TECHNOLOGY DIGEST
TD-16-001
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TIMELY TECHNOLOGY TRANSFER

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FAST Premium Rail Wear Test Results: 2014-2015

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Summary

In February 2014, Transportation Technology Center Inc. (TTCI) began testing six premium rails in a 5-degree curve of the Facility for Accelerated Service Testing (FAST). The curve is designed to have 4 inches of superelevation and is being maintained in a dry condition. The FAST 39-ton axle load train's operating speed results in approximately a 1.7 inches of overbalance condition. TTCI is monitoring rail wear and rolling contact fatigue (RCF) for the different rails, and the test has currently accumulated 343 million gross tons (MGT). This *Technology Digest* summarizes the rail wear and RCF results and the influence of the material properties of these rails on the results.

The following conclusions are being made from this analysis:

- At 268 MGT, on high rail average area loss rates for the various rail types varied from 0.11 in^2 to 0.07 in^2 for every 100 MGT, whereas area loss on the low rail was negligible.
- Cross-sectional hardness has been shown to be directly related to wear. Rails with higher hardness values are showing lower amounts of area loss and vice versa.
- Grinding was done to remove surface RCF, and RCF ratings were made before and after grinding by using a visual scale. The effectiveness of the grinding to remove RCF differed for the rail types, which suggests that the depth of RCF cracks also varied by rail type.
- RCF ratings and yield strength are correlated with cementite content. This was determined by microstructural analysis of samples from the test rails.
- None of the rails have developed any internal defects, and the rail degradation modes are primarily wear and RCF. Another significant failure mode is electric flash butt weld failure. However, this may be related to the test configuration, because dissimilar rails are joined together at each weld.
- Gage face wear is the dominant wear mechanism compared to head wear or gage corner wear and might ultimately determine the service lives of these premium rails in the future of this test. The test curve is not lubricated.

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INTRODUCTION

Premium rails produced by six different manufacturers are currently being tested in a 5-degree curve at FAST. The test was started in February 2014 and has so far accumulated 343 MGT of tonnage. Rail manufacturers are Nippon Steel (Japan), JFE Steel (Japan), Arcelor-Mittal (USA), TATA Steel (France), VoestAlpine Schienen (Austria) and Panzhihua Steel (China).

This test is on a dry curve with no top of rail or gage face lubrication. The rails are laid on a reverse 5-degree curve having 4 inches of superelevation. The FAST train operates at 40 mph and the balance speed of the curve is approximately 33 mph, resulting in 1.7 inches of overbalance for the train's operating speed. The rail manufacturers have supplied 40-foot segments of rail; 25 of these segments are on the high rail and 22 are on the low rail. The layout of the test was planned so that dissimilar rails are joined to one another with no segments of any particular manufacturer occupying a certain section of the curve. Electric flash butt welding was used to join the rails, and so far there had been five weld failures with causes not related to the rails. No internal defects have been observed on the test rails.

This *Technology Digest* (TD) outlines rail wear performance at 268 MGT as well as a metallurgical analysis of RCF and the influence of rail properties on rail wear. This test will be continued until the rails show significant wear or develop detrimental defects.

RAIL WEAR

Figure 1 shows the comparison of area loss of all the six different rails at 268 MGT. The gap in the area loss curves signifies the area loss due to grinding of the entire testing curve between 241 MGT and 251 MGT. The curve at FAST has a preventive grinding schedule to keep the RCF development of rails to a minimum. This loss due to grinding has been removed from the plot to avoid errors in calculating area loss rates. The highest area loss rate is 0.11 in^2 and the area loss rate is lowest at 0.07 in^2 for every 100 MGT.

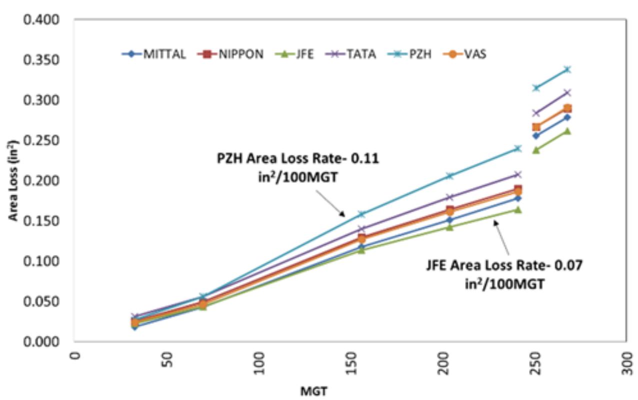

Figure 1. Comparison of area loss rate (in^2/100 MGT) among all six premium rail types

Area loss rate variations required further investigation into the material properties of each rail. At 0 MGT, sections of these rails were tested for microstructure and hardness.

The cross-sectional hardness was measured as per AREMA specifications and has been found to be inversely related to the area loss at 268 MGT, as Figure 2 shows. The rail with the lowest hardness of 362 Brinnell Hardness Number (BHN) has the highest area loss, whereas the rail with 400 BHN hardness has the least area loss. Premium rails are designed to have higher hardness than standard rails, because the higher hardness leads to better wear resistance and Figure 2 emphasizes this fact.

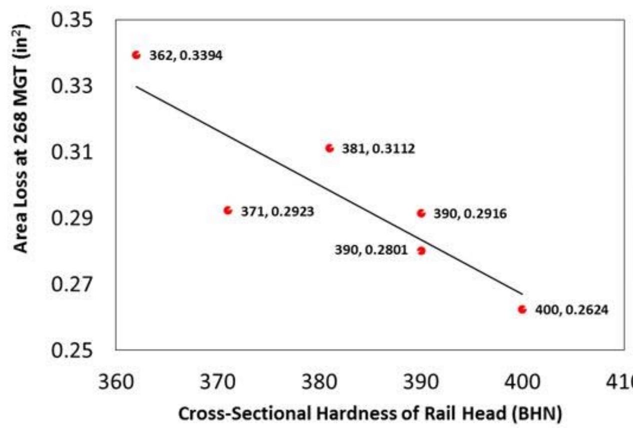

Figure 2. Influence of cross-sectional hardness on area loss

Along with area loss, head loss from top of rail, gage corner loss, and gage surface loss have been calculated for all the rail types. Among these parameters, gage face wear has been found to be the most dominating factor. Since this test is on a reverse curve with 4 inches of superelevation, the low rail has significantly lower wear compared to the high rail. Figure 3 shows the comparison of gage face wear of this test for high rail and the FAST limit. The FAST wear limit is shown by a red line, and at 268 MGT all rails on the high rail have considerably less wear with some variation among the six rail types. Compared to the high rail, the wear on all the low rails has been found to be negligible (0.001 inch) at 268 MGT. This suggests that this test may continue for another 300-400 MGT before the wear gets close to the FAST wear limit (0.50 inch).

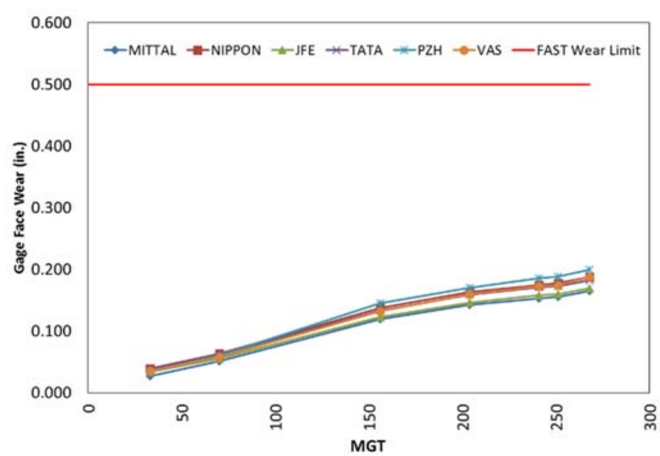

Figure 3. Comparison of gage face wear of all six premium high rails with FAST wear limit (red)

RCF ANALYSIS

RCF is an existing problem among rail steels and one of the driving forces for the continuous research on producing better quality rail steels. Previous FAST tests of premium rails and intermediate strength rails have shown RCF to be a significant factor, and test results showed that premium rails have better RCF resistance than intermediate strength rails. These results have been documented in previous TDs.[1,2,3] RCF estimations of the test rails were made before grinding at 241 MGT, after grinding at 251 MGT, and also at 340 MGT.

The estimations of RCF are made by a qualitative assessment using a visual scale as mentioned in TD-13-016.[1] The same methodology is used in this test, but the scale varies from 0-3 where 0 is no RCF, 1 is mild (having minimal RCF cracks and sporadic spalling), 2 is heavy (having interconnected spalled areas), and 3 is severe (having continuous spalled bands). In previous tests, the highest number on the rating scale was 4 for extreme condition, which indicated continuous spalled areas on the rail running surface with increased width. In this test, "severe" and "extreme" are considered the same, because severe RCF is detrimental for rail operations, and the rails should not be allowed to develop to an extreme RCF condition. The visual scale used for RCF ratings is shown in Figure 4.

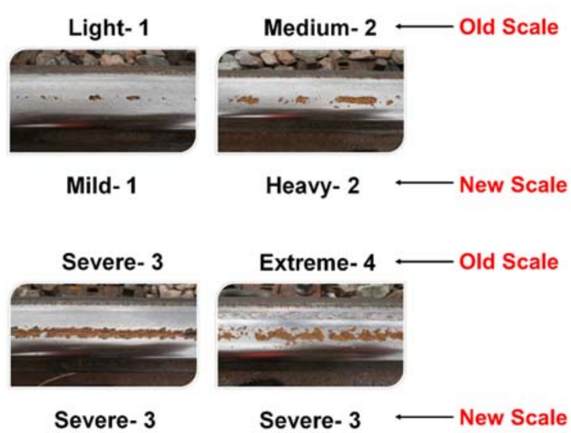

Figure 4. RCF Assessment scale changes

Visual inspection of all rail segments of the high rail at every tie was done and a rating is noted. For every 40-foot segment, a minimum of 24 readings were taken and averaged to find the average RCF rating. The 39-ton axle load train operating at a higher speed than the balance speed of the curve with a non-lubricated dry condition facilitates the development of RCF cracks. In Figure 5, the y-axis indicates comparison of mean RCF rating on the scale of 0-3 for all rail types and for all three measurements. One rail showed RCF (rating 2.15) in the heavy category. All other rails had mild RCF (ratings 1.06–1.70) before grinding at 241 MGT. After grinding at 251 MGT, RCF ratings showed a different trend, and the rail with the highest RCF rating before grinding now had the lowest rating. Figure 5 suggests that the rails with the highest RCF ratings prior to grinding had less depth to the RCF cracks than those that had lower RCF ratings. This is illustrated by the grinding effectiveness of removing the RCF indications. The trend after grinding at 251 MGT continues to be the same at 340 MGT. All of the rails currently have RCF conditions below the mild category as indicated by their RCF ratings of less than 1. RCF monitoring will be continued for the rest of the test and will be reported in subsequent TDs.

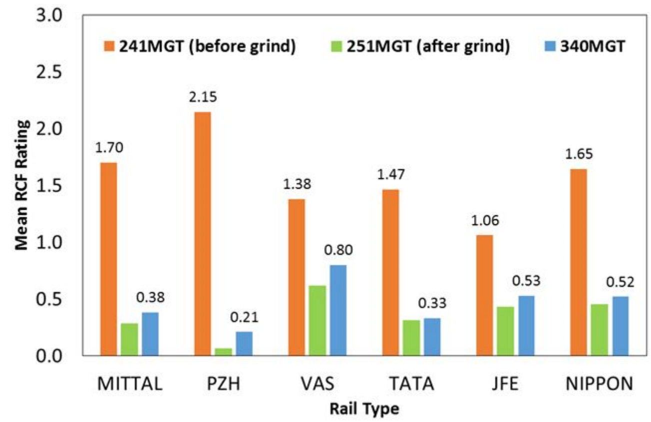

Figure 5. Comparison of mean RCF ratings of all six rail types measured at different tonnage

CEMENTITE (Fe_3C) ANALYSIS

Previous TTCI publications have shown cementite as a contributing factor for RCF in rails.[2,4] Premium rail types previously tested at FAST had carbon contents above the eutectoid composition of 0.76 percent weight. Similarly in this test, all six rail types have carbon contents varying in the range of 0.79 percent to 1.02 percent. From the Iron-Iron Carbide equilibrium diagram, such steels should have proeutectoid cementite phase depositions along the grain boundaries. This proeutectoid cementite has much higher hardness than the pearlite grains and provides higher hardness and wear resistance to these premium grade rails. The amount of cementite on the grain boundaries of a premium grade rail steel is dictated by the presence of other alloying elements and the post processing of the cast steel billet/bloom before the final rail is made.

Microstructures of all six rail types were analyzed for cementite content. All rail types showed similar grains of pearlite and presence of proeutectoid cementite, but in slightly varying amounts. Thirty images were taken for each sample and analyzed by a phase analysis program to find out cementite content. Figure 6 shows the influence of average (mean) cementite content (average of 30 measurements) of each rail on the average RCF rating at 340 MGT. The linear trend shows higher cementite causes higher RCF on the rail running surface. The role of cementite is both advantageous and disadvantageous. The presence of hard cementite increases the overall hardness of the rail and prevents wear and batter by the wheels. But on the other hand, drastic microstructural hardness variation along the grain boundaries between harder cementite phase and softer pearlite grains cause weak areas for RCF crack initiation.

Figure 7 shows the inverse relationship between mean Fe_3C percentage and mean 0.2 percent yield strength of all rail types.

Yield strength is a measure of the ductility of the rail steel, and according to the linear regression shown in Figure 7, higher yield strength of a rail steel has a lower mean cementite content. This trend is in conjunction with the trend shown in Figure 6, because the presence of more cementite along grain boundaries causes lower ductility of the steel due to sudden hardness changes from the inside of the grain to the grain boundary. Consistent hardness across the grains in a microstructure leads to better isotropic behavior when a rail steel is being tested during a tensile test for ductility.

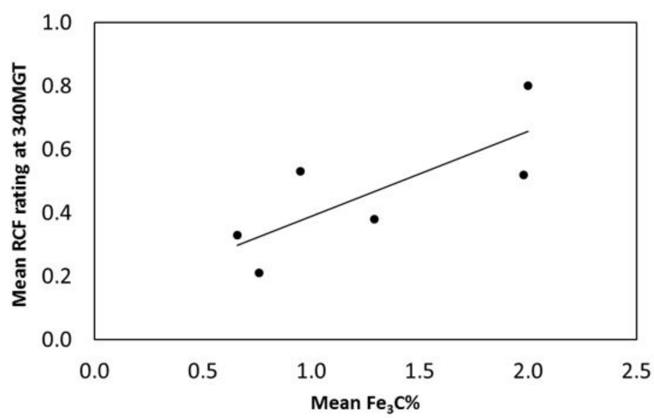

Figure 6. Influence of mean Fe_3C% on mean RCF rating at 340 MGT of six rail types

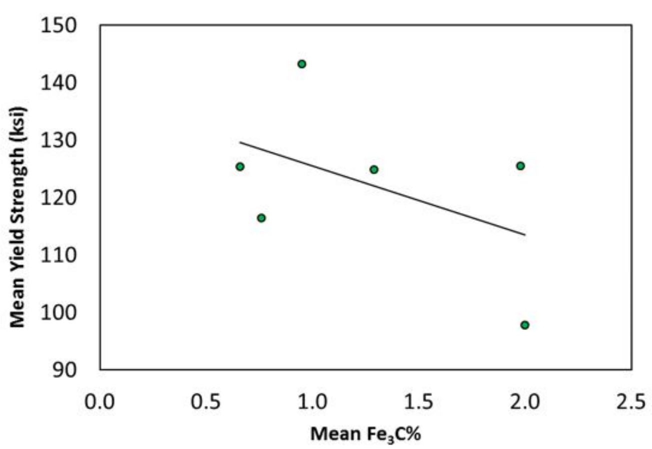

Figure 7. Inverse relationship between mean Fe_3C% and mean Yield Strength of six rail types

CONCLUSIONS

Six premium rails from six different manufacturers are currently being tested in a 5-degree reverse curve at FAST with no lubrication on the rails. The test is currently at 343 MGT with grinding done between 241 MGT and 251 MGT. The test is expected to go on for few more hundred MGT with continuous monitoring of rail wear profiles and RCF crack developments. This TD summarizes the results and trends that have been observed so far in the test.

The area loss plots of the various rail types indicate that at 268 MGT, on the high rail the highest rate is at 0.11 in^2 and the lowest rate is at 0.07 in^2 for every 100 MGT. Among the other wear parameters, gage face wear seems to be the dominant factor and may ultimately determine the service lives of these rails. Comparison of gage face wear among high rail and low rail shows the combined influence of superelevation, unbalance, and degree of curvature of the test curve is more wear on high rail and almost no wear on low rail. At 268 MGT, high rail wear of all rail types is well below the FAST wear limit. A plot of cross-sectional hardness of railhead and area loss shows an inverse linear trend, and indicates a rail with higher hardness is showing less wear and vice versa.

RCF measurements of all rails were made using a qualitative assessment method of a visual scale and average RCF ratings before and after grinding, and they show opposite trends. The rail with the highest RCF rating before grinding has the lowest rating after grinding, suggesting the rail had shallow cracks that were removed during grinding. Depth of cracks varied for each rail type and the opposite trend is noted for two rail types. None of the rails have any heavy RCF conditions, and overall RCF ratings are promising.

Cementite analysis was done for all six rail types, and cementite measurements were found to have a linear trend with RCF ratings and yield strengths. Higher cementite amounts generally led to higher RCF due to the presence of weak spots along grain boundaries having hardness variations due to presence of hard, brittle cementite adjacent to softer pearlite grains. The presence of these weak spots also explains the lower yield strength values and lower ductility of rail types with higher cementite contents. RCF monitoring and ratings will be conducted at successive intervals for this test and will be correlated to other material properties to observe any obvious trends. Results of further analysis will be reported in future TDs.

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