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Evaluation of High-Strength Rail Properties for 2018 Rail Wear Test

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Key Findings:

- Surface hardness of all eight rail types exceeds the minimum AREMA recommended value of 370 Brinell hardness (HB).
- Cross-sectional hardness for all seven locations of all eight rail types exceeds the minimum recommended value of 352 HB.
- Yield strengths and tensile strengths of the eight rail types are above the minimum requirements of 120 ksi and 171 ksi, respectively.
- Microcleanliness of the eight samples measured per ASTM Standard Practice E45 have a maximum severity rating of around 3 or less, and an average severity rating varying between 2 and 2.5 on a severity scale of 0.5 to 5 for six out of eight samples.
- Impact toughness measured by Charpy impact tests indicated that fractures for all rails investigated were brittle in the -58° to 176°F range, and ductile/brittle transition temperatures could not be identified.
- Fracture toughness was measured in the head and base of all rail types and the average values were 34.8 and 33.1 ksi-in$^{1/2}$, respectively.

Transportation Technology Center Inc. (TTCI) began a new rail test in a 1,000-foot-long, 5-degree reverse curve at the Facility for Accelerated Service Testing (FAST) near Pueblo, CO. TTCI has been involved in high-strength (premium) rail testing for more than 25 years and 2018 marks the start of a test for the evaluation of the latest generation high strength rails. Eight different manufacturers donated rails for this test and the properties of each of these rail types have been evaluated, analyzed and documented in this *Technology Digest.* Results for some of the properties have been compared with minimum recommended values mentioned in Chapter 4-Rail, of the American Railway Engineering and Maintenance-of-Way Association's (AREMA) *Manual for Railway Engineering.*[1] The results in this TD are a preliminary evaluation of the rails and will be used to compare rail performance metrics such as wear, fatigue defect occurrences and rolling contact fatigue (RCF) intensities observed during the test.

A 1,000-foot reverse 5-degree curve on the HTL has been the test bed for high strength rail tests under heavy axle loads for decades. This curve has 4 inches of superelevation and is kept unlubricated to achieve accelerated wear. 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. Traffic is bi-directional, operating at approximately 50 percent of the time in each direction. A new high-strength rail test has started, and eight rail manufacturers are participating as listed below:

- Arcelor-Mittal Steelton LLC. (USA) - AHH grade
- EVRAZ Rocky Mountain Steel (USA) - OCP grade
- Steel Dynamics Inc. (USA) - HC grade
- Angang Group International Panzhihua Co. Ltd. (China) - PG5 grade
- British Steel (UK, France) - MHH400 grade
- voestalpine Schienen GMBH (Austria) - UHC grade
- Nippon Steel Corporation (Japan) - HE-X grade
- JFE Steel Corporation (Japan) - JFE-D (SP4) grade.

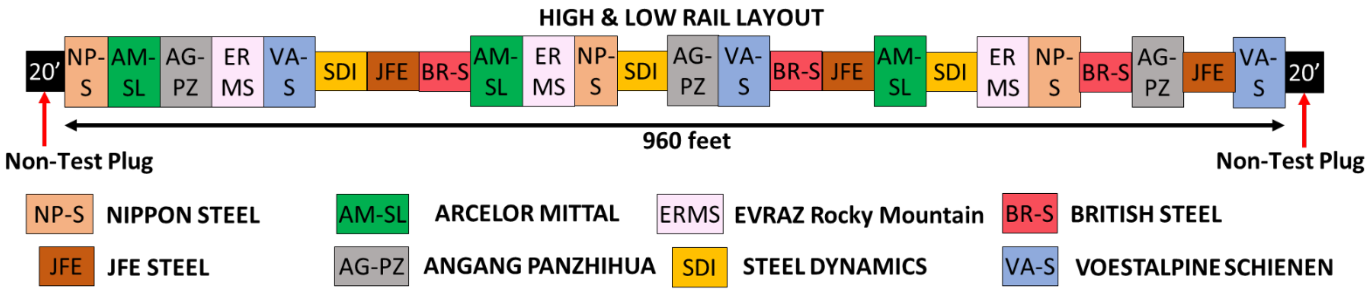


Figure 1. Layout of 2018 High-Strength (premium) rail test at FAST

Three 39- or 40-foot rail pieces from each supplier were installed on the high rail and on the low rail. The same rail types were installed across from each other on high and low rails. Each rail section measures 39 or 40 feet in length. The layout of the high and low rails is shown in Figure 1 with the legend showing abbreviated names of the rail manufacturers. Two 20-foot long non-test plug rails were welded at the ends of the test rails to reduce effects of vehicle dynamics on test rail performance because of curve to spiral transition. The layout was designed so that every rail type has three rails spread in an even manner throughout the curve.

This TD discusses the preliminary evaluation of rail properties of the eight rail types participating in this test and the comparison with AREMA Chapter 4 recommendations. Tests for evaluating tensile properties, impact toughness and fracture toughness were conducted in independent certified testing laboratories while hardness and microcleanliness analyses were done internally at TTCI. To maintain confidentiality, the names of the eight rail suppliers were not used in regard to results.

Properties per AREMA Chapter 4: Rail[1] Hardness

Surface hardness was measured on the top of all rails and results are shown in Figure 2. The measured values were compared with surface hardness values provided by the rail manufacturers and all eight rail types have values well above the AREMA recommended minimum value of 370 HB as per Table 4-2-1-3-2a and 2b.[1]

Figure 3b shows the seven locations labeled in red on the original Figure 4-2-1 of Chapter 4: Rail.[1] Internal cross-sectional hardness of the head of the eight rail types was measured at seven locations as per Figure 3b using Rockwell C indenter and converted to Brinell scale per the conversion equation in Table 4-2-1-3-3a of Chapter 4. All rail types exceed the minimum AREMA recommended value of 352 HB as shown in Figure 3a.

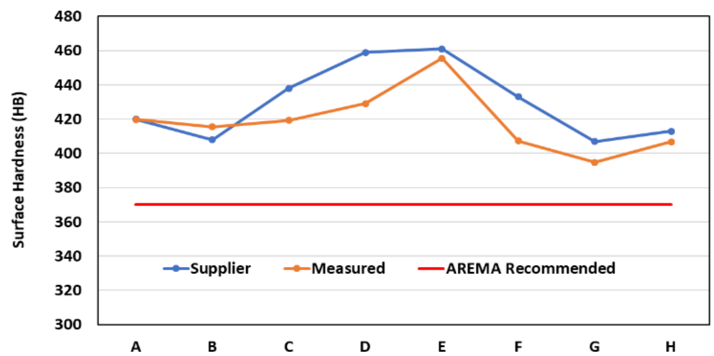


Figure 2. Surface hardness measurements

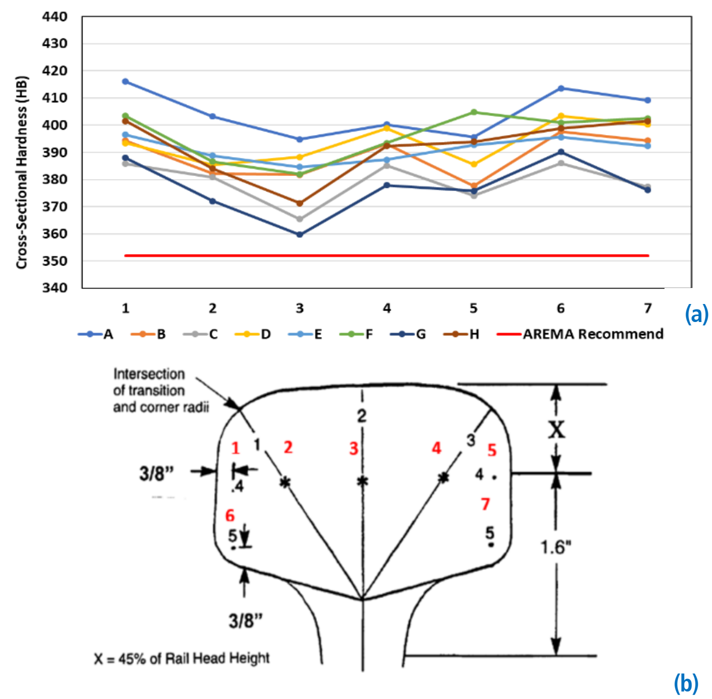


Figure 3. (a) Cross-sectional hardness of head; (b) measurement locations (red) consistent with Figure 4-2-1[1] of AREMA Chapter 4: Rail

Tensile Properties

Tensile bars were machined from one gage corner of the head and center of the base for all rail types as per Article 2.1.3.4 of Chapter 4 and tested for yield strength, tensile strength and percentage of elongation. Tests results were compared with manufacturers' data and AREMA recommended values from Tables 4-2-1-3-4a and 4b and have been shown in Figures 4a and 4b. Although results from rail base are shown for comparison, the minimum AREMA recommended values only apply to samples machined from the head portion of rails as per Article 2.1.3.4.[1] All rail types have tensile strengths above the minimum recommended value of 171 ksi and yield strengths above the minimum recommended value of 120 ksi. Type D measured 121 ksi as yield strength although manufacturer's measured yield strength was 147.2 ksi. Average percentage of elongation for five rail types were found to be below 10 percent. Some tests were repeated, and significant variation of elongation percentage was noticed, and results have not been reported here due to this variation. On the contrary, minor variation of yield and tensile strengths were observed from the re-tests. Measurement methodologies affect results and may account for some differences between results provided by manufacturers and results from the independent laboratories selected by TTCI.

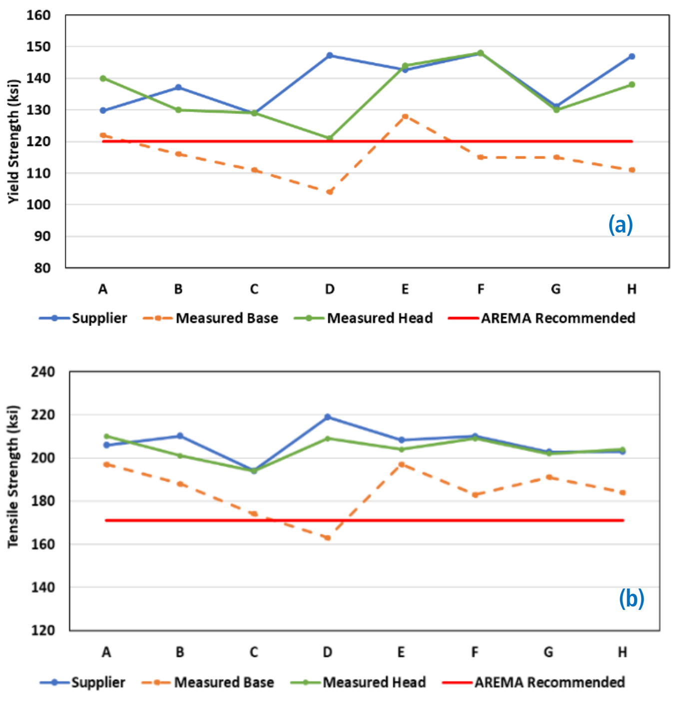


Figure 4. (a) Yield strength results; (b) Tensile strength results

Comparison of results with previously tested high strength rail types back in 2011 (TD11-031)[2] show an increase in average yield strength from 126.4 ksi to 131.9 ksi and average tensile strength changing by only 0.36 percent (increased by 0.7 ksi).

Microcleanliness

Samples for microcleanliness analysis were machined from the head of the rail as per Figure 4-2-3 of Chapter 4 and evaluated for severity rating of inclusions on a scale of 0.5-5 as per Article 2.1.9.6.3 which refers to American Society for Testing and Materials (ASTM) standard practice E45 Method A. As per Article 2.1.9.6.3, "Each individual metallographic sample shall have a maximum average rating of 2 and a maximum individual rating of 3 for any inclusion type, thin or heavy." The microcleanliness software looks at Type D (globular) inclusions collectively as oxides and voids because it is difficult to visually differentiate oxides and voids without doing individual chemistry analysis at every inclusion that appears globular in shape. Figure 5 shows microcleanliness results where all rail types have a maximum severity rating around 3 or less (maximum = 3.08). The average rating is around 2.5 for types E and F although the maximum individual severity rating for both E and F types is below 3. The average ratings for types B and G are below 2 while types A, C, D and H are above 2 and below 2.25.

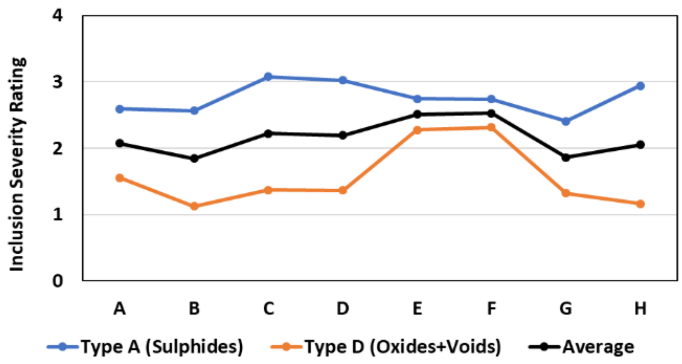
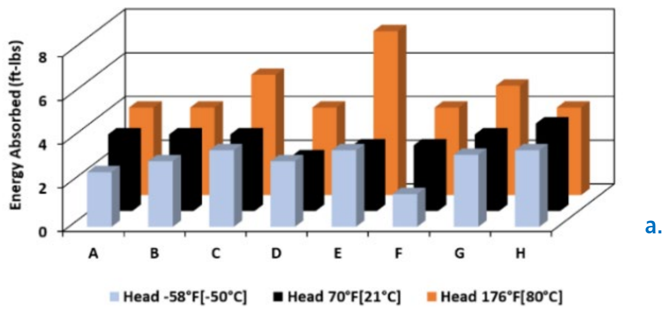


Figure 5. Microcleanliness results

Properties outside AREMA Chapter 4: Rail Impact Toughness

To understand the resistance of rails to brittle fractures occurring in the base and head as a function of temperature, Charpy impact tests were performed as per ASTM E23 method at three different temperatures: -58°F (-50°C), 70°F (21°C) and 176°F (80°C). This temperature range was chosen as it represents the approximate range of temperature rails exhibit in response to weather variations in North America. Four (A, B, G, H) rail types show an increase in absorbed energy in the head with increase in temperature as shown in Figure 6a. Six (B, C, D, E, G, H) rail types show the same trend of increase in absorbed energy in the base with temperature as shown in Figure 6b. All samples had brittle fractures and ductile/brittle transition could not be identified for any rail type.



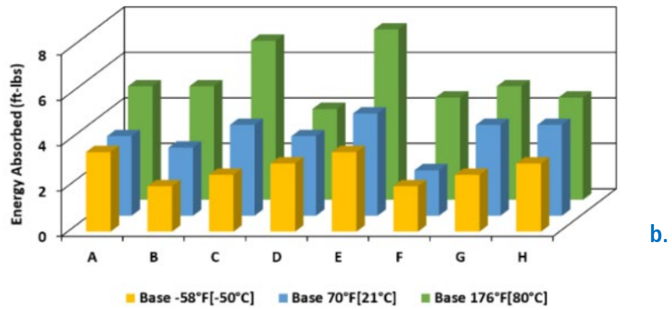


Figure 6. Charpy Impact test results of (a) head and (b) base

Fracture Toughness (K_{1C})

Fracture toughness (K_{1C}) was measured in the head and base of the rails and have been reported in Figure 7. The average value of K_{1C} for base and head were 33.1 ksi-in$^{1/2}$ and 34.8 ksi-in$^{1/2}$, respectively. Rail types tested earlier have shown higher K_{1C} values and although theoretically higher fracture toughness means higher resistance to brittle crack propagation; other factors along with K_{1C} can affect brittle crack propagation in service conditions.[2]

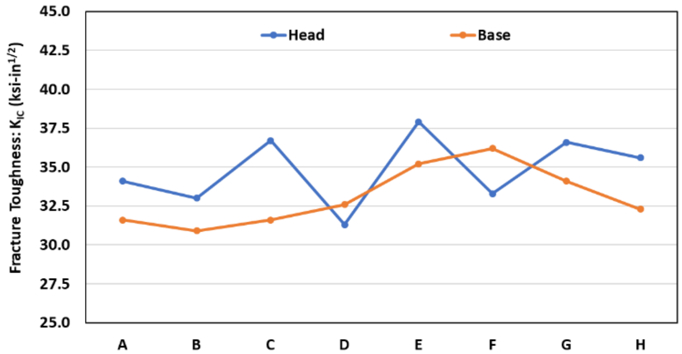


Figure 7. Fracture toughness results

CONCLUSION

Eight rail manufacturers participated in the new high strength rail wear test on the HTL at FAST . Surface hardness, cross-sectional hardness, microcleanliness, tensile properties including yield strength and tensile strength have been evaluated and compared with minimum recommended values mentioned in AREMA Chapter 4. For properties such as impact toughness (Charpy Impact test) and fracture toughness (K_{1C}) not mentioned in AREMA Chapter 4, tests were done for all eight rail types and these results will be used in the future for correlation with rail performance metrics such as wear, RCF formation and fatigue defects.

ACKNOWLEDGEMENTS

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References

1. American Railway Engineering and Maintenance-of-Way Association. 2017, Chapter 4: Rail, *Manual for Railway Engineering*.
2. Szablewski, Daniel, Semih Kalay, and Joseph LoPresti. September 2011. "Preliminary Evaluation of Premium Rail Steels for Heavy Haul Operations" *Technology Digest* TD-11-031. AAR/TTCI, Pueblo, CO.

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