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Preliminary Evaluation of Intermediate Hardness Rails 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. In 2010, rail wear testing was extended to the intermediate hardness (IH) rails employing the same track geometry as the premium rail test, with the only difference being that the IH curved track is lubricated. IH rail type refers to the intermediate strength rail recommended values as specified by American Railway Engineering and Maintenance-of-Way Association (AREMA). This test offers a unique opportunity to compare wear performance of the IH rails to the premium rails in the same track environment (same MGT, track geometry, and environmental conditions).

It is too early to draw any conclusions from the wear test. However, TTCI conducted mechanical tests on both the head and base of the IH rails to correlate the mechanical test performance with the rail wear performance in a 39-ton-axle load environment applied at FAST. To date, the following conclusions can be made from these tests:

- To date, there have been three high rail field side base corner breaks (one in each Mittal, ERMS-2, and Tata Steel rail grades). These breaks were determined to have originated at either base corner nicks introduced during rail installation or base plate corner mechanical damage during train operation.
- 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.
- Two of the IH rails have head hardnesses just below the minimum (AREMA) recommendations.
- Almost all of the tensile results for the railhead in the IH rails met the minimum AREMA recommendations, with the best properties displayed by the Lucchini rail. The only property that did not meet the minimum AREMA recommendation was yield strength in the ERMS-SS rail. Although generally lower, the base tensile properties closely mimic the tensile railhead performance, which is particularly evident in the ultimate tensile strength readings.
- The average fracture toughness (K_{IC}) values on the head and base regions for the IH rails ranged from $36.7\ ksi\sqrt{in}\ to\ 36.9\ ksi\sqrt{in}$, with some of the individual values ranging as high as $44.6\ ksi\sqrt{in}$. These are relatively high values and are expected to yield a lower occurrence of base breaks in revenue service conditions.
- Charpy testing of the rail base indicates that all Charpy sample fractures for all rail grades investigated were brittle in the 50-200°F range. As a result, ductile/brittle transition temperature could not be identified. Averaging the results, however, indicates that some rails on average perform better than others.
- The rolling contact fatigue development in each rail grade tested is relatively minor. The rails display limited head checks in the gage corner of the high rail and on top of the low rail. These head checks are very shallow and have not led to any spalling as of yet. Lubrication in the curve appears to be reducing the development of head checks as compared to the premium rails.

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INTRODUCTION

With the advent of increased heavy axle load (HAL) operations in North America, the railway industry is placing increased emphasis on rail performance testing. Rail suppliers have made product improvements with the goals of improved rail cleanliness, metallurgy, and thermomechanical 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.[1] 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. However, the performance improvements tend to be incremental. Rolling contact fatigue (RCF) and wear still result in reduced rail life[2,3] and in large capital and maintenance expenditures.

Premium rail testing has been conducted at FAST for over 20 years. However, the IH rail test setup in 2010 is the first of its kind at the Transportation Technology Center (TTC). This test is currently located in Section 3 of the High Tonnage Loop (HTL), in a 5-degree curve with gage face (GF) lubrication on the high rail and light top of rail (TOR) lubrication on the low rail. The curve is 800 feet long with 4-inch superelevation.

The metric used to quantify rail wear performance is railhead profile measurements taken with the Miniprof™. Also, a qualitative assessment of TOR RCF performance is being carried out.

The test train at FAST consists of 110-115 railcars with a gross weight per car of 315,000 pounds, which yields a 39-ton/axle load. 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 inch of superelevation deficiency. Traffic is bidirectional, operating at approximately 50 percent of the time in each direction. During 2010 train operations, the average daily tonnage was approximately 1.7 MGT.

For the IH rail-wear test, there are six participating manufacturers with the following eight rail grades:

- Tata Steel Rail Mill (France) – one grade: HP rail (as rolled)
- ERMS Rail Mill (USA) – three grades: ERMS-1 (IH), ERMS-2 (IH HS), SS (*control rail*)
- Panzhihua Rail Mill (China) – one grade: PG4 (as rolled)
- Mittal Rail Mill (Spain) – one grade: ML
- Trinecké Zelezárny Rail Mill (Czech Republic) – one grade: TZ
- Lucchini Rail Mill (Italy) – one grade: IH

Each manufacturer provided its own rail sections in 40 foot lengths. These sections were then welded at the Holland Company welding facility in Pueblo, Colorado, and delivered to the TTC via a rail train. The test track in Section 3 at FAST 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. As with the previous premium rail wear test conducted at FAST,[1] each rail grade was placed adjacent to a *control rail*, which, for the purpose of this test, was selected as ERMS-SS rail. This placement was done to account for any position-in-curve effects. Due to the large number of rail grades tested and space limitations in the curve, it became difficult to place each rail grade tested next to a control rail. An arrangement sequence was developed that allowed the placement of at least one rail grade adjacent to a control rail in the string.

RESULTS

Rail Microstructure

Railhead microcleanliness analysis to determine the amount of inclusions was performed on each IH steel grade tested at FAST. Sample extraction was done according to the AREMA manual recommendations.[4] 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. Figure 1 shows the results for all the steel grades tested. Based on these results, all steels can be classified as very clean. The amount of oxides and voids in the railhead is relatively small in all grades tested.

Assessment of the head microstructures of all the above mentioned rails, indicates that all rails are fully pearlitic, which meets AREMA recommendations.[4] The presence of inclusions can be directly linked to the steel chemistry. However, the individual rail chemistries for the test rails are not provided here at the request of the rail manufacturers.

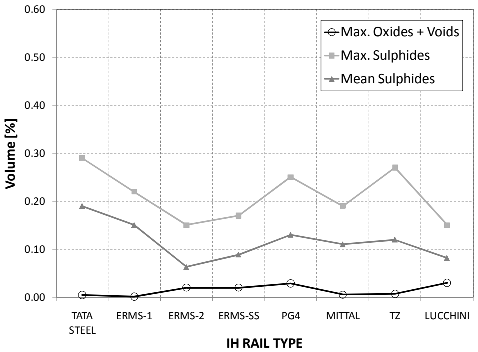

Figure 1. Railhead Microcleanliness Test Results

Railhead Hardness

Brinell hardness measurements (HBW 10/3000) were taken on top of the railhead for all rail grades. The average reading was 335±15HB, and all but two of the readings met the minimum AREMA recommendation (Figure 2). 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. It should be noted that although the IH rail curve has a substantially lower average hardness, this curve is lubricated on the GF of the high rail and has low rail TOR friction control. As a result, the wear performance is expected to be better than in the premium rail curve, which is not lubricated.

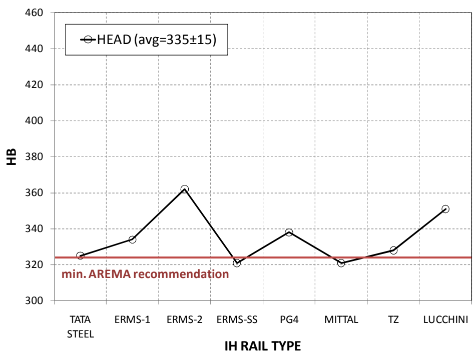

Figure 2. Railhead Hardness Test Results

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 according to ASTM E399-09 specification.

The mechanical properties obtained from the tensile testing were the yield strength, the ultimate tensile strength, and the elongation to failure. During the first round of testing, the mechanical properties of some rail grades failed to meet the minimum AREMA recommendations.[4] Thus, for verification purposes, the tests were repeated. Both rounds of blind study testing were conducted at two different independent laboratories.

Figure 3 graphs show tensile test results for the railheads and bases of the IH rail grades, as well as the minimum AREMA recommendations for the head of the rail. As indicated, almost all of the tensile results for the railhead in the IH rails met the minimum AREMA recommendations, with the best properties displayed by the Lucchini rail. The only property that did not meet the minimum AREMA recommendation was yield strength in the ERMS-SS rail. Although generally lower, the base tensile properties closely mimic the tensile railhead performance, which is particularly evident in the ultimate tensile strength readings.

Fracture toughness testing was performed on both the railhead and the base, and it was carried out similar to the previous rail wear test.[1] As Figure 3 graphs show, the average K_{IC} values for both the premium and IH rails in the head and base regions ranged from $36.7\ ksi\sqrt{in.}\ to\ 36.9\ ksi\sqrt{in.}$ with some of the individual values ranging as high as $44.6\ ksi\sqrt{in}.$ 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 relatively resistant to base breaks.

There is a perception that fracture toughness values are strongly affected by the carbon content in the rail steel. As a result, the attained K_{IC} values for the railhead and base regions in the IH rail grades were linearly correlated to the carbon content in each steel grade tested. There is a poor correlation between C[wt.%] and K_{IC} of R^2=0.04 for the head of the IH rails; however, there was a relatively good correlation in the base region (R^2=0.67). 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 for base fractures in revenue service.

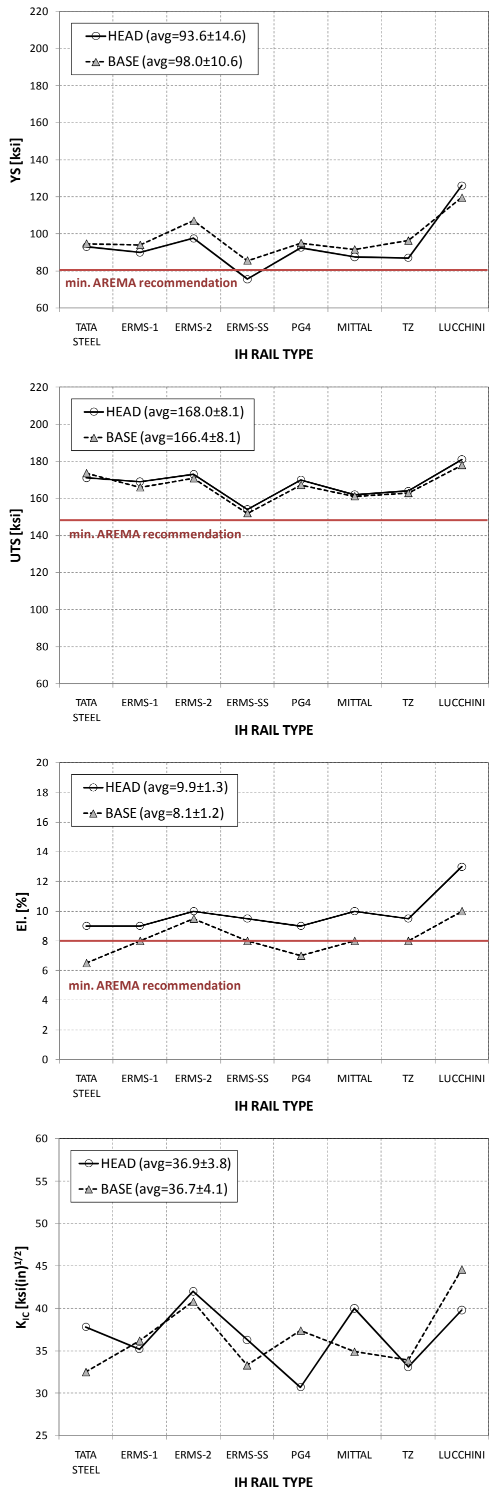

Figure 3. Tensile and Fracture Toughness Test Results

Rail Base Charpy Test Results

To analyze the rail resistance to base fractures as a function of temperature, Charpy samples were taken from the base region of the rail. Tests were carried out according to ASTM E23 Type-A specification in the 50-200°F temperature range with the notch oriented toward the bottom of the base, and results were organized in an ascending order. This temperature range was selected in order to pinpoint the ductile/brittle transition temperature. The test temperature and the energy absorbed by the samples showed no correlation. All the fracture surfaces observed were 100-percent brittle in nature. As a result, ductile/brittle transition could not be identified in any of the rails. However, 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 (see Figure 4). Based on these results, Lucchini rail performed the best out of all IH rails in the temperature regime studied.

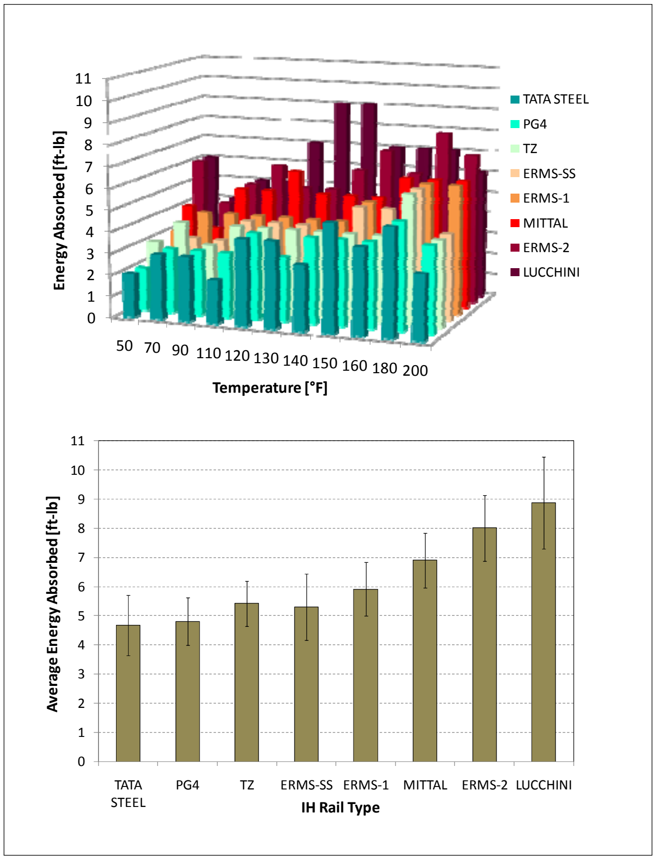

Figure 4. Charpy Test Results

Preliminary Rail Wear and RCF Results

Rail wear measurements were taken at 32, 60, 89, 140, and 200 MGT of accumulated traffic at FAST using the Miniprof. Five rail profile measurements were taken at each rail test segment with the outer measurements 6 feet on either side of the weld. This setup allowed for 10 rail profile measurements on the high rail and 10 on the low rail for each rail grade being tested in this curve. To date, three rail measurement locations were eliminated from the curve because of 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 it is still relatively early on in the test, the only metric presented here is the average high rail wear area (see Figure 5). The smallest wear to date is in the ERMS-1 rail, whereas the largest wear is in the Mittal rail grade. However, the wear trends are preliminary, and they may change with additional accumulated tonnage from work hardening effects in the head.

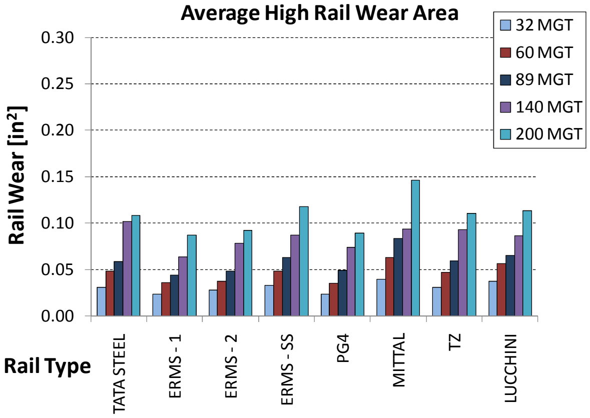

Figure 5. Preliminary Rail Wear Test Results

To date, the RCF development in each rail grade tested is relatively minor. The rails display limited head checks in the gage corner of the high rail and on top of the low rail. These head checks are very shallow and have not led to any spalling as of yet. Lubrication in the curve appears to be reducing the development of head checks as compared to the premium rails.

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