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FAST Premium Rail Test Results: 2010 through 2013 Test Period

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Summary

Transportation Technology Center, Inc. (TTCI) tested premium rails from 2010–2013 at the Facility for Accelerated Service Testing (FAST). Results from these tests are presented herein. Premium rails have been evaluated at FAST since 1976. The latest test evaluated rail types from eight manufacturers. The test was run in a dry 5-degree curve at FAST under a 39-ton axle load train. The normal operating speed of the train is 40 mph. Balance speed in the curve is approximately 33 mph; the curve is approximately 1.7 inches overbalance for the train's operating speed. The test concluded at 560 million gross tons (MGT) of accumulated tonnage in November 2013. Test results addressed in this *Technology Digest* compare wear and rolling contact fatigue (RCF) performance of the tested rail types. In addition, grain boundary cementite (Fe_3C) distribution as a function of carbon content in selected rail steels is presented and correlated to in track RCF.

Based on FAST test results, the following conclusions can be drawn:

- Two sample t-test statistical analysis of rail wear distribution at 559 MGT indicates that three rail types, namely voestalpine VAS-2, Panzhihua PG4, and EVRAZ ERMS, wear statistically more than control Nippon HEX rail and that none of the other rail grades wear statistically less than control Nippon HEX rail.
- Rail with lowest rail area loss rate in the test was ArcelorMittal wearing at a rate of $0.082 \text{ in}^2/100 \text{ MGT}$, whereas rail with highest rail area loss rate was voestalpine VAS-2 wearing at a rate of $0.099 \text{ in}^2/100 \text{ MGT}$, which presents an approximately 20 percent increase in rail area loss rate.
- Comparison of control Nippon HEX rail wear in two 5-degree curves at FAST, one dry and one gage face (GF) lubricated, revealed that in dry conditions the rate of wear was $0.086 \text{ in}^2/100 \text{ MGT}$, whereas in lubricated track the rate of wear was $0.026 \text{ in}^2/100 \text{ MGT}$. This indicates that in dry conditions Nippon HEX rail wears approximately 3.2 times faster than in GF lubricated track.
- Analysis on voestalpine VAS-1 rail could not be completed as all rail measurement sites in that rail type, except one, were lost due to either rail or weld breaks.
- Analysis of grain boundary Fe_3C indicates that as carbon content in rail increases, Fe_3C content tends to increase as well. Also, Fe_3C distribution is wider at higher carbon content.
- Grain boundary Fe_3C distribution results also indicated that it is possible to have an elevated carbon content in the rail while still producing a relatively Fe_3C free microstructure, as evidenced by 0.96wt% C rail steel. Targeted alloying elements and thermo-mechanical processing can suppress the development of Fe_3C .
- Relating the median of each rail steel grain boundary Fe_3C distribution to RCF occurrence in track indicates that rail steels with elevated levels of cementite tend to have more RCF and that this RCF becomes relatively worse at elevated MGT, as compared to rails with lower levels of grain boundary Fe_3C . Future quantitative assessment of RCF with eddy current technology will address this relationship in greater detail.
- There were two rail base breaks in the high rail. All defects originated in the high rail base corner. They were due to either mechanical damage during rail installation or from contact with the edge of the tie plate as a result of tie misalignment during operations. No rail breaks were observed in the low rail.



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Introduction

Premium rail types produced in 2009 from eight different rail manufacturers were tested at the Facility for Accelerated Service Testing Heavy Axle Load (FAST HAL) track from 2010 through 2013. Test participants included two USA steel mills: EVRAZ Rocky Mountain Steel, and ArcelorMittal Rail Mill, as well as five international rail mills: TATA Steel (from France), Nippon and JFE steel mills (from Japan), Panzhihua steel mill (from China), and voestalpine rail mill (from Austria). Rail mechanical and microstructural properties, as well as preliminary rail wear and RCF performance have been detailed in previous reports.¹⁻³

The current report outlines rail wear performance at 559 MGT (at the end of the FAST rail test) as well as rail cementite content as it relates to in-track RCF performance.

Rail Wear

Operating conditions through the entire test were as follows:

- Ten 136RE premium rail types
- Dry 5-degree curve with 1.7 inches of unbalance
- 39-ton axle load train
- 40 mph train speed with bidirectional traffic
- One grind cycle at 400 MGT to address RCF

Total tonnage accumulated on the track section at end of test was 560 MGT. Figure 1 shows a typical rail profile for the high rail. It indicates that there is a substantial amount of gage face wear, which is attributed primarily to a lack of GF lubrication in the curve.

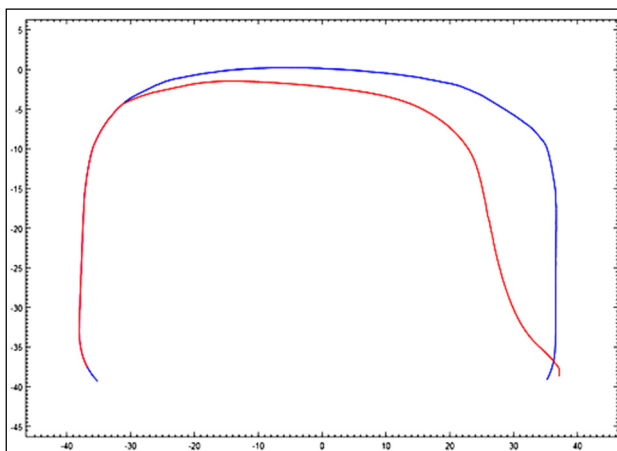


Figure 1. Comparison between new 136RE rail profile (blue) and worn high rail profile (red) at 559 MGT

Two sample t-test statistical analysis of rail wear distribution at 559 MGT indicates that compared to the HEX control rail type none of the rail types tested have statistically less wear than the control HEX rail. Three rail types (namely, VAS-2, PG4, and ERMS) have statistically more wear than the control HEX rail type (Figure 2).

Note that VAS-1 rail type does not display a boxplot distribution of rail wear values in Figure 2. This is due to the fact that all, except for one, rail wear measurement sites were lost during the test period due to rail and weld breaks. As a

result, wear in this rail type cannot be statistically compared to the HEX rail type.

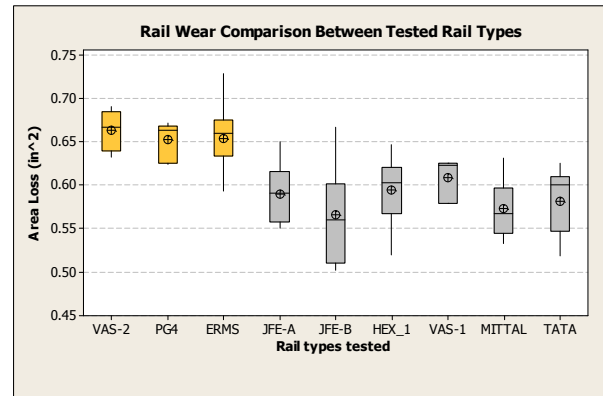


Figure 2. Two-sample t-test rail wear comparison between tested rail types and control (HEX) rail at 559 MGT. Orange – statistically more wear than control HEX, gray – statistically not different than control HEX.

Comparison of area loss in all rail types tested across all MGT levels at which rail wear measurements were made allows for mapping rail wear trends for each rail type (Figure 3). Note that a grind cycle was made on the premium rail curve at approximately 400 MGT.

Calculating the differences between area loss rates in each rail type per 100 MGT accumulated tonnage [$\text{in}^2/100 \text{ MGT}$] reveals that the difference between the least worn and the most worn rails is relatively narrow. The loss rate was calculated as the slope of the line between 32 and 400 MGT of accumulated traffic. ArcelorMittal had a loss rate of $0.082 \text{ in}^2/100 \text{ MGT}$, whereas VAS-2 had a loss rate of $0.099 \text{ in}^2/100 \text{ MGT}$, approximately a 20 percent increase (Figure 3).

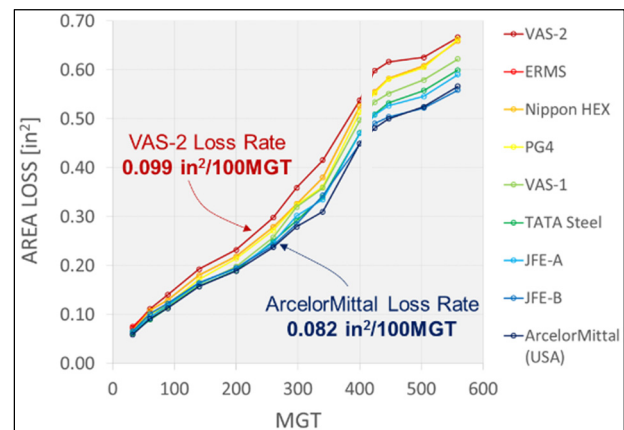


Figure 3. Rail area loss rate ($\text{in}^2/100 \text{ MGT}$) indicating the difference between best and worst performing rail steel

The difference in rail wear is a lot more noticeable between rail that is dry and rail that is GF lubricated. Comparison of premium Nippon HEX control rail in dry and lubricated conditions in two 5-degree FAST curves at 260 MGT (the rail was installed in the lubricated curve two years after being installed in the dry curve, hence the lower tonnage) of accumulated tonnage indicates that dry rail wears

approximately 3.2 times more rapidly than the same HEX rail in GF lubricated condition (Figure 4). This observation confirms and quantifies the importance of GF lubrication as a method of rail life extension in curved track. When considering rail wear alone in rail life cycle planning, FAST test results suggest that selection of rail grade is of lesser importance as compared to the application of appropriate GF lubrication practices.

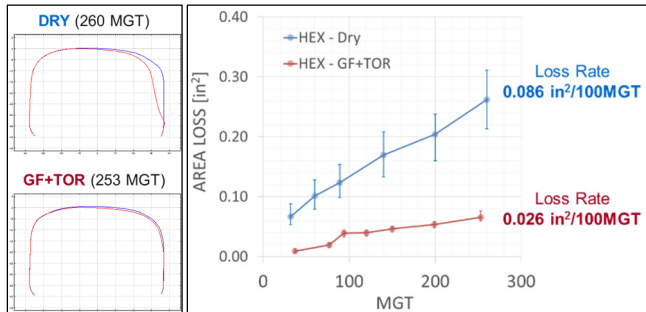


Figure 4. Nippon HEX rail type area loss difference due to use of GF lubrication and TOR friction control

Rail Cementite at Grain Boundaries

A previous TTCI publication⁴ established cementite (Fe_3C) as a possible contributing cause of RCF on the rail running surface. Subsequent publications³ indicated that carbon composition in premium rail steel types tested at FAST ranged from 0.79-1.01wt%, all above eutectoid carbon composition of 0.76wt%, which means that all premium rail steel chemistries used in the current test at FAST have a driving force toward Fe_3C formation. The degree of that driving force is being dictated by the amount of carbon content above eutectoid composition as well as the amount of alloying elements present in each chemistry and the rail thermo-mechanical processing (TMP) by the manufacturer. So, the more carbon the rail has above 0.76wt% carbon, the more likely it is that Fe_3C will form at the grain boundaries.

In order to determine the amount and distribution of cementite in premium rail steels as a function of carbon content, six premium rail steels were selected for microstructural analysis. Figure 5 contains examples of railhead microstructures showing differences in cementite morphology at the grain boundaries in three such premium rail steels with carbon contents of 0.79, 0.93, and 1.01wt% C, respectively. It is evident that the rail steel with a composition close to 0.76wt% C does not display much grain boundary Fe_3C . The opposite is true for the rail steel with 1.01wt% C, where uninterrupted lines of grain boundary Fe_3C are quite pronounced (arrows in Figure 5).

Cementite distribution in each rail steel as a function of carbon content was presented using distribution of Fe_3C . Results of this analysis are presented in Figure 6, where grain boundary Fe_3C % area fraction (AF) distribution in each steel is presented as a function of the carbon content.

Rail steels with carbon at 0.79 and 0.83wt% indicated distributions that are mostly below 0.1 percent AF. Steels with

higher carbon content between 0.92 and 1.01wt% indicate higher AF percent cementite distributions in each railhead. In addition, the AF range of cementite distribution in steels with higher carbon content is wider. The exception is the rail steel with 0.96wt% C, where cementite content was relatively low.

As mentioned earlier, since Fe_3C is controlled not only by carbon content, but also by alloying and TMP, these two factors most likely contributed to reduced Fe_3C distribution in the railhead with 0.96wt% C. This indicates that it is possible to attain a relatively Fe_3C free microstructure in rail steels with higher carbon content through targeted alloying and TMP implementation.

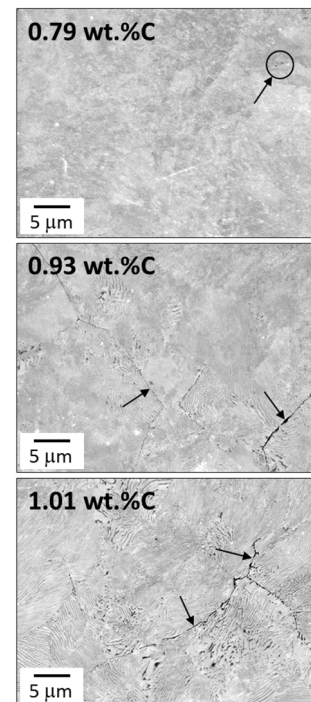


Figure 5. Railhead microstructures indicating grain boundary cementite as a function of carbon content in the rail steels

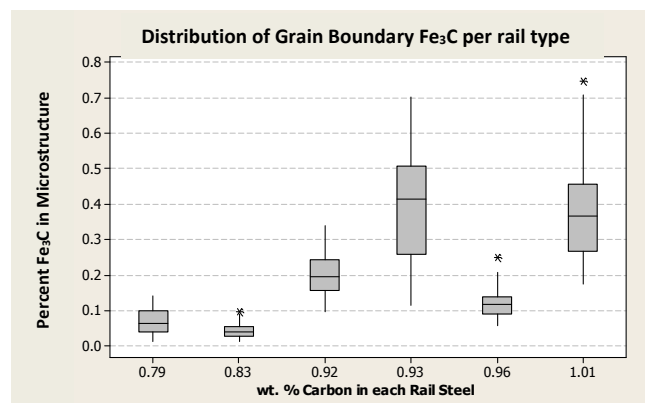


Figure 6. Distribution of Grain Boundary Fe_3C in the tested premium rails as a function of weight % rail carbon content in each rail type

The next task at hand was to relate the median of each Fe₃C distribution to the amount and severity of RCF as a function of MGT accumulated in track.

Rail RCF as a Function of Grain Boundary Cementite

A previous study³ presented the amount of RCF in each 40-foot rail segment, distribution in the curve, and its severity, ranging on a 5-point scale from none to extreme. Using the data from that investigation and combining it with the acquired information on Fe₃C amount in the premium rail steels allows establishing a relationship between median Fe₃C in each rail steel and its RCF occurrence at 200, 300, and 400 MGT of accumulated tonnage. Figure 7 shows such a relationship.

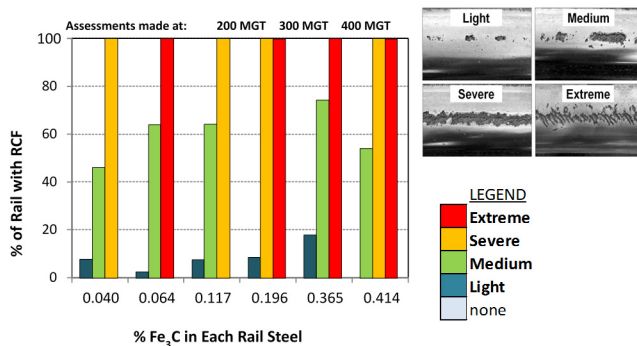


Figure 7. RCF development in premium rail steels containing varying amounts of Fe₃C as a function of tonnage increase for 200, 300, and 400 MGT at each median Fe₃C amount. RCF severity level is indicated by color coding. First bar (left) is 200 MGT, second bar is 300 MGT, third bar is 400 MGT.

The graph indicates that rails with more cementite tend to have more RCF and that this RCF tends to become worse at a lower MGT, as compared to rails with lower grain boundary cementite content.

This relationship is currently being verified with quantitative RCF measurements through both eddy current technologies (i.e., Rohmann’s Draisine) as well as light optical microscopy techniques on rail microstructural cross section. The relationship between RCF and grain boundary Fe₃C will be addressed in greater detail in future publications.

CONCLUSIONS

The premium rail steel test conducted at FAST from 2010 through 2013 evaluated rail types from eight different manufacturers. Total accumulated tonnage at the end of the test was 560 MGT. High rail two sample t-test statistical analysis of rail wear distribution at 559 MGT indicates that three rail types, namely VAS-2, PG4, and ERMS, wear statistically more than the HEX control rail and that none of the other rail grades wear statistically less than the control rail. Analysis on VAS-1 rail could not be completed, because all rail measurement sites except one were lost due to either rail or weld breaks.

The rail with the lowest rail area loss rate was ArcelorMittal, wearing at a rate of 0.082 in²/100 MGT and the rail with the highest area loss rate was VAS-2, wearing at a rate of 0.099 in²/100 MGT, which presents an approximately 20 percent increase in rail area loss rate (see Figure 3).

The difference in rail wear was more noticeable between dry rail and GF lubricated rail. Comparison of the HEX rail in two 5-degree curves at FAST, one that was dry and one that was GF lubricated, revealed that in the dry condition the rate of wear was 0.086 in²/100 MGT, whereas when rail was GF lubricated, the wear was reduced to 0.026 in²/100 MGT. This indicates that in dry conditions the HEX rail wears approximately 3.2 times faster than in GF lubricated track. Combining this observation with the FAST premium rail wear test results in the dry 5-degree curved track, it is evident that when considering rail wear life in curves, selection of rail grade is of lesser importance than the application of appropriate GF lubrication practices.

Cementite formation at grain boundaries is controlled by the amount of carbon above the eutectoid composition, alloying elements in rail steel, and TMP implemented by the manufacturer. Railhead cementite distribution at grain boundaries was determined for six premium rail steels tested at FAST. Results indicate that steels with carbon content close to eutectoid composition tend to have cementite content that is relatively low. As the carbon content increases, the amount of cementite increases and the distribution tends to be wider. However, it is possible to have an elevated carbon content while still producing a relatively Fe₃C free microstructure, as evidenced by the 0.96wt% C rail steel. Targeted alloying elements and TMP can aid in that regard.

Relating the median of Fe₃C distribution of each rail steel to RCF occurrence in track indicates that rail steels with elevated levels of cementite tend to have more RCF and that this RCF becomes worse at elevated MGT, as compared to rails with lower levels of grain boundary Fe₃C. Future quantitative assessment of RCF using eddy current technology will address this relationship in greater detail.

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