TECHNOLOGY DIGEST

TD-05-034
©DEC. 2005

TIMELY TECHNOLOGY TRANSFER

The work described in this document was performed by Transportation Technology Center, Inc.,
a wholly owned subsidiary of the Association of American Railroads.

Rail Performance Evaluation at FAST

October 2001 to May 2005

by Joseph Kristan and John Wedeking, Consultants,
Joseph LoPresti, TTCI

Summary

The completion of the rail performance evaluation test, performed by Transportation Technology Center, Inc. at the Federal Railroad Administration's (FRA) Facility for Accelerated Service Testing (FAST), from October 2001 through May 2005, showed a statistical difference in wear rate (cross-sectional area loss per million gross ton) between the rail types after accumulating 478 million gross tons (MGT) of traffic. Overall, state-of-the-art rails installed at FAST in October 2001 have shown an average 8.7 percent decrease in wear (area loss) in comparison to the previous generation rails tested under similar operating conditions (*Technology Digest* 01-012, June 2001). The pearlitic test rails have an average hardness of 395 Brinell (HB) while that of the previous test was 365 HB.

Significant test results include:

- 8.7 percent increase in rail life (average 395 HB) compared to previous generation rail (average 365 HB)
- Estimated average rail life is 11.2 years (141 RE rail) at 150 MGT per year (in the absence of grinding) with that of the previous being 10.3 years.
- Surface performance was acceptable throughout, with localized rolling contact fatigue (RCF) present on each of the various rail types with the exception of one rail type which sustained RCF over nearly the entire length of the rail.
- Seven rail fractures occurred in the pearlitic test rail during the course of the test (one was in a lower carbon, lower hardness repair rail) with zero failures having occurred in 517 MGT with the previous rail evaluation – additional information is provided in TD-05-024, October 2005.
- Statistically significant difference in high rail wear rate (cross sectional area loss per MGT) exists between the J6 bainitic and NSC rails in comparison to the mean of the six pearlitic rails in test. The J6 wore more than the group, and the NSC rail wore less.
- There is a strong correlation ($R^2 = 0.7$) between rail wear and initial hardness subsequent to 478 MGT that did not exist earlier in the testing. Rails with pearlitic microstructure showed a trend of improved wear with increased rail hardness.

BACKGROUND

As steel prices increase, the longevity of rail is of utmost importance to the continued economic viability of the railroads. In recent years, railroads have purchased over 500,000 tons of replacement rail per year (*Railroad Facts* 2004 Edition). With current prices, this results in expenditures of over 1.3 billion dollars per year (not including installation costs). Of superior importance and intertwined with economics are the safety ramifications of rail utilization. Thus, the Heavy Axle Load Research Committee (HALRC) initiated an evaluation of the newest premium rail steels available in October 2001, with the testing concluding in May 2005. The effort, funded by the Association of American Railroads (AAR) and the FRA was performed at FAST, Pueblo, Colorado.

The objective of the FAST rail performance evaluation was initially two-fold. The first objective was to quantify the wear performance of the state-of-the-art rails available at the outset of the test in 2001 under the heavy axle load conditions provided at FAST. Second was to quantify the surface or rolling contact fatigue (RCF) performance of the rail. RCF can significantly influence the usable life of the rail. A third evaluation was the fracture performance of the rail. Seven fatigue fractures occurred in the test rail, each initiating at the base of the rail.

The six state-of the-art premium rail steels available in 2001 are listed below. A seventh rail type was added to the test, J6 bainitic rail, as the control, but was removed prior to the end of the test due to numerous fractures and thus is not included in the final statistical performance analysis of the rail. Each of the rail types was tested in 141 RE section with the exception of J6 which was 136 RE.

The premium pearlitic rail types tested included:

- Corus America, Inc.: Low-alloy, head-hardened rail
- Nippon Steel Corporation (NSC): High carbon, hypereutectoid HE 400 rail
- JFE Steel America, Inc. (formerly NKK Corporation): Type SP rail
- International Steel Group, Inc. or ISG (formerly PST, Inc.): Low-alloy, high-carbon rail
- Rocky Mountain Steel Mills (RMSM): 1-percent carbon pearlitic (OCP) rail
- Voest-alpine
- Low-alloy, high-carbon rail type UHC-HSH

The test rails were installed in Section 7 at FAST — a 1,000-foot, 5-degree reverse curve with nominal 4-inch superelevation resulting in a cant deficiency of 1.7 inches. The FAST train is made up of 315,000-pound cars accumulating tonnage at a rate of roughly 1 million gross tons (MGT) per operating day for a total of approximately 125 MGT per year. There is no direct lubrication of the high rail gage face in this curve. The only lubrication is from top of (low) rail lubrication on adjacent curves and from the wheels when the train is turned. The absence of direct lubrication under these operating conditions does produce accelerated wear, as is evident by the orange peel appearance of the high rail gage face. Two rails from each of the six manufacturers were installed in each of the high and low rail positions, as Figure 1 shows. Experimental design was used in an attempt to optimize the robustness of this test to account for variables such as position in curve, variation in superelevation and curvature within the curve, and relative position between the different rail types. Experimental conditions that could be controlled, such as fastener type, were addressed, as all of the fasteners were changed to elastic type specifically for this test.

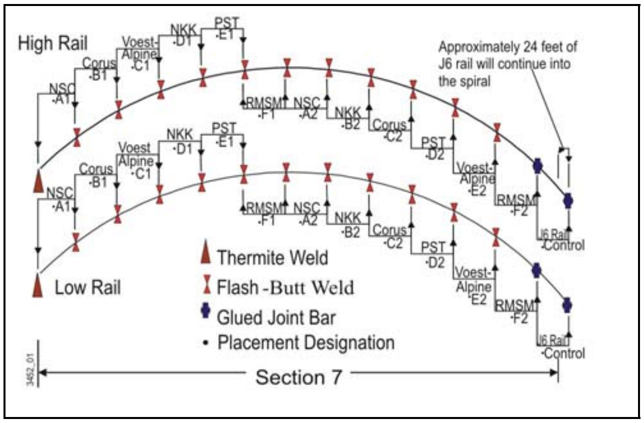

Figure 1. Rail Evaluation Test Layout, Section 7 at FAST

The final results follow 478 MGT which is an additional 207 MGT of HAL traffic since the preliminary performance update (TD 04-010, July 2004). The results presented are considered representative of performance that would be achieved through the life of the rail. Analysis of the wear rate of each of the rail types produced statistically significant variation for the J6 and NSC rail types when evaluated against the mean of the pearlitic rail group. The wear rate was used as the primary evaluation criterion as this information allows predictions in ultimate rail life and scheduled maintenance. The regression fit of each of the pearlitic rails was $R^2 > 0.98$; correlating well with the tonnage accumulation.

Test Rail Rolling Contact Fatigue and Fractures

The resistance of the rail steel to both RCF and fractures is of equal or greater importance than the wear properties of the steel. RCF fatigue damage (e.g., head checks) can propagate into the railhead and produce fractures as well as inhibit the detection of internal defects by a detector car. Preventative and remedial rail grinding removes RCF damage, but also removes rail that would otherwise be available for service. Fractures in the rail (detail or otherwise) can compromise safety and require remedial action. Thus, rail possessing superior RCF and fracture performance will provide both economic and safety advantages.

The rails throughout the test zone contained a small number of minor localized shells, except for one rail type. The RMSM rail contained RCF throughout the test rail lengths. However, RMSM reports changes have been made to the OCP rail since the prototype rail used in this testing at FAST was produced.

There were seven fractures of the pearlitic test rail during the course of testing. All were due to fatigue initiated at mechanical damage at the base of the rail. Additional information in regard to the rail base fractures is provided in TD-05-024, October 2005.

Rail Wear and Statistical Analysis

Rail wear was measured using a rail Miniprof™ profilometer at the 1/3 and 2/3 positions for each 80-foot high and low rail in test. The exception is the single, 80-foot 136 RE J6 control rail that was removed prior to the completion of the test. Initially, rail wear measurements were taken approximately every 15 MGT; however, at 175 MGT the interval was increased to every 25 MGT. Two independent measurements are taken at each rail location during each measurement cycle in order to increase the accuracy of the analysis. The wear measurements are plotted against tonnage to allow calculation of wear rates needed to estimate rail life. Under consistent operating conditions at FAST, the wear rate (linear regression of wear versus MGT) plot produces an excellent fit with correlation coefficients of between 0.98 and 0.99. The regression includes the 15 and 30 MGT wear measurements that were previously omitted in the analysis to ensure bias resulting from the possible transient break-in of the rail at the initiation of the test. It was found that these data points correlated well with the subsequent data, and thus were also included.

Figure 2 shows the high rail area loss wear data at test completion of 478 MGT. The wear rate data was then analyzed to establish statistical significance. The data from each rail type was first examined to ensure normality and equal variance. The test data was found to be normal, but the variance of the RMSM data differed from that of the group (see Figure 3). This can be attributed to the variation in the two measurement locations of the same 80-foot rail as well as between test rails. Thus, it is not statistically correct to include RMSM in the analysis due to the excessive variation. However, for the purposes of this evaluation, analysis including and excluding RMSM data will be performed. The observed trend of increased variation with tonnage is consistent among all rail types tested, but not to the same magnitude, as variation in wear at each relative measurement location has increased with increased tonnage. Figure 4 shows an example of the increasing variation with tonnage for one of the rail types, but is similar among the entire group with RMSM having the most variation and NSC the least. This variation is attributed to inhomogeneity in rail performance along the length of the rail and within rails as the repeated measurements have confirmed the accuracy of the measurement system. Utilizing the repeated measurements, the measurement system variation was determined to be consistent among all test locations with a 99-percent confidence of the value falling within ±6.6 mm^2.

Passing the normality and equal variance criteria, with the exception of RMSM, a One-Way Anova test was used to statistically determine if a difference between the test means existed with 95 percent confidence. This test was performed on the high rail wear rate data of each rail type and identified statistical difference in the group of means. To isolate the variation in wear rate between the various rail types, a one-sample "t" test was performed to compare the test mean of the pearlitic rail group to that of each individual rail type. The test showed that the J6 and NSC rail types deviated from the test mean, which is an indication that their respective wear rates differ statistically from those of the group with 95-percent confidence (see Figure 5). Again because of the variance differing between the RMSM rail type and the group, a statistical difference could not be established though the average total wear between NSC and RMSM is similar as shown previously in Figure 2.

A final important characteristic of the data is a sinusoidal type pattern in the wear over the course of the test as shown by the representative residuals versus best fit line (linear regression) plot in Figure 6. The residual is the difference between the linear regression and the actual wear data of which the same trend for each of the different rail types is represented in Figure 6. A pattern present in the residuals indicates a factor(s) influencing the data has not been accounted for in the experiment. A mitigating factor is that each of the rails in test shows the same response and has received the same input and thus comparison between the different types should not be significantly influenced.

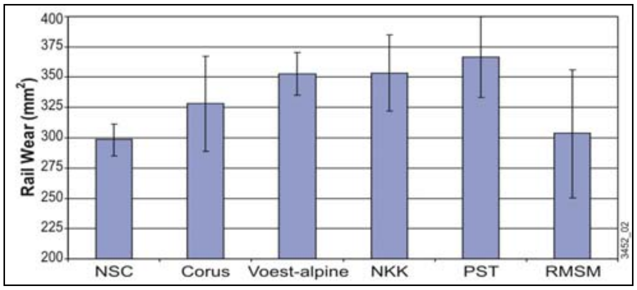

Figure 2. Total Averaged High Rail Wear at 478 MGT with the Standard Deviation Indicated

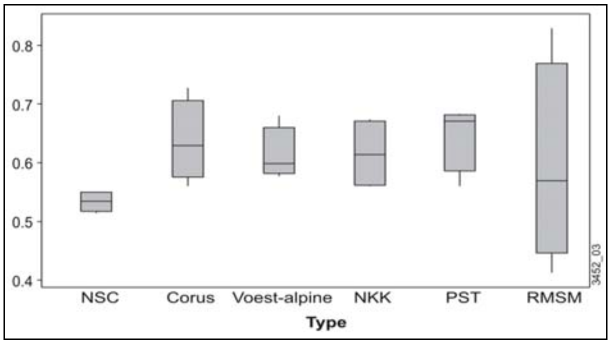

Figure 3. Test of Equal Variance among the Six Premium Pearlitic Rail Types in Test at FAST with RMSM showing Variance Beyond that of the Group

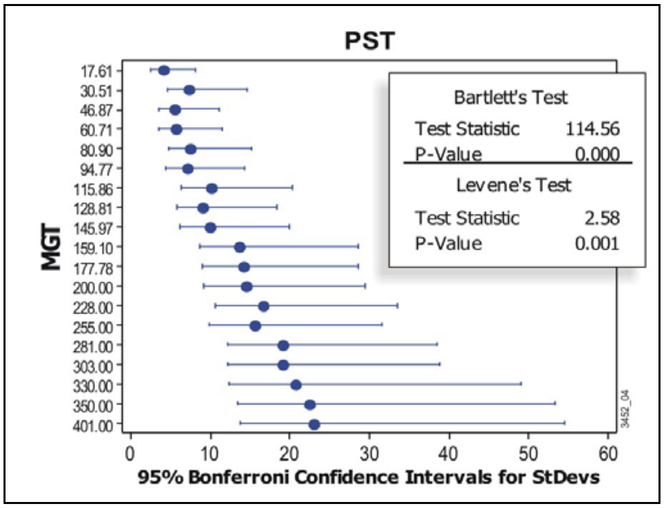

Figure 4. Example Variance that Increases with Increasing Tonnage

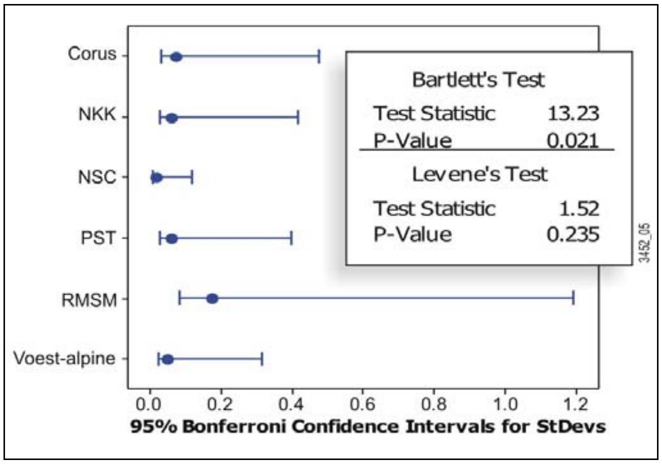

Figure 5. Boxplot of Wear Rate mm2/MGT for Each of the Rail Types in Test (J6 bainitic rail omitted from figure)

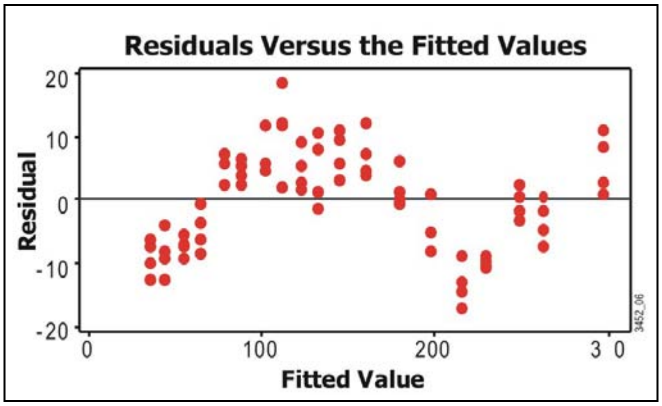

Figure 6. Example of Difference between Best Fit Line (linear regression) and Actual Data Value showing a Sinusoidal Pattern

WEAR RESULTS

It is valuable to compare these results to those for previous rails tested at FAST under similar conditions. However, to account for variations in operating conditions between the two tests, a control rail is required which was present and evaluated during each test. The control rail was 136 RE J6 bainitic rail. This rail was removed during the course of testing and thus was not available at the end of the test to allow direct correlation between this and the previous generation rail tested at FAST. Thus, the data presented does not account for any differences in operating conditions between this and the previous rail evaluation test.

There appears to be a statistical correlation between wear rate and rail hardness with a correlation coefficient of (R^2 =0.7) for this analysis after nearly 500 MGT. Thus, as expected, the general trend of improved wear with increased rail hardness appears to be verified (only applicable within the same microstructure as bainitic rail of higher hardness has sustained higher wear in comparison to pearlitic rail at FAST).

The desired result of the rail evaluation test at FAST is to establish the wear, surface RCF, and fracture performance of the state-of-the-art rails available in North America. Rail surface conditions of some rails at the end of test would require grinding to remove RCF damage. The necessity to grind the rail will also influence the life of the rail. However, assuming rail grinding was not necessary, the average rail life for the group in 141 RE was calculated. It must again be mentioned that the current wear data and that of the previously performed test are not normalized to account for differences in operating conditions. The estimate of average rail life for the current rail in test is 11.2 years at 150 MGT per year (assuming no grinding) for the 141 RE profile rail. The previous generation rail would have an approximate average service life of 10.3 years. Thus, without accounting for the differences in operating conditions at FAST, between the two rail evaluation tests, the current rail provides an estimated 8.7 percent increase in allowable tonnage when compared to the previous generation rail based on high rail wear.

FUTURE WORK

The next rail performance evaluation has begun with each of the previous rail manufacturers participating with submission of their most modern premium rail steel with the exception of Corus Rail. The next generation rail from Corus was not available at the time the new test rail was installed.

Acknowledgements

Union Pacific Railroad, Progress Rail, and the six named rail manufacturers donated rail for this research endeavor.