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Preliminary Evaluation of Premium Rail Steels for Heavy Haul Operations

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Summary

Transportation Technology Center, Inc. (TTCI) has been involved in premium rail wear testing at the Facility for Accelerated Service Testing (FAST) for over 20 years. Recently, a new heavy axle load (HAL) train has been delivered to FAST, which allows greater tonnage accumulation over time. TTCI conducted mechanical tests on both the head and base of the rails in order to correlate the mechanical test performance with the rail wear performance in a 39-ton axle load environment utilized at FAST.

To date, the following conclusions can be made from the HAL tests:

Laboratory Test Results

- Based on the microcleanliness investigation, all steels are considered to be very clean with a relatively low level of sulphides, and very low levels of oxides and/or voids. Although all rails are fully pearlitic, some of the head microstructures have limited amounts of intergranular proeutectoid cementite (Fe_3C), which has been linked to increased occurrences of rolling contact fatigue in previous studies.¹
- All hardness measurements for the premium rails met the minimum American Railway Engineering and Maintenance-of-Way Association (AREMA) recommendations.
- Uniaxial tensile testing in the railhead region revealed that ultimate tensile strength (UTS) is the only property that met the minimum AREMA recommendations in all the rail grades tested. Both yield strength (YS) and elongation to failure (El.) values failed to meet the minimum AREMA recommendations in some of the grades tested. The best YS and UTS values were attained in the Tata Steel rail, whereas the best El. value was attained in the 400NEXT rail.
- The average fracture toughness (K_{IC}) values for the rails in the head and base regions ranged from 34.8 to 36.3 $ksi\sqrt{in}$, with some of the individual values ranging as high as 42.5 $ksi\sqrt{in}$ in the head region of the JFE-B rail. These high values indicate that all rails being tested should be resistant to base breaks.
- Charpy testing of the rail base indicates that all fractures for all rails investigated were brittle in the 50-200°F range. As a result, ductile/brittle transition temperature could not be identified. Averaging all the Charpy readings in each of the rails indicates that JFE-B rail had the best performance for the premium rails tested.

Field Test Results

- Due to the 200 MGT level accumulated at this point in the test, the only measurement comparison presented is the area loss on the high rail. For the premium rails, the smallest wear is in the Mittal rail, whereas the highest wear is in the VAS-2 rail. However, the wear trends are preliminary, and they may change with accumulated tonnage due to work hardening effects.
- Comparison of average rail wear results from 2005 at 200 MGT indicates that the current rails exhibit approximately 20 percent improvement in wear over the previous generation rails.
- There have been two rail breaks in the premium test curve due to base plate corners digging into the field side rail base corner of the high rail, which may have created stress concentrations at those locations. In addition, there was one flash butt weld break that initiated at the shear marks in the web.



INTRODUCTION

With the advent of increased HAL operations in North America, the railway industry is placing greater emphasis on rail performance testing. Rail suppliers have made product improvements with the goals of improved rail cleanliness, metallurgy, and thermo-mechanical processing, resulting in rails that wear and fracture less, thereby lasting longer. TTCI has been conducting rail performance research to enhance and accelerate the improvement of rails.²⁻⁴ Testing at FAST and in revenue service has shown that rail quality and performance has improved. Today's rails are more resistant to wear and fatigue than rails produced decades ago were. However, the improvements are incremental. Rolling contact fatigue (RCF) and wear still result in reduced rail life^{5,6} and in large capital and maintenance expenditures. In an attempt to significantly improve rail performance, TTCI initiated a cooperative research program with the University of Pittsburgh. That effort led to the development of a next-generation (400NEXT) rail steel, which is a fully pearlitic premium rail. The properties of the 400NEXT rail were engineered to extend in-service rail life by reducing wear and RCF development.

Premium rail tests are currently being conducted by TTCI in Section 7 of the High Tonnage Loop (HTL) at FAST, a 5-degree dry curve with 4 inches of superelevation and 1,000 feet long. The metric used to quantify rail wear performance is railhead profile measurements taken with the Miniprof™. Also, a qualitative assessment of top of rail RCF performance is being carried out.

The FAST train consists of 110-115 railcars with a gross weight per car of 315,000 pounds. The train is operated on the HTL using three locomotives at a speed of 40 mph. The balance speed is 33 mph, which yields 1.7 inches of superelevation deficiency. Traffic is bidirectional, operating at approximately 50 percent in each direction. During train operations in 2010, the average daily tonnage was approximately 1.7 MGT.

The premium rail performance test has seven participating manufacturers and 10 different rail grades. The manufacturers, countries of origin, and number and type of rail grades in test are as follows:

- ERMS Rail Mill (USA) – one grade: OCP
- Tata Steel Rail Mill (France) – one grade: HP (head hardened)
- Nippon Rail Mill (Japan) – one grade: NSC-HEX (*control rail*)
- JFE Rail Mill (Japan) – two grades: JFE-A (SP2), JFE-B (SP3)
- Mittal Rail Mill (USA) – one grade: HC
- Panzhihua Rail Mill (China) – one grade: PG4 (head hardened)
- Voestalpine Rail Mill (Austria) – three grades: VAS-1, VAS-2, 400NEXT

Each manufacturer provided its rail sections in 40-foot lengths. These sections were then welded at the Holland welding facility in Pueblo, Colorado, and delivered to the Transportation Technology Center via a rail train. Note that the track in Section 7 was renewed prior to rail installation. Ballast

was screened and replenished, and new wood ties were installed in the test sections. The ties were plated with Pandrol heavy haul cast plates with 'e' clips. The renewal was intended to provide uniform conditions through the test zones. Similar to the previous rail wear tests conducted at FAST,²⁻⁴ each rail grade was placed adjacent to the NSC-HEX *control rail* to account for any remaining position-in-curve effects.

RESULTS

Rail Microstructure

Railhead microcleanliness analysis, to determine the amount of inclusions, was performed on each steel grade tested at FAST. Sample extraction was done according to the AREMA manual recommendations.⁷ The mean and maximum volume percents of voids, oxides (inclusion matter other than sulphides), and sulphides were determined according to ASTM E1245-03(2008) specification. All microcleanliness testing was performed at an outside independent laboratory. Based on the test results (Figure 1), all steels can be classified as very clean. The amount of oxides and voids in the railhead is relatively small in all steel grades.

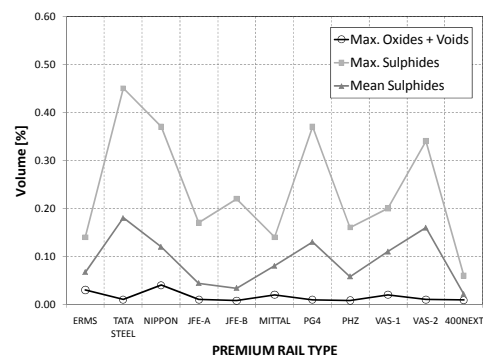


Figure 1. Railhead Microcleanliness Test Results

Assessment of the head microstructures of all the above mentioned rails, indicates that all rails are fully pearlitic, which meets AREMA recommendations for premium rails.⁷ However, using Scanning Electron Microscopy analysis, some proeutectoid cementite (Fe_3C) has been observed at the grain boundaries in some rails. Data from previous investigations on the rail condition following HAL traffic has shown that the presence of Fe_3C may be linked to the occurrence of RCF.¹ The rail industry recognizes that a combination of rail chemistry and thermomechanical processing is the cause of the formation of Fe_3C at the grain boundaries. Previous investigation has shown that the presence of proeutectoid cementite combined with an elevated inclusion level is detrimental to RCF prevention, because RCF cracks that initiate at the intergranular cementite can branch out into secondary cracking with the assistance of the entrained inclusions.¹ Thereby, inclusions tend to speed up the occurrence of RCF in the railhead. The influence of inclusions on RCF development continues to be an important area of investigation. Future work will address this issue.

The presence of inclusions can be directly linked to the steel chemistry, but individual rail chemistries for the test rails are not provided here at the request of the rail manufacturers.

Railhead Hardness

Brinell hardness measurements (HBW 10/3000) were taken on top of the railhead for all rail grades. The average hardness was 407±11 HB (Figure 2), which is similar to the hardness measurements of the 2005 premium rail wear test.² All the premium rail readings exceeded the minimum AREMA hardness recommendation for premium rails.⁷

Improvements in rail hardness are generally associated with improved in-service wear performance. As such, all premium rails are expected to have relatively good wear performance over time. Future reports will focus on a link between head hardness, head work hardening over time, and wear performance of each grade as a function of these factors.

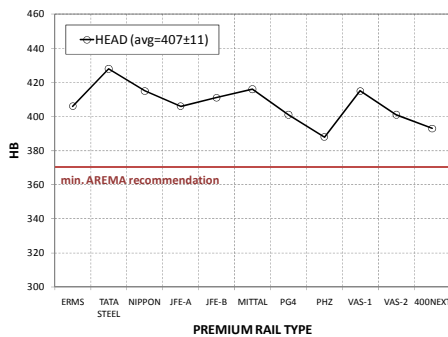


Figure 2. Railhead Hardness Test Results

Rail Mechanical Properties

Tensile and fracture toughness samples were taken from both the railhead and the base for each rail grade. Tensile testing was carried out at room temperature according to ASTM E8-09 specification. Fracture toughness testing was carried out at room temperature to ASTM E399-09 specification.

The mechanical properties obtained from the tensile testing were the YS, the EL, and the UTS. During the first round of testing, the mechanical properties of some rail grades failed to meet the minimum AREMA recommendations.⁷ Thus, for verification purposes, the tests were repeated, and the second round of testing yielded similar results. Both rounds of blind study testing were conducted at two different independent laboratories. Figure 3 shows tensile railhead and base test results for the rail grades analyzed, as well as the minimum AREMA railhead recommendations.

Considering the tensile properties in the head region of each rail, UTS is the only mechanical property that met the minimum AREMA recommendations in all the rail grades tested. Both YS and EL failed to meet the minimum AREMA recommendations in some of the grades tested. The best YS and UTS values were attained in the Tata Steel rail, whereas the best EL value was attained in the 400NEXT rail.

Although generally lower, the base tensile properties closely mimic the tensile railhead performance, which is particularly evident in the EL readings.

Fracture toughness testing was performed on both the railhead and the rail base, and it was carried out similarly to the previous rail wear test.³ As indicated on the graphs in Figure 3, the average K_{IC} values for the rails in the head and

base regions ranged from 34.8 to 36.3ksi√in, with some of the individual values ranging as high as 42.5ksi√in in the head region of the JFE-B rail. Fracture toughness measurements are aimed at correlating the material's resistance to brittle crack propagation, which may be used as a means to assess the propensity for in-service base cracks. These high values indicate that all rails being tested should be resistant to base breaks.

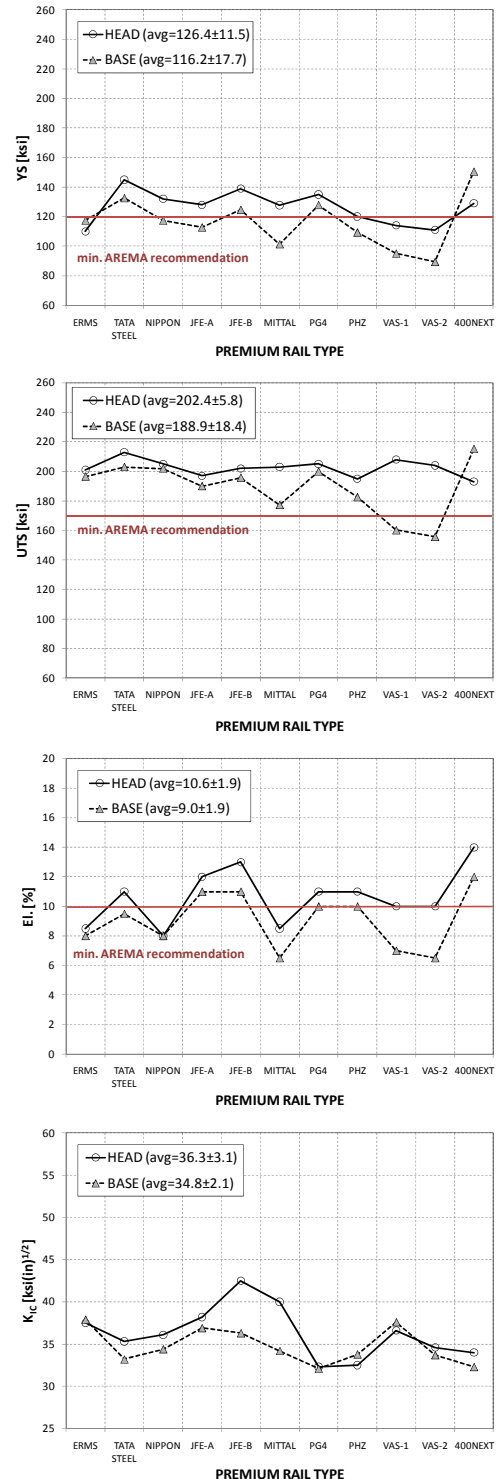


Figure 3. Tensile and Fracture Toughness Test Results

The AAR Rail Technical Advisory Group suggested that fracture toughness values are affected by the carbon content in the rail steel. As a result, the attained K_{IC} values for the railhead and base regions were linearly correlated to the carbon content in each steel grade tested. There was a poor correlation between $C[wt. %]$ and K_{IC} of $R^2=0.04$ for both the head and base. These correlations may be an indication that carbon content alone is not a good predictor of the K_{IC} value, and thereby not a good predictor of the resistance to base fractures in revenue service environment.

Rail Base Charpy Test Results

To gage the rail resistance to base fractures as a function of temperature, Charpy samples were taken from the base region of the rail. Based on test results, JFE-B rail had the best performance for the premium rails tested (Figure 4). Tests were carried out according to ASTM E23 Type-A in the 50-200°F temperature range. This temperature range was selected in order to pinpoint the ductile/brittle transition temperature. However, test temperature versus energy absorbed by the samples showed no correlation. All the fracture surfaces observed were brittle in nature at all temperatures tested. As a result, ductile/brittle transition could not be identified in any of the rails. Averaging all the Charpy readings in each of the rails and utilizing standard deviation to account for the distribution presents a more discerning representation of the rail performance in the investigated temperature range.

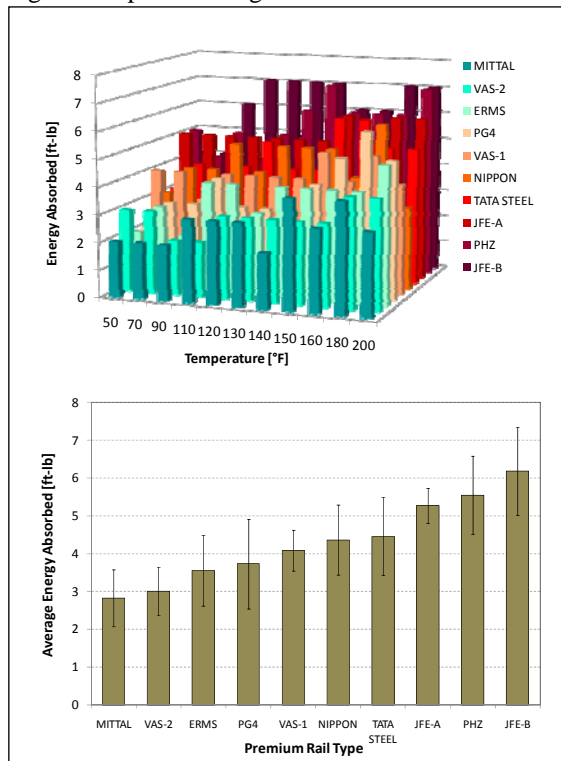


Figure 4. Charpy Test Results

Preliminary Rail Wear Results

Rail wear measurements were taken with the Miniprof at 32, 60, 89, 140, and 200 MGT of accumulated traffic at FAST. Comparison of average rail wear results from 2005 at 200 MGT

indicates that current rails exhibit approximately 20 percent improvement in wear over the previous generation rails. To date, four rail wear measurement locations have been eliminated from the curve due to high rail field side base break defects.

Profile measurements yielded W1 (vertical), W2 (horizontal), and W3 (auxiliary) location measurements, as well as the “area loss” measurements. Because the current accumulated MGT level is relatively low at this point in the test, the only measurement comparison presented here is the area loss on the high rail (Figure 5). For the premium rails, the smallest wear was in the Mittal rail, whereas the highest wear was in VAS-2 rail. However, the wear trends are preliminary and may change with accumulated tonnage due to work hardening effects. The 400NEXT rail was installed at a later date than the other premium rails and has only accumulated 120 MGT to date. For future comparison, measurements in the 400NEXT rail will be taken at the comparable tonnage as the other premium rails.

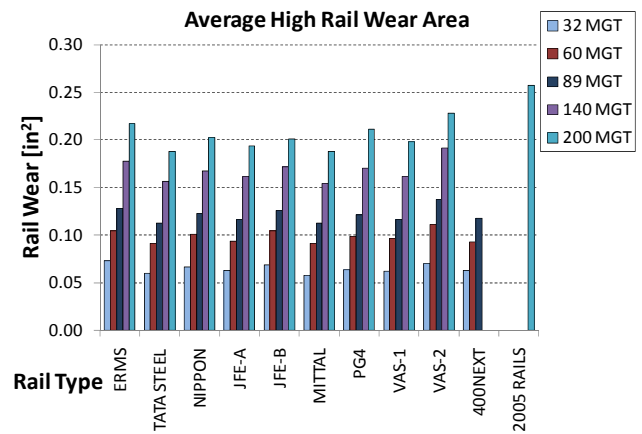


Figure 5. Preliminary High Rail Wear Results

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