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# Premium Rail Testing at FAST

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## Summary

Transportation Technology Center, Inc. (TTCI) has been involved in rail testing at the Facility for Accelerated Service Testing (FAST) for over 20 years. In January 2010, TTCI began testing 10 premium rails in a dry 5-degree curve under a 39-ton axle load train. To date, the test curve has accumulated approximately 420 million gross tons (MGT). The test results addressed in this *Technology Digest* include rail wear performance, rolling contact fatigue (RCF) performance, as well as the observed rail base defects and their mechanism.

Based on the current findings at FAST, the following conclusions are drawn:

- All premium rails performed well under heavy axle load traffic, with less wear as compared to previous rail wear test, no internal defects to date, and with no lubrication or grinding.
- Premium high rail experiences greater amounts of wear than low rail.
- Box plot rail wear distribution at 381 MGT of traffic indicates that Mittal rail wears statistically less than control HEX rail; ERMS, PG4, and VAS-2 rail grades wear statistically more than control HEX rail, and other rail types experience wear that is statistically indifferent from control grade.
- A comparison of carbon content present in the current generation of premium rail grades tested at FAST and their respective head hardnesses indicates a poor relationship between carbon content and head hardness. This is attributed to head hardness being a function of both rail chemistry and thermo-mechanical processing during manufacturing.
- Rail hardness alone is not a good indicator of wear behavior in track. In general, only half of the difference in rail wear is directly attributed to observed differences in rail hardness. Lateral forces present in the high rail are a factor in the formation of top-of-rail RCF. RCF that initiated at 90 MGT of traffic extended to 30, 80, and 100 percent of the high rail length at 200 MGT, 300 MGT, and 400 MGT of traffic, respectively.
- To date, there have been two rail base breaks in the high rail (five similar breaks have occurred in the test of intermediate strength rail). All defects originated in the high rail field side base corner. They were due to either mechanical damage induced during rail installation or from contact with the edge of the tie plate as a result of tie misalignment during operations. The large tensile field present in the rail base corner located on the field side of the high rail caused these locations to become notch sensitive during train operation, leading to fatigue crack initiation and subsequent critical failure.
- To date, there were no rail breaks in the low rail.
- Finite element analysis performed on the rail base and tie plate interface indicates the presence of localized high stresses at the rail base vertical face plate and tie plate seat edge.

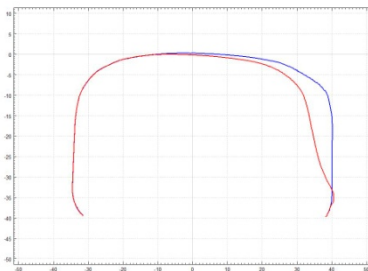


**INTRODUCTION**

In January 2010, the current rail wear and RCF evaluation of the latest generation premium rail steels began. There are 10 premium rail types in this study. Their designation, mechanical properties, as well as microcleanliness results have been detailed in other documents.<sup>1,2</sup> At the end of 2012 FAST operations, the test rail had accumulated approximately 420 MGT of tonnage. Test results presented here address rail wear, RCF development, and rail breaks that initiated in the rail base.

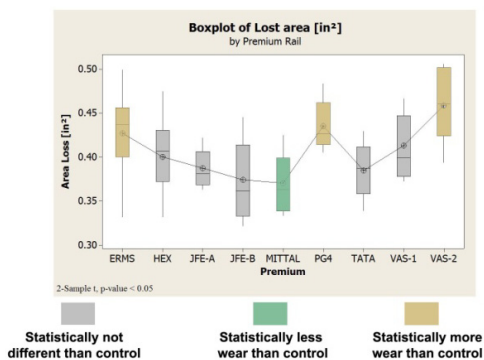
**RAIL WEAR**

Due to the operating conditions in the premium rail 5-degree curve, no direct rail lubrication, overbalance speed, the high rail experiences greater amounts of wear.<sup>1</sup> Figure 1 indicates the difference between the wear profile at 381 MGT and the initial 0 MGT measurement. It shows there is a substantial amount of gage face wear, which is attributed primarily to a lack of gage face lubrication in the curve.



**Figure 1. Typical Premium Rail Wear Representing High Rail Profile at 0 MGT (blue) and Worn Rail Profile at 381 MGT (red)**

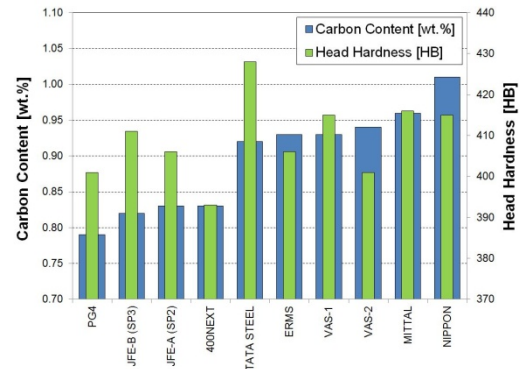
Box plot analysis of the rail wear distribution at 381 MGT indicates that compared to the HEX control rail grade three of the rail types (namely, ERMS, PG4, and VAS-2) have statistically more wear than control rail. Mittal rail has statistically less wear than control rail, and other grades experience wear that is statistically not different than control rail (Figure 2).



**Figure 2. Box Plot Indicating Rail Wear Distribution in Premium Rail Types at 381 MGT**

The 400NEXT rail jointly developed by TTCI and University of Pittsburgh is part of the premium rail wear test.<sup>3</sup> However, since it was installed in track 90 MGT after all the other premium rail types, its wear performance is for less tonnage than the other premium rail types shown in Figure 2. The wear performance of the 400NEXT rail will be documented when it accumulates ~381 MGT.

Increases in premium rail hardness have been driven primarily by the goal of increasing resistance to wear. It is generally believed that increasing the carbon content increases the hardness level. However, for the current generation premium rail grades, a comparison of the carbon content in each rail type tested at FAST with the respective head hardness indicates a poor relationship between the two (Figure 3).

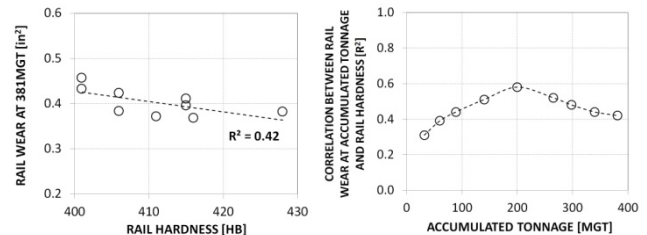


**Figure 3. Rail Carbon Content Influence on Head Hardness**

The rail type was plotted with the carbon content (blue) in an ascending order to show that there is no clear relationship with the railhead hardness (green) that applies to all rails.

The reason for this disparity between the two is that rail mechanical properties (head hardness among them) are a product of both chemistry and thermo-mechanical processing (TMP) during manufacturing. Looking at chemistry alone presents an incomplete picture. A consideration of both chemistry and TMP allows a more complete assessment of the rail mechanical performance.

The relationship between initial rail hardness and rail wear during the rail lifetime is even more complex. Considering the wear data at 381 MGT and plotting rail wear for individual rails against rail hardness reveals a linear best fit  $R^2$  of 0.42 (Figure 4). This is not a strong correlation. Tracking this trend over a period of 381 MGT of accumulated tonnage reveals an overall correlation that at best reaches an  $R^2=0.58$  at 200 MGT accumulated tonnage, and it is substantially below that value at other tonnages (Figure 4).



**Figure 4. Influence of Initial Railhead Hardness on Wear Behavior in Track**

Although this analysis does not account for the work hardening effect in correlating rail hardness to the wear behavior, in general, as rail work hardens, its running surface hardness increases, which one would expect to have an impact on rail wear behavior. Analysis of this work hardening influence on the rail wear behavior in track would require a more in-depth investigation, which was not conducted here.

Wear analysis was based on initial rail hardness, because in revenue service that initial rail hardness is often used as an indication of expected rail wear behavior in track.

To sum up the findings from FAST premium rail wear testing, in FAST’s heavy axle load (HAL) environment and under dry conditions, rail hardness alone is not a good indicator of rail wear. A more complete picture of the expected wear behavior can be acquired by considering the mechanical properties that are (as mentioned above) a product of both the rail chemistry and applied TMP. TCI rail research is focusing efforts on accomplishing just that, and building a relationship between mechanical properties, resulting rail microstructure, and their impacts on rail wear and RCF behavior.

**RAIL RCF**

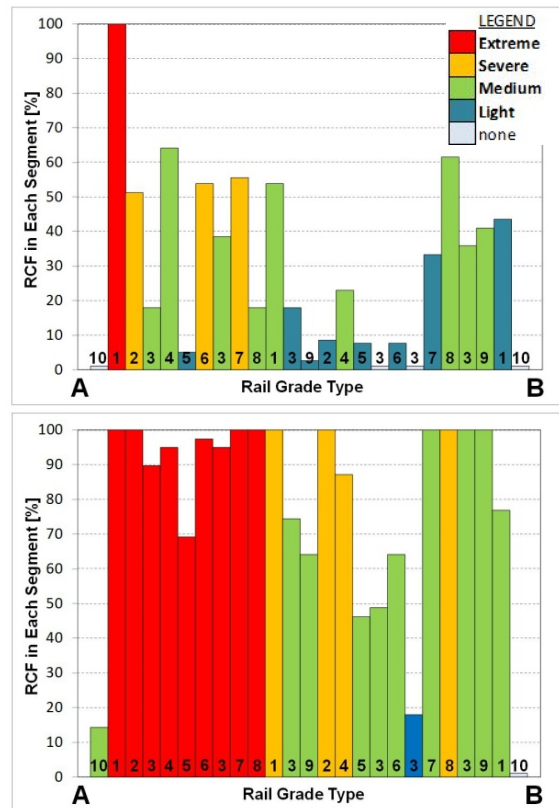
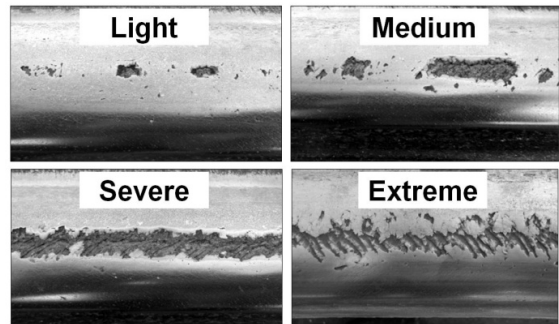
RCF development in the high rail of the premium test curve has been tracked since its inception at 90 MGT. The 39-ton axle load environment at FAST and the lack of lubrication in the test curve facilitates the development of these cracks. Recent instrumented wheelset data indicates that the average lead axle vertical load on the high rail in the test curve is ~47,000 pounds, whereas the lateral load is ~7,000 pounds. These forces are a factor in the formation of this top-of-rail RCF.

At ~100 MGT of traffic, these cracks were periodic in appearance, suggesting that truck steering issues might have contributed to RCF initiation.

There is no standardized method for measurement of RCF, meaning there is no single objective and quantitative way to assess RCF, only subjective and qualitative assessment methods. Therefore, an RCF rating chart was developed that ranks the RCF performance on various steels as “light” (having minimal RCF cracks and limited sporadic spalling), “medium” (having greater RCF with interconnected spalled regions), “severe” (having a continuous spalled band), and “extreme” (having a continuous rail running surface spalling band of increased width), as Figure 5 shows. High rail RCF in all the premium rail steels in the test curve was assessed utilizing this chart at 200 MGT and 300 MGT of accumulated tonnage (note that tonnage is lower for 400NEXT rail). A number of trends emerged.

At 200 MGT of traffic, 30 percent of all premium high rails experienced some level of RCF. The graphs in Figure 5 show (1) the relative amount of RCF in each segment, (2) the severity of the RCF (color coding), and (3) its distribution in the curve.

The numbers provided at the base of each bar graph indicate the rail type. Rail grade type 3 is the control rail. One can see that the performance of different rail types varies depending on its position in the curve (e.g., rail grade types 1, 2, 6). However, there are rail types that show similar performance irrespective of the position in the curve (e.g., rail grade type 5). This suggests that RCF performance is a function of both position in curve and rail metallurgy, and that the influence of each factor varies with rail type. There appears to be more RCF at the extremities of the curve, positions A and B, with RCF at position A ranked as extreme.



**Figure 5. RCF Rating Scheme used to Assess RCF in the High Rail of the Premium Curve. Rating done at 200 MGT and 300 MGT between Locations A and B Representing Curve Extremities**

A similar RCF evaluation, conducted after 300 MGT of traffic, indicated that within 100 MGT of traffic (200 to 300 MGT) RCF increased to encompass approximately 80 percent of the test curve, and nearly half of the RCF was ranked as extreme near the A end of the curve. Train dynamics are believed to be the major contributor to this increase in RCF. FAST operations and track conditions are being modeled using NUCARS to validate that hypothesis.

By 400 MGT, the amount of RCF covered nearly the entire high rail and was ranked extreme, and the rail in the curve was ground to allow continued testing.

**RAIL BASE DEFECTS**

To date there have been two rail base break defects in the premium rail wear test (and five breaks in the intermediate strength rail test). Table 1 shows the rail type and MGT at which the breaks occurred.

**Table 1. Rail Base Defects in FAST Rail Tests**

Section 7 – Premium Rails	
RAIL TYPE	MGT
VAS-2 (Austria)	130
VAS-1 (Austria)	260
Section 3 – Intermediate Strength Rails	
RAIL TYPE	MGT
MITTAL (Spain)	83
ERMS-2 (USA)	92
MITTAL (Spain)	133
TATA Steel (France)	209
LUCCHINI (Italy)	270

All the defects originated in the high rail field side. Four of them initiated due to the tie plate corner digging into the base corner of the rail, one was due to rail base fretting on the plate, and two originated in the cribs of the track.

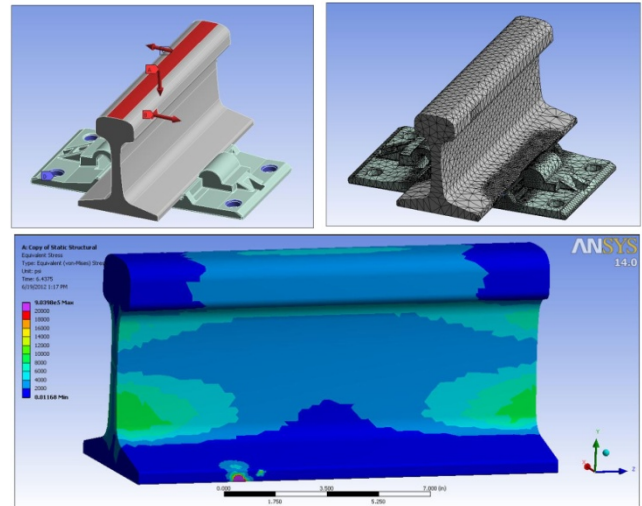
The failure mechanism in each defect was essentially the same. Mechanically induced nicks were introduced into the rail base sometime during the life cycle of the rail. Some nicks might have been induced during rail string delivery and installation (i.e., sliding of rail into place prior to welding) or through plate rubbing action during train operation. When subjected to a field of high tension, the pre-existing nicks caused these locations to become notch sensitive, thereby initiating the fatigue cracks on the base. These cracks can lead to eventual critical failure of the rail (Figure 6).



**Figure 6. Base Corner Defect found in VAS-2 High Rail Field Side Base Corner on Base Plate Corner Mating Surface**

Although it is difficult to avoid damage caused to the rail base during handling and installation, defects caused by base plate digging into the rail base corner due to tie skewedness could be reduced by redesigning the plate corners. To aid in understanding the mechanism of tie plate and rail base contact induced stresses under train operation, ANSYS stress modeling was conducted (Figure 7). This analysis indicates that tie skewedness forces the plate corner to create a point-contact with the rail base corner causing high stresses in the rail base. It is believed these high stresses initiate fatigue cracks that eventually lead to critical failures.

Future investigation will focus on redesigning the base plate corner to reduce and/or redistribute the amount of stress present in that location, the aim of which is to delay the onset of fatigue initiation.



**Figure 7. Finite Element Analysis Performed with ANSYS Software Indicating Presence of Stress Concentration at the Rail Base Corner where Base Plate Contacts the Rail Base**

## CONCLUSION

Results presented in this TD address premium rail performance for 10 rail types investigated up to 400 MGT of accumulated traffic. Box plot analysis indicates that at 381 MGT ERMS, PG4, and VAS-2 rail grades have statistically more wear than control HEX rail grade, and that Mittal rail has statistically less wear than control rail, and that other rail grades experience wear that is statistically not different than control rail. A comparison of the initial rail hardness with rail wear measurements yield a poor correlation, as does the comparison of initial rail hardness with carbon content. This suggests that rail wear and mechanical performance is a function of both chemistry and TMP. The current premium rail test will end at approximately 530 MGT of traffic, scheduled at the end of 2013 operations at FAST.

An investigation of high rail RCF, in the absence of lubrication and grinding, during the life cycle of the curve indicates a rapid progression of RCF from spalling initiation at 90 MGT to severe spalling at 400 MGT of traffic, for both top and gage face of all test high rails.

Analysis of the root causes of rail base breaks in the high rail indicates that these defects initiate as fatigue cracks at notch sensitive locations. This finding is supported by finite element analysis.

## REFERENCES

1. Szablewski, D., S. Kalay, J. LoPresti. September 2011. "Preliminary Evaluation of Premium Rail Steels for Heavy Haul Operations." *Technology Digest*, TD-11-031, AAR/TTCI, Pueblo, Colorado.
2. LoPresti, J. and S. Kalay. April 2012. "Testing at the Facility for Accelerated Service Testing Summary of 2011 Results." *Technology Digest*, TD-12-007, AAR/TTCI, Pueblo, Colorado.
3. Ordóñez Olivares, R. et al. April 2009. "New Rail Steel for the 21<sup>st</sup> Century: Advanced Alloy Thermo-Mechanical Processing Development." *Technology Digest*, TD-09-011, AAR/TTCI, Pueblo, Colorado.

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