: leonard.allen@dot.gov

**KEYWORDS**: Plastic/composite tie, wood tie, tie plate