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# Intermediate Strength Rail Test: Wear and Defect Analysis

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## Summary

In 2012, Transportation Technology Center, Inc. (TTCI) initiated a performance test of intermediate strength (IS) rails at the Facility for Accelerated Service Testing (FAST). In 2016, this test was concluded after 598 MGT due to multiple shell formations on the high rail. There were five different IS rail types donated by five suppliers. One standard strength (SS) rail was included for baseline comparison. This article summarizes the performance and shell formations of the different rails, and also compares the results with the previous IS rail test.

Findings from the 2012-2016 IS rail test include:

- Wear performance of all IS rails were similar to one another and all had less wear compared to the SS rail.
- Seventeen shells and four transverse defects were identified in four rails including the SS rail. Two out of the four transverse defects formed under shells. Two of the IS rails did not develop any shells or transverse defects during the test.
- Rolling contact fatigue (RCF) was moderate and similar among all rails due to gage face lubrication of the rail and preventive grinding.
- The previous IS rail test lasted 390 MGT, and the second IS rail test lasted 598 MGT; the difference was due to preventive grinding cycles employed in second test to remove surface cracks and inhibit shell initiation.
- Though the second IS rail test had preventive grinding, shell formation was reduced but not eliminated.
- The number of shells formed in different IS rail types were compared to the surface and cross-sectional hardness, but no strong correlation was observed.
- A high-strength type (premium) rail located in the same curve as the IS rail has accumulated 674 MGT with no defects and less wear than all IS rails.

This was the second test of IS type rails; the first test was conducted from 2010-2012.<sup>1</sup> Preliminary results for the second test were published in 2015.<sup>2</sup>



**INTRODUCTION**

The second intermediate strength (IS) rail test at FAST started in September 2012 and concluded in May 2016. The test was conducted in a 5-degree lubricated curve with 4 inches of superelevation. The FAST train, with its 39-ton axle loads, runs approximately the same number of laps in both clockwise and counterclockwise directions at an average speed of 40 mph, compared to a balance speed of 34 mph. The test consisted of 40-foot lengths of 136RE rails, and all were flash butt welded to form an 800-foot string of high rail. The number of rail types tested was determined by the rail availability and the length of the test curve. The number of rail pieces of each type is mentioned in a previous *Technology Digest*.<sup>2</sup> The test participants are listed in Table 1. The standard strength (SS) rail type had lower hardness of 320 Brinell hardness number (BHN) compared to the IS rail types, which ranged from 330 to 360 BHN.

**Table 1. 2012-2016 IS Rail Test Participants**

Test Participant (Country of Manufacture)
ERMS-IH (U.S.)
Lucchini (Italy)
Arcelor Mittal (U.S.)
Steel Dynamics Inc. (U.S.)
Třinecké železárny (Czech Republic)
Standard Strength (U.S.)

As per AREMA Chapter 4 recommended guidelines, the minimum surface hardness values for three different rail types made from low alloy steels are:

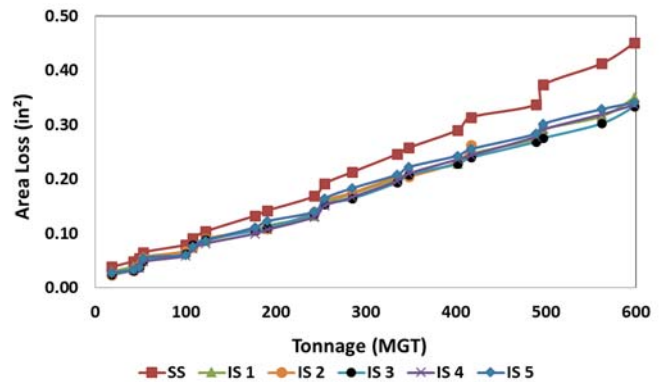
- Standard Strength (SS) Rail – 310 BHN
- Intermediate Strength (IS) Rail – 325 BHN
- High Strength (Premium) Rail – 370 BHN

The current AREMA recommended minimum for carbon steel IS rail is 350 BHN.

**Wear Performance Analysis**

Rail profiles were measured at approximately every 60 MGT and before and after every preventive grinding cycle. Figure 1 shows the average area wear of all the six rail types during the entire test. The SS rails had the highest wear rate, while the five IS types had similar wear rates. One of the IS rail types developed multiple shells before 417 MGT and had to be eliminated from the test. All other IS rail types that performed until 598 MGT had lost approximately 6.9 percent of the total area of the

railhead, and the SS type had lost approximately 9.2 percent. The small vertical steps noticed in the plot in Figure 1 are due to the metal loss caused by preventive grinding for removing surface rolling contact fatigue (RCF) and delaying shell formations by reducing the sub-surface exposure to fatigue related stress cycles.



**Figure 1. Average area loss of IS rail test types**

The 2010-2012 IS rail test lasted for 390 MGT and was concluded due to excessive shelling of the rails. No preventive maintenance grinding was done in this test and it ended with eighteen shells formed between 340 MGT and 380 MGT. One of the goals of the second IS rail test was to monitor defect formation and longevity of the rail performance by doing preventive maintenance grinding at regular intervals.<sup>1</sup> Although preventive grinding was not done at equally spaced time and traffic intervals, eight grinding cycles at an average interval of 60 MGT were completed. These grinding cycles as well as gage face lubrication led to longer life of the rails and delayed initiation of shells. Figure 2 shows the comparative performance and difference in MGT between the previous and recently concluded IS rail tests. It should be noted that Figure 2 shows a comparison of metal loss of IS rails from both tests and not a comparison of wear. The metal loss of the recently concluded IS rail test is due to a cumulative loss of metal due to wear and grinding cycles, whereas the metal loss of the previous IS rail test was due to wear only.

The head wear performance of a high-strength (premium) rail is also shown in Figure 2. The premium rail has lasted for 674 MGT with an average head loss of 0.06 inch, which is about 34 percent of the average head loss of the SS rail type and about 48 percent of the average head loss of the IS rail types at 598 MGT.

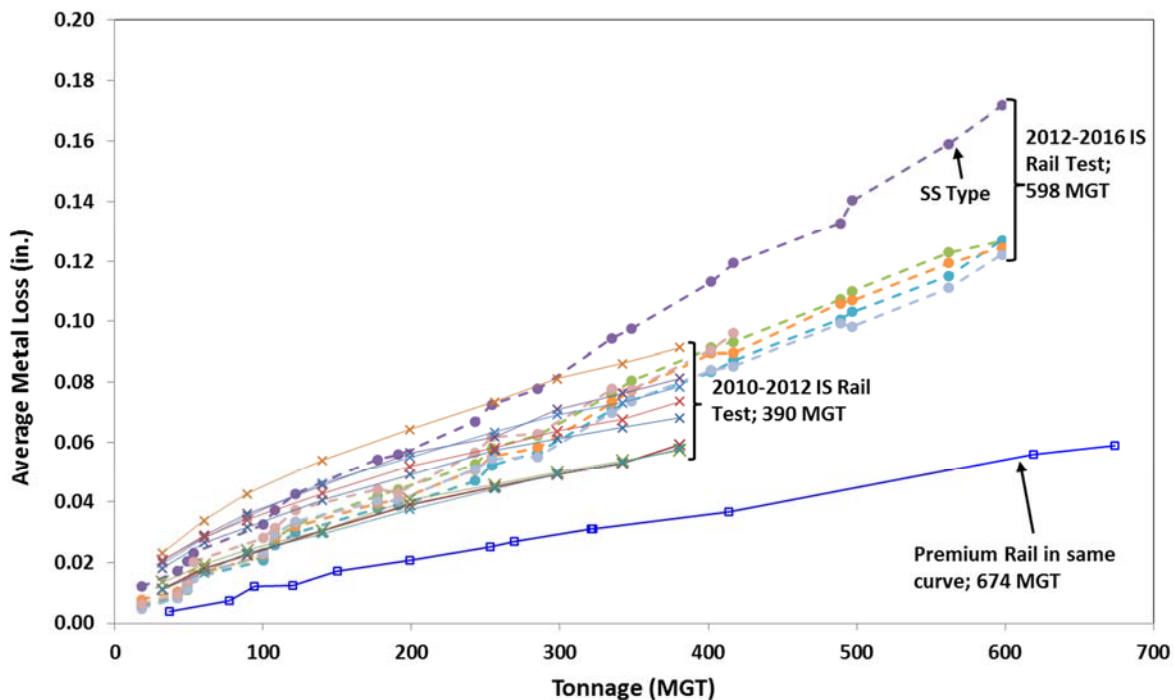


Figure 2. Comparison of average metal loss of railhead between premium rail, 2010-2012, and 2012-2016 IS rail tests

**Rolling Contact Fatigue (RCF)**

RCF occurred similarly on all IS rail types. RCF was not severe and was not a major concern for this test due to the presence of gage face lubrication and preventive grinding cycles. Gage face lubrication provided reduced friction between the wheels and the gage face of the rails, whereas preventive grinding cycles removed the shallow cracks formed on the top of the rails. Figure 3 shows two images of RCF along with shells at nascent stages in two IS rail types. The RCF was concentrated mainly on top of the rails as bands of small cracks, but none of these cracks caused any failures.

**Shell Formation**

Table 2 summarizes the total number of observed shells and transverse defects. The SS rail type is shown in blue to differentiate from the IS rail types. The IS 1 and IS 3 rails did not develop any shells or transverse defects during the entire test. There were two IS 2 rail test pieces, and both pieces developed multiple shells and had to be removed from the test. The first IS 2 rail piece developed three shells and the rail was removed at 280 MGT. One out of these three shells transformed into a transverse fissure. One shell was observed in the second piece along with shells located on welds and this IS 2 rail piece was removed at 417 MGT.

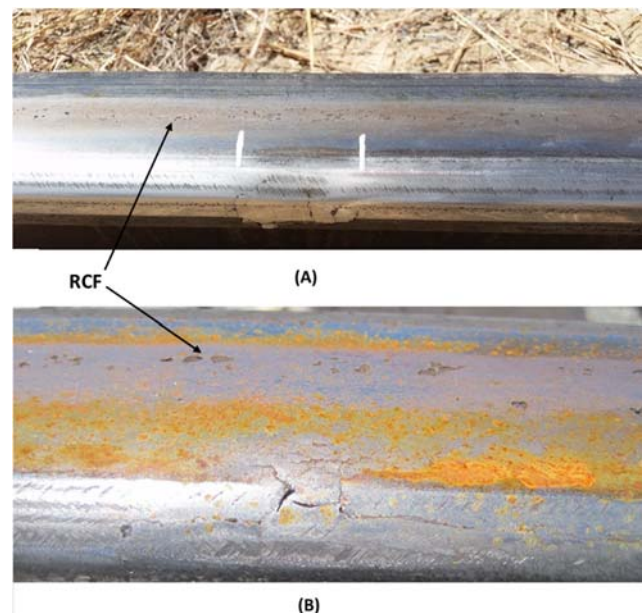


Figure 3. RCF and shell initiation in (A) IS 5 rail; (B) IS 2 rail

One of the IS 5 rails developed a shell that grew to form a transverse defect and had to be removed at 310 MGT. Two other shells on IS 5 rail were removed at 548 MGT, and one remaining shell and one remaining transverse defect were removed at the end of the test.

The IS 4 rails developed shells at a later stage of the test. Two shells opening to the surface and two sub-surface shells were removed between 548 MGT and 560 MGT. These were the only sub-surface shells observed in this test while the remaining 15 shells opened to the surface. Two remaining shells of the IS 4 rails were removed at the end of the test. Two of the SS rails that developed shells had to be removed at 320 MGT and 474 MGT. A third piece of SS type rail was removed at 550 MGT due to a transverse defect and the fourth piece having a shell was removed at the end of the test. All 17 shells formed at the gage corners of the rails.

Table 2. Summary of shells and TDs among rail types

Rail Type (Number of Rails)	Shells	Transverse Defects (TD)
IS 1 (3)	0	0
IS 2 (2)	4	1 (TD under shell)
IS 3 (3)	0	0
IS 4 (4)	6	0
IS 5 (4)	4	2 (1 TD under shell)
SS (4)	3	1
<b>Total</b>	<b>17</b>	<b>4</b>

Images showing growth patterns of transverse defects in the IS 1 and IS 5 rails were shown in a previous *Technology Digest*.<sup>2</sup> These growth patterns appeared to be in periodic step formations, and the periodic reversal of growth direction might be linked to the bidirectional movement of the FAST train.

Figure 4 shows two shells observed in the SS and IS 2 rails and one sub-surface shell observed in an IS 4 rail.

The number of shell formations was compared to the top of rail hardness and cross-sectional hardness of railheads of these six rail types. No strong correlation was found between hardness and the number of shells. Wear and cross-sectional hardness of railheads have shown good correlation in other FAST rail wear tests. The causes of shell initiation and formation of transverse defects cannot be directly correlated with hardness because of various factors. Future tests of IS rails will be tested for fatigue and impact toughness properties for better understanding of the possible correlation between mechanical properties and the number of shells.

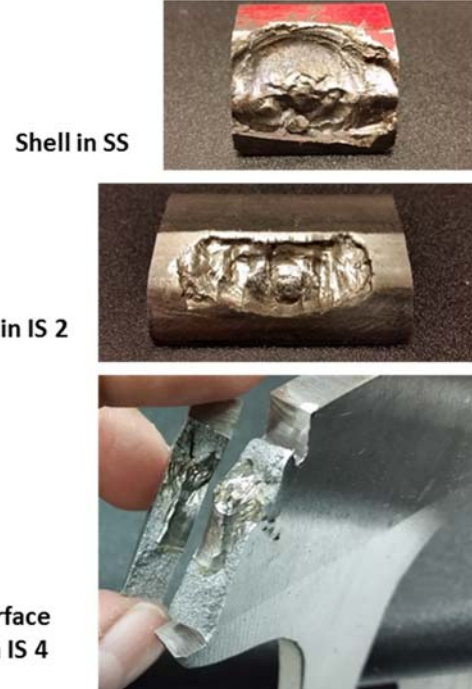


Figure 4. Shells in SS, IS 2, and IS 4 rails

CONCLUSIONS

A test on rail wear performance and defect formations of IS rails was conducted at FAST from 2012 to 2016. The test concluded at 598 MGT due to excessive shelling of the high rail. Four out of six rail types developed shells and transverse defects, which included a SS rail type used as the baseline comparison.

The 2012-2016 test was longer than the previous 2010-2012 IS rail test by 208 MGT due to regular preventive maintenance grinding cycles that helped to delay shell formations. But preventive grinding at an average interval of 60 MGT could not eliminate shell formation, and the test concluded with seventeen shells and four transverse defects. Wear rates of the IS rail types were similar and the SS rail type wore at a rate of about 33 percent higher than the IS rails by the end of the test.

REFERENCES

1. Szablewski, Daniel and Joseph LoPresti. "Intermediate Strength Rail Testing at FAST: Wear, RCF, and Deep-Seated Shelling Analysis." *Technology Digest* TD-14-010. AAR/TTCI, Pueblo, Colorado, May 2014.
2. Szablewski, Daniel, Joseph LoPresti, and Miles Lucero. "FAST Intermediate Strength Rail Test Results: 2012-2014." *Technology Digest* TD-15-001. AAR/TTCI, Pueblo, Colorado. February 2015.

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