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Intermediate Strength Rail Testing at FAST: Wear, RCF, and Deep-Seated Shelling Analysis

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Summary

Transportation Technology Center, Inc. has been involved in rail wear testing at the Facility for Accelerated Service Testing (FAST), Pueblo, Colorado, for over 20 years. The test reported here began in January 2010 with eight intermediate strength (IS) rail types under heavy axle loads (HAL) in a lubricated 5-degree curve. The normal unbalanced operating condition for the curve is 1.7 inches of unbalance. Testing personnel exercised normal maintenance practices while providing standard biodegradable rail lubrication. The test concluded at 390 MGT of accumulated tonnage in August 2012 because of excessive shelling on the high rail. Test results addressed in this *Technology Digest* compare wear and rolling contact fatigue (RCF) performance of different rail types in a HAL environment. In addition, root causes of shell initiation are presented and discussed.

Based on findings from this test, the following conclusions are made:

- There was relatively minor metal loss on the high rail in the 0-340 MGT test period, ranging from about 3 percent to 5 percent of the railhead area. This was attributed to the use of gage face (GF) lubrication and the lack of grinding.
- A two-sample t-test of rail wear data shows that at 340 MGT, ERMS-1, ERMS-2, Lucchini, PG4, and TATA Steel rails have less wear statistically than the control rail, whereas Mittal Spain rail has more wear statistically than the control ERMS-SS rail. Wear in the TZ rail is no different statistically from the control rail.
- RCF in both high and low rails initiated after more than 100 MGT of accumulated tonnage and progressed very slowly over time. It was uniform in nature and in the high rail RCF was presented primarily on the GF corner; whereas, in low rail, it was confined to a narrow band on the center of the rail running surface. None of the RCF cracks led to rail failures.
- Eighteen rail shells were detected on the 800-foot-long high rail section between 340 and 380 MGT of accumulated tonnage. Due to this finding, the IS rail test was terminated at 390 MGT because of the number and depth of shell defects.
- Analysis of 11 shell origins indicated that their distribution lies at a vertical depth of 0.29±0.05 inch from the top running surface and at a horizontal distance of 0.43±0.06 inch from the high rail gage running surface.
- Microstructural analysis of shell initiation cross-sections and subsequent hardness testing did not reveal any material inhomogeneities in the railhead that could have contributed to shell initiation.

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Introduction

The first IS rail test began in January 2010 at FAST. The test, comprised of eight industry-leading IS rail types, concentrated on analyzing wear and RCF performance. The rail type designations, mechanical properties, microcleanliness results, initial test setup, and preliminary test results have been addressed in other publications.[1,2,3] By the middle of 2012, the test had accumulated approximately 380 MGT. However, the test was terminated in August 2012 at 390 MGT because of excessive shelling on the high rail. Test results presented here address rail wear, RCF development, and shelling mechanism root cause.

Rail Wear

Wear in the high rail is controlled by wayside GF lubrication using biodegradable lubricant. Figure 1 indicates typical wear differences between 0 MGT new rail profile (blue line) and 340 MGT worn rail profile (red line). Relatively minor wear on the high rail in that time frame is attributed to use of GF lubrication.

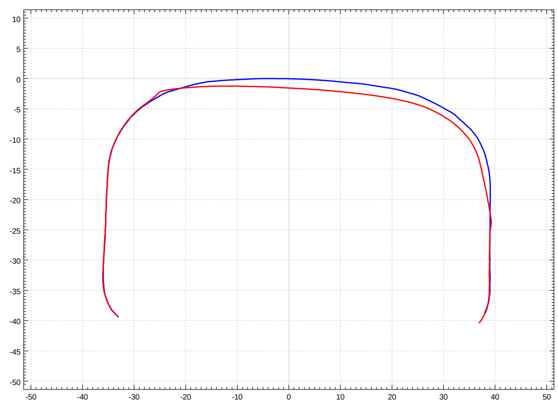


Figure 1. Typical IS Rail Wear Representing High Rail Profile at 0 MGT (blue) and Worn Rail Profile at 340 MGT (red)

A two-sample t-test comparing ERMS-SS (standard strength) control rail type to other rails in the test zone at 340 MGT indicated that one rail type (Mittal Spain) has statistically more wear than the control rail**,** five rail types (namely, ERMS-1, ERMS-2, Lucchini, PG4, and TATA Steel) have less wear statistically than the control rail**,** and the TZ rail type has wear that is statistically no different from the control rail (Figure 2).

Rail Rolling Contact Fatigue

RCF on the IS high rail was initiated after more than 100 MGT of accumulated tonnage and progressed very slowly over time. It occurred uniformly in all of the test rails. RCF began on the GF corner of the rail and was confined mostly to the high rail location (Figure 3). This limited RCF (as compared to the premium rail test[4]) is due primarily to the use of wayside GF lubrication in the test curve, but benefits may also be attributed to the rail metallurgy. Figure 3 shows a typical high and low rail RCF condition at 340 MGT.

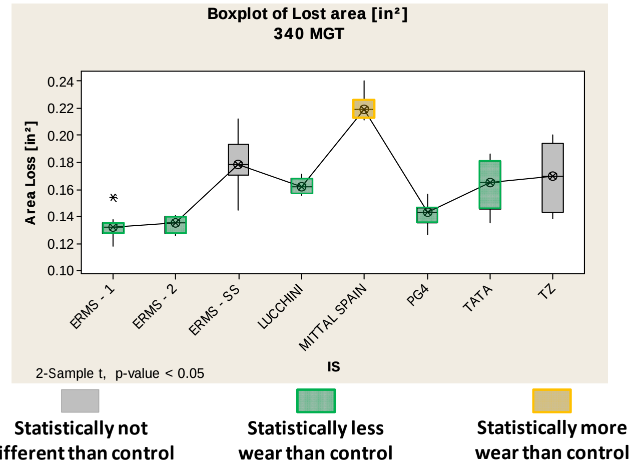


Figure 2. Statistical Analysis of IS Rail Wear at 340 MGT of Accumulated Tonnage

The low rail had RCF on the top surface of the rail. It initiated at approximately the same time as in the high rail and was also uniformly distributed through all the rail types tested. As Figure 3 shows, the RCF was present as a narrow band of longitudinal cracks. None of the cracks (in either high or low rail), however, led to rail critical failures.

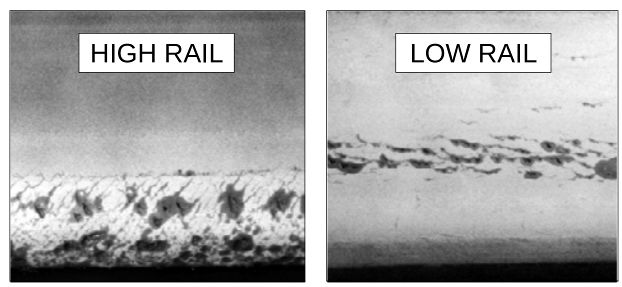


Figure 3. Typical RCF Condition in the High Rail and Low Rail at 340 MGT of Accumulated Tonnage in IS Rail Test Curve; Rail GF is on the Bottom of Each Image (Note that visibility of RCF was enhanced with dye penetrant.)

Rail Shelling

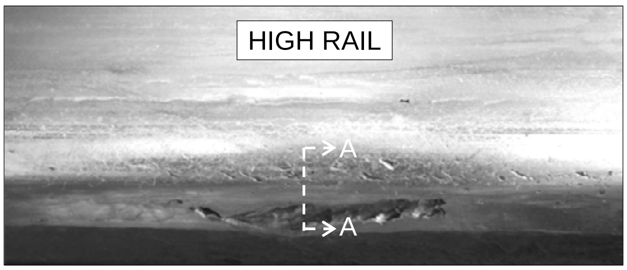
Rail shelling mechanism in the high rail has been described previously.[5,6] The IS rail initially developed seven shells in a 80-foot section of one manufacturer's rail. These defects occurred at approximately 340 MGT of traffic. The affected section was removed from test. However, within a short amount of time, shell defects appeared throughout the high rail of the test curve (Table 1). These shells (totaling 18 in an 800-foot section of the high rail) caused an early termination of the IS rail test in Section 3 at 390 MGT of accumulated tonnage.

Closer inspection of shell defect surfaces revealed that all shell origins laid in very close proximity to the rail GF corner. An analysis of 11 shell origins indicated that their distribution lies at a vertical depth of 0.29±0.05 inch from the top running surface and at a horizontal distance of 0.43±0.06 inch from the high rail gage running surface.

Table 1. Shelling Defects in IS Rail Test at FAST

RAIL TYPE	MGT	No. of DEFECTS
Manufacturer 1	340 - 380	10
Manufacturer 2		1
Manufacturer 3		1
Manufacturer 4		2
Manufacturer 5		2
Manufacturer 6		2

Figure 4 indicates a typical GF shell defect, as seen from the outside (prior to exposing the defect fracture surface) and at the fracture surface (following exposing defect fracture surface), where shell origin is clearly identifiable.



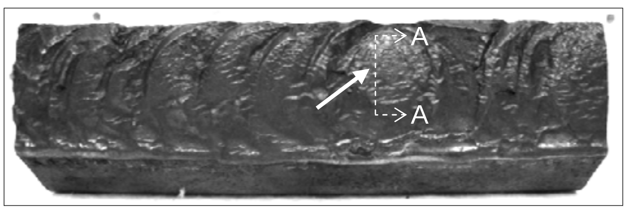


Figure 4. Typical High Rail Gage Corner Shell Defect Indicating the Condition of the Running Surface (top image), and Opened-up Shell Fracture Surface Showing Defect Origin (arrow in bottom image)

Microstructural analysis of the shell origin cross-sections revealed that microstructures surrounding the shell initiation points were no different from the bulk rail microstructure and lacked any discontinuities (e.g., inclusions, porosity, cracks) that might have contributed to shell initiation. In some instances, these microstructures were locally deformed (Figure 5). However, these localized deformations are believed to have been caused in the post-fracture rubbing of the two cracked rail surfaces during train operation, which resulted in microstructural deformities. These microstructural artifacts are not believed to be related to shell initiations.

Traverse hardness profiles were taken through some shell origin locations (both above and below the shell origins). This analysis indicated smooth hardness transitions through the shell origins supporting the observation of visible lack of microstructural inhomogeneities surrounding the shell origins. In addition, microsegregation at the shell origin location was not found in any of the shell defect cross-sections.

Referencing back to rail test results on the premium test curve, it is evident that shelling defect did not take place in the premium high rail.[1,3,4] Also, wear in the premium high rail was substantially greater than in the IS rail test curve (due mainly to lack of a GF lubrication on the premium rail test curve). Considering that fact and in light of the information presented above, namely, presence of localized shell origins, lack of any microstructural inhomogeneities in the vicinity of shell origins, and a lack of hardness increase surrounding shell origins suggest that shell defects are most likely not due to the rail microstructure but rather are related to the load environment in the railhead through the life cycle of the rail. Rail mechanical properties may have contributed to shell initiation as well.

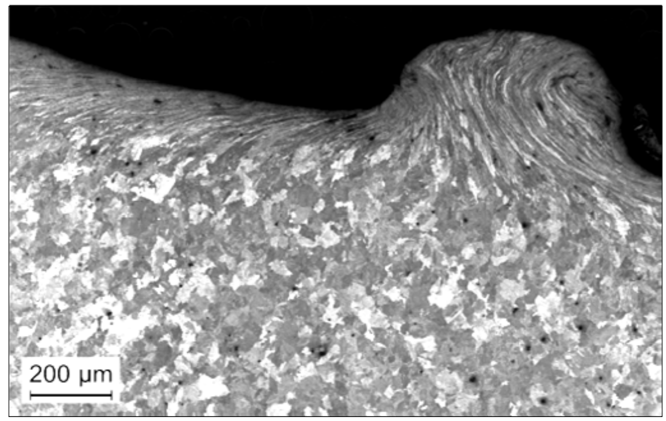


Figure 5. Light Optical Microscopy Image of Cross-Sectional Microstructure at the Shell Origin (see A-A in Figure 4) Indicating Localized Microstructural Deformation

Discussion

IS rail profile differences between 0 MGT and 340 MGT of accumulated tonnage (Figure 1) show that high-rail metal loss remained minimal. This is primarily due from the use of GF lubrication and lack of grinding on the high rail through the life of the test.

Because the test train at FAST operates consistently at 40 mph through the curve, the load environment that the rail is subjected to over time is relatively consistent. This, combined with a relatively unchanged profile of the high rail, is believed to have subjected the railhead to a consistent stress environment over time, which led to the development of shelling defects.

Similar deep seated shell (DSS) defects on the high rail were observed on Canadian Pacific (CP) lines in "100% effective gauge face lubricated" territories.[6] The CP-led investigation revealed that DSS defects are attributed to a lack of wear on the gage corner leading to the development of a shiny wear band in the 30-60 degree high rail GF corner band, along with plastic flow to the gage corner. The proposed solution was to remove 0.016 inch of metal from the GF corner at the 45-degree location through preventive grinding. Proposed grinding interval was "when the last grinding scratch marks at upper gauge corner are almost gone."[6] To that end, a new grinding template was developed at CP to prevent DSS defect occurrence in gage face lubricated territories.

Grinding allows overall stress reduction in the railhead, and it offers an effective way to reduce the fatigue damage at the shell initiation site by moving the stress field downward into the railhead and preventing a 2-point contact on the rail running surface. This would most likely prevent shell initiation.

In a supporting 2010 study, a researcher at the Texas A&M Center for Railway Research demonstrated that continuous preventive grinding cycles move the highly concentrated stress field downward into the railhead.[7] The internal fatigue defect life of the rail can be optimized by removing metal at a rate that the fatigue life is reached when that portion of the rail is removed through wear and grinding.

Conclusions

Results presented in this TD address the IS rail performance of eight industry leading rail types. Analysis was concentrated on wear and RCF performance as well as rail defects.

Statistical wear analysis indicates that at 340 MGT, the Mittal Spain rail type has statistically more wear than the control ERMS-SS rail; whereas, ERMS-1, ERMS-2, Lucchini, PG4, and TATA Steel rail types have statistically less wear than the control rail. The wear of the TZ rail is no different statistically from the control rail.

RCF initiated after 100 MGT of traffic and progressed very slowly over time. It was uniform in nature and present only on the GF corner; whereas, in low rail, RCF was confined to the rail running surface and was present as a narrow band of longitudinal cracks.

Eighteen rail shells were detected on the 800-foot-long high rail section between 340 and 380 MGT of accumulated tonnage. The IS test was terminated at 390 MGT because of the large number of shells. Shell analysis revealed similar defect location initiation points. Microstructural analysis of shell initiation cross-sections and subsequent hardness testing did not reveal any material inhomogeneities.

CP research[6] into deep-seated shelling confirms defect mechanism observed at FAST, which points to preventive grinding as a means of DSS prevention. A supporting Texas A&M study[7] points to regular optimized grinding as a solution to control the stress state in the railhead, thereby preventing defects initiation while optimizing the life cycle of rail.

The current IS rail test implements preventive grinding to displace the stressed zone downward into the railhead to prevent shell initiation.

Future Work

Since the removal of the IS rail test from FAST in mid-2012 because of shelling, a new IS rail test was initiated in the same location. The new test is comprised of IS rails of similar hardness range. Testing is being conducted in a similar fashion (i.e., same load conditions and GF lubrication). However, in the new test, preventive grinding is implemented every 50 MGT of traffic. Current tonnage accumulation is 200 MGT. No shelling has been observed to date. Rail condition will be closely monitored during the life of the test. Future publications will address new rail test results.

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