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# Interim Evaluation of Premium Rail Steels at FAST

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## Summary

Transportation Technology Center, Inc. (TTCI) is conducting rail performance tests on premium rail steel at the Facility for Accelerated Service Testing (FAST). AREMA mechanical properties criteria for high strength rails are being used to evaluate the rails being tested. The rails were tested for fracture toughness in the laboratory and are now being tested in track for wear and fatigue. It is important to mention that the relationships among the mechanical properties and between the mechanical properties and in-track performance are complex. Conventional laboratory tests do not necessarily provide a good indication of field performance. Therefore, one of the objectives of TTCI research is to develop performance evaluation criteria suitable for premium rail.

After 200 MGT of traffic, the following preliminary results were obtained:

- The average hardness of the rails (410 Bhn) is 15 Bhn higher than the average of the test that ended in 2005 and 45 Bhn higher than the high strength rail tested that ended in 2001.<sup>1,2</sup>
- Maximum wear on any of the rails to date is approximately 5 percent of head area. The wear results indicate that the currently tested rails have better wear resistance than the previously tested rails. However, the low rail on this test shows significant rolling contact fatigue.
- The first rail break occurred after approximately 220 MGT of HAL traffic at FAST.
- The fracture toughness of current test rails is lower than that of the previous rails: average 2.3 ksi√in lower (-0.6 to -4.8)  $K_{IC}$  at the head of the rail and 4.1 ksi√in lower (+0.4 to -9.4) at the base of the rail. Traditionally, it was considered that lower fracture toughness can be related to rail breaks. The current results at FAST show a weak correlation from fracture toughness to rail breaks.
- Most rails currently being tested failed to meet some AREMA mechanical property specifications.
- Two of the 22 electric flash butt welds on the high rail and one of 22 on the low rail have failed. Reasons for these failures are under investigation.



**INTRODUCTION**

In July 2005, TTCI began the latest rail performance test at FAST using the most modern state-of-the-art premium rails. The rails are being tested in a 5-degree reverse curve where there is no direct rail lubrication.

The test train at FAST consists of four locomotives and approximately 75 cars weighing 315,000 pounds each. Five rail manufacturers are participating in the rail performance test:

- JFE Steel Corporation
- Mittal Steels
- Nippon Steel Corporation
- Rocky Mountain Steel Mills
- voestalpine

In addition, rail with the same metallurgy corresponding to the previous test in 2005<sup>1</sup> was included in this test to facilitate comparisons.

The average hardness of the five new test rail types, 410 Bhn, is 15 Bhn higher than the average for the previous test that ended in 2005, 45 Bhn higher than average hardness of the rails tested in the previous test that ended in 2001, and 40 Bhn higher than the AREMA requirement for high strength rail.<sup>1,2</sup> Historically, higher hardness has been related to better wear performance.<sup>3</sup> However, increases in hardness can adversely affect other mechanical properties such as fracture toughness and ductility. For this reason, the latest generation of rails was tested for fracture toughness in addition to the tests required by AREMA for high strength rail.<sup>3</sup>

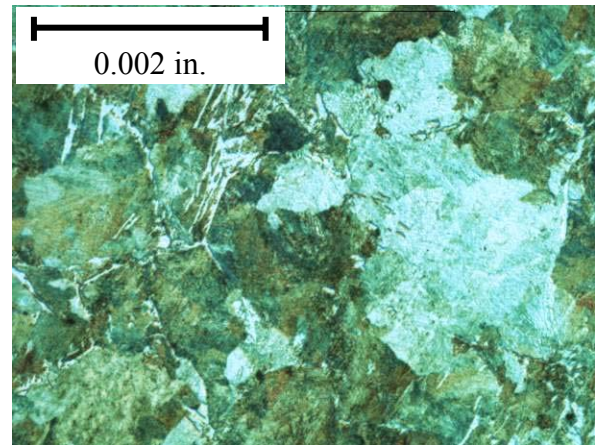
- Hardness = 370 Bhn
- Yield strength = 120 ksi
- Tensile Strength = 171 ksi
- Elongation > 10 %\*
- Fully pearlitic microstructure

Per AREMA criteria, one tensile test and hardness sample per heat of steel or 10,000 feet of rail, which ever is smaller, should be tested.<sup>3</sup> If a sample does not meet the AREMA criteria, two additional samples should be tested. If either of these two samples does not meet the requirements, two more samples should be tested. If any of these results are unsatisfactory, individual rails must be sampled and tested for acceptance.

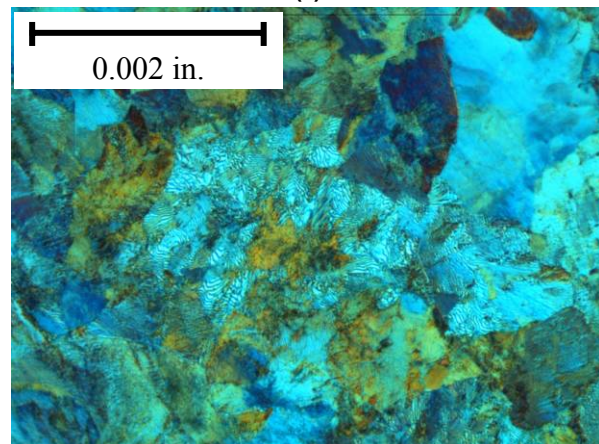
**Microstructure and Mechanical Properties Microstructure**

AREMA specifications recommend that high strength or premium rails should be fully pearlitic. Figure 1, a & b, shows representative microstructures of the premium rails that are currently under test at FAST. In some of the rails, small amounts of pro-eutectoid ferrite were detected in the

microstructure at depths of approximately 0.5 inch below the head surface (Figure 1a).



(a)



(b)

**Figure 1. Representative Microstructures of Two Different Premium Pearlitic Rails**

**Hardness**

Rockwell C and Brinell hardness measurements were conducted at the locations prescribed by AREMA.<sup>3</sup> Table 1 shows the results of the head hardness measurements for the investigated rails. It is important to note that for some rails, there was up to a 25 HB variation in hardness along the length of the rail. Cooling practices and roller straightening may have contributed to the variations.

**Table 1. Results of the Head Hardness Measurements**

Rail Manufacturer	Brinell Hardness
JFE Steel Corporation	430
Mittal	375
Nippon Steel Corporation	429
Rocky Mountain Steel Mills	415
voestalpine	401
Avg. of previous test rails	395
High strength rail (AREMA requirement)	370

\*Up to 5% of the order may be less than 10% elongation, if purchaser's authorized representative and supplier agree, but in no case may elongation be less than 9%.

**Tensile Test Results**

Because some rails failed to meet some AREMA specifications, TTCI conducted three sets of tensile tests. The tests were conducted by TTCI and by an independent laboratory. In order to further confirm these results, TTCI had two more tensile samples of each rail type tested in a second independent laboratory. Table 2 shows the results of these tests.

**Table 2. Results of the Tensile Tests Conducted on Premium Rails**

Rail Type	Yield Strength (ksi)	Tensile Strength (ksi)	Elongation (%)
A*	146 ± 4	202 ± 1	10.5 ± 1
A**	136 ± 2	204 ± 1	10 ± 1
A***	134 ± 2	202 ± 1	9 ± 0
B*	125 ± 0	198 ± 2	9.7 ± 1.2
B**	115 ± 0	193 ± 1	7 ± 0
B***	121 ± 2	196.5 ± 3	6.5 ± 0
C*	121 ± 2	197 ± 1	7 ± 0.5
C**	133 ± 6	204 ± 1	7.5 ± 0.5
C***	119 ± 1.5	196.5 ± 4	6.5 ± 0.5
D*	112 ± 1	196 ± 1	9 ± 1
D**	115 ± 6	200 ± 3	8 ± 1.5
D***	113 ±	197 ±	7.5 ± 0.5
E*	120 ± 3	196 ± 2	8.3 ± 0.3
E**	114 ± 2	195 ± 1	7 ± 0
E***	119 ± 5	203 ± 2	6.5 ± 0.5

\*Tested at TTCI, \*\*Tested at Independent Lab No. 1, \*\*\*Tested at Independent Lab No. 2

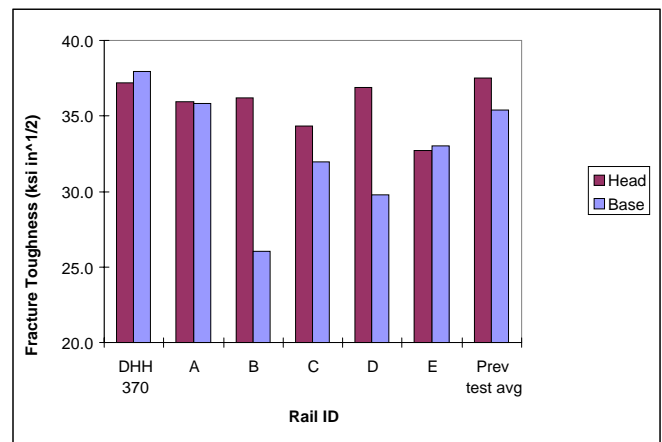
**Fracture Toughness**

Fracture toughness is a measure of the resistance of a pre-cracked or scratched material subjected to a static tension to crack propagation in a brittle manner. Fracture toughness is a common concern in components (e. g., rail) with thick sections that may fail in a brittle fashion. For a given material, there is generally a good correlation between hardness and fracture toughness — as hardness increases, fracture toughness decreases. However, this is not the case for the rails currently being tested. Statistical analysis of head hardness and fracture toughness of the test rail showed an R<sup>2</sup> less than 0.5; the relationship at the base was even weaker. Figure 2 shows the fracture toughness results of the tested rails. The fracture toughness was conducted at the head and base of the rails; three compact test samples were extracted from the base and one from the head of the rails. Also, high strength rail was tested for fracture toughness for comparison purposes. Fracture toughness results can be summarized as follows:

- The current test rails average 2.3 ksi√in lower (-0.6 to -4.8) K<sub>IC</sub> at the railhead and 4.1 ksi√in lower (+0.4 to -9.4) K<sub>IC</sub> at the base of the rail compared to the average from the 2005 test.<sup>1</sup>
- Three of the base values from the current test are lower than the lowest value measured in the 2005 test.<sup>1</sup>
- Despite the lower fracture toughness, there have been no base breaks in the current test (there was one base break

after 43 MGT in a non-test rail of the same type as a test rail, installed in the same curve at the same time as the test rail), while the first base break in the previous test occurred after 88 MGT. Additionally, in the 2005 test<sup>1</sup> there were no base breaks in the rail with the lowest fracture toughness, but there was a break in a rail with 7 ksi√in (~20 %) higher K<sub>IC</sub>. Clearly, the effect(s) of fracture toughness on rail performance needs more study.

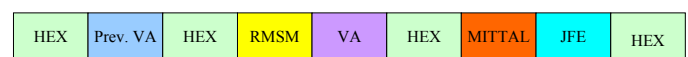
- There have been three breaks in electric flash butt welds in the current test, two of them in the high rail and the third one in the low rail. Microscopic examination of the current welds revealed no significant differences in metallurgy compared to welds from the 2005 test.<sup>1</sup>
- In the rail test concluded in 2001, there were no rail breaks reported. In the test concluded in 2005, six rail breaks were identified. In the current rail performance test, the first rail break occurred after 200 MGT of accumulated traffic at FAST.
- Similar rail steels are being tested in revenue service under 280,000-pound cars. Future reports will include a comparison of field performance of rail steels at FAST and in revenue service.



**Figure 2. Average Fracture Toughness Results of Three Base and One Head Samples Tested**

**Rail Wear**

Figure 3 shows a portion of the layout of the current rail steel evaluation test at FAST. The rail designated HEX is manufactured by NSC and is used as the control rail for the test. Every third (40 foot) rail through the 1,000-foot test curve is a control rail. Each of the other rails abuts a control rail three times in the curve.



**Figure 3. Illustration of the Current Layout of the Rail Steel Evaluation**

Profile measurements are taken 4 and 8 feet from the weld between control and test rails, and each rail is compared to its adjacent control rail.

Figure 4 shows the results of the rail steel evaluation after 252 MGT of accumulated heavy haul traffic at FAST. At the beginning of the test, the control rail (HEX) showed better wear performance than the other test rails, but the difference has been decreasing as tonnage increases.

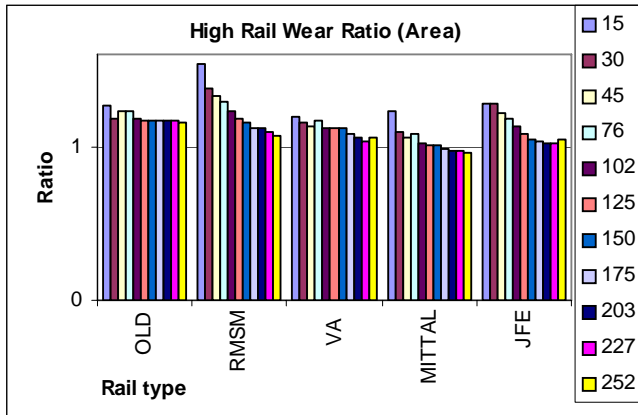


Figure 4. Rail Steel Evaluation after 252 MGT of Accumulated FAST Heavy Haul Traffic

### Rail Surface Appearance

Rail performance is a combination of parameters including mechanical properties, wear performance, rolling contact fatigue, and welding performance. Therefore, rail evaluation should consider the above-mentioned aspects. For instance, wear performance, as Figure 4 shows, indicates that Mittal is wearing less than the other rails with a wear performance comparable to the control rail. On the other hand, wear performance of JFE is 9 percent higher than MITTAL and 4 percent higher than the control rail. However, by comparing the surface characteristics of both rails (Figure 5), the Mittal rail is showing more rolling contact fatigue than the JFE rail. It is important to note that this condition is not uniform along the curve. Therefore, further analysis will be done on wear and rolling contact fatigue and the results will be reported in a later TD.

### CONCLUSION

The rails are performing well to date, with no rail fractures, and less wear than the rail from the 2005 test.<sup>1</sup> But it is too early to draw final conclusions about performance in track. The failure of some rails to meet AREMA mechanical test requirements may indicate the need to re-evaluate those requirements or predict future performance issues. The mechanical properties evaluation, including tensile and toughness tests, warrants further study. Rail performance is a combination of parameters and cannot be solely concluded based on one characteristic; e.g., wear.

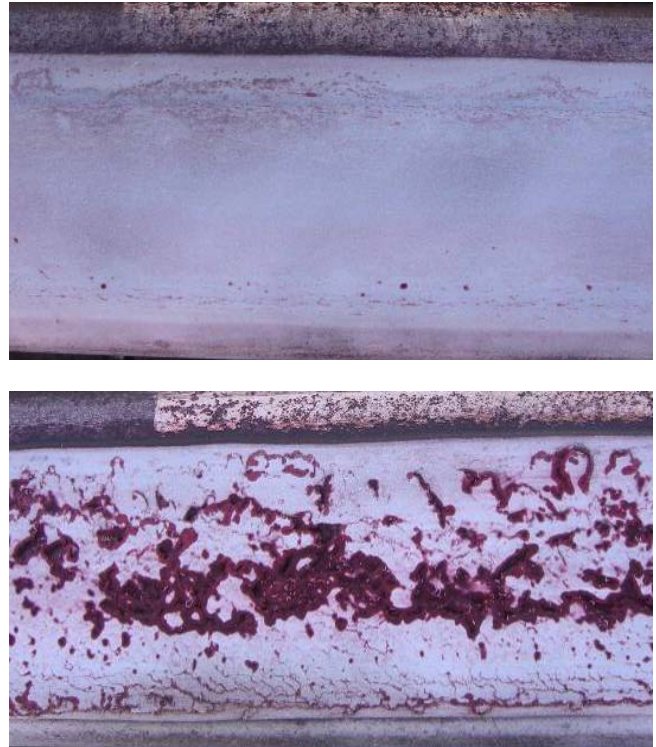


Figure 5. Surface Appearance of Two Premium Rails from Current Rail Performance Test

### REFERENCES

1. Kristan, Joseph. May 2005. "R&T Results of AAR Developed J6 Bainitic Type Rail Steel." *Technology Digest*, TD-05-014. Association of American Railroads, Transportation Technology Center, Inc., Pueblo, Colorado.
2. Kristan, Joseph. July 2004. "Preliminary Results: Rail Performance at FAST." *Technology Digest*, TD-04-010. Association of American Railroads, Transportation Technology Center, Inc., Pueblo, Colorado.
3. The American Railway Engineering and Maintenance of Way Association. 2006. *Manual for Railway Engineering*, Vol. 1 Chapter 4, Rail Specifications 4-2-1.