TECHNOLOGY DIGEST
TD-04-010
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## Preliminary Results:

# Rail Performance Evaluation at FAST

**by Joseph Kristan**

### Summary

Ongoing rail performance tests, performed by Transportation Technology Center, Inc. at the Federal Railroad Administration's Facility for Accelerated Service Testing (FAST), have begun to produce a statistical difference in wear rate (cross-sectional area loss per million gross ton) between the rail types after accumulating 281 million gross tons (MGT) of traffic. Overall, state-of-the-art rails installed at FAST in October 2001 have shown an average 12.5 percent decrease in wear (area loss) in comparison to the previous generation rails tested under similar operating conditions (normalizing the wear rates using the J6 bainitic control rail also used in the previous test). Two pearlitic rail types, as well as the J6 bainitic rail, each show a statistically significant difference in wear rate in comparison to the mean of the six pearlitic, head-hardened rail steels in test.

Rail wear rate has been used as the primary evaluation criterion as this information allows predictions in ultimate rail life and scheduled maintenance. The decreased wear noted in the 5-degree test curve translates to an approximate average rail life of 11.8 years for 141 RE rail without rail grinding assuming 150 MGT per year. The current test rails possess an average hardness of 395 Brinell (HB) while that of the previous test was 365 HB. The surface condition of each of the rails is acceptable. To date, there has been no need for remedial grinding. However, there have been five fractures in the pearlitic test rail during the accumulation of just over 300 MGT with no fractures occurring through 517 MGT of the previous rail evaluation at FAST.

The premium pearlitic rail types in test (all in 141RE section unless indicated) include:

- 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 Pennsylvania Steel Technologies, Inc.): Low-alloy, high-carbon rail
- Rocky Mountain Steel Mills: 1-percent carbon pearlitic (OCP) rail
- Voest-Alpine Schienen GmbH & Company KG: Low-alloy, high-carbon rail type UHC-HSH
- AAR-developed J6 bainitic used as the test control rail: 136 RE section

Summary of significant preliminary results include:

- A 12.5 percent reduction in average high rail wear compared to previous generation rail.
- Surface performance is good throughout (no rolling contact fatigue).
- Five rail fractures have occurred in the current test (303 MGT) with none having occurred during the entirety of the previous rail evaluation (517 MGT).

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## BACKGROUND

Rail is the single most valuable asset in the inventory of the railroads. In the past five years, railroads have purchased close to 500,000 tons of replacement rail per year at an approximate total cost of $1.25 billion. The importance of rail performance is obvious — with both safety and economic ramifications to operation. Thus, the Heavy Axle Load Research Committee (HALRC) initiated an evaluation of the newest rail steels available in October 2001. The effort, funded by the Association of American Railroads (AAR) and the Federal Railroad Administration (FRA), is being performed at Facility for Accelerated Service Testing (FAST), Pueblo, Colorado.

The objective of the FAST rail performance evaluation is two-fold. The obvious performance criterion is wear or metal loss incurred in the rail during operation. However, of equal or more importance is the surface or rolling contact fatigue performance of the rail. Additionally, fatigue performance (fractures) of rail steel holds ramifications in terms of safety and economics.

The test rails were selected based on rail type and availability in North America. Rail in curves requires frequent replacement due to wear and surface damage; thus, the typical practice is to use premium or head-hardened rail in these applications generally with curvature above 2 degrees. Premium rail is of particular interest. The state-of-the-art premium rail selected for installation in this test came from six manufacturers with AAR-developed J6 bainitic used as the control rail (all rail is 141 RE section with the exception of J6 which is 136 RE).

The premium pearlitic rail types in test include:

- 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 Pennsylvania Steel Technologies, Inc.): Low-alloy, high-carbon rail
- Rocky Mountain Steel Mills (RMSM): 1-percent carbon pearlitic (OCP) rail
- Voest-Alpine Schienen GmbH and Company KG: 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 ton (MGT) per operating day for a total of approximately 125 MGT per year. There is no lubrication of the high rail gage face in this curve and only carry-over for the top of rail locations from the adjacent curves. 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 shown in Figure 1. Experiment design was used 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.

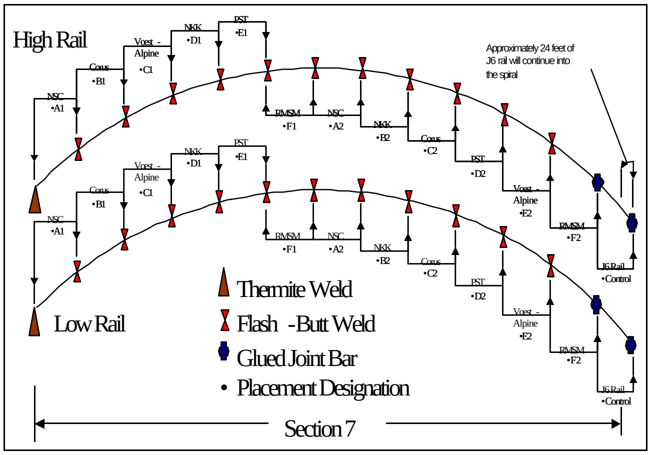

**Figure 1. Rail Evaluation Test Layout, FAST's Section 7**

The most recent results include 281 MGT of HAL traffic at FAST. Therefore, the results presented are preliminary and will not be finalized until approximately 500 MGT of traffic. Analysis of the wear rate of each of the rail types produced statistically significant variation for the J6, ISG, and NSC rail types when evaluated against the mean of the pearlitic rail group. The data was analyzed from 60 MGT onward to avoid the influence of the possibly transient rail break-in period. The wear rate was used as the primary evaluation criterion as this information allows predictions in ultimate rail life and scheduled maintenance. Also, the regression fit of each of the pearlitic rails was $R^2>0.98$; thus the wear of the rail correlates very precisely with the tonnage accumulation to date.

## TEST RAIL ROLLING CONTACT FATIGUE AND FRACTURES

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

The rails throughout the test zone are free of head checks, shelling, or other RCF damage with the exception of a small number of minor, localized shells covering a few inches in total length. The wear on the gage face of the high rail is the only surface feature of note. The high rail gage face has an orange peel appearance from the unlubricated gage face contact, which is consistent with previous tests. This appearance is due to plasticity exhaustion at the contact patch of the gage face. However, the fracture performance of the current rail is not consistent with that of previous rail performance evaluations at FAST.

There have been several fractures of the test rail. However, with the exception of the J6 bainitic rail, all of the test rail fractures have been due to fatigue initiated at mechanical damage at the base of the rail. The first fracture occurred in the Corus rail after 91 MGT. As shown in Figure 2, this fracture was due to small nicks at the edge of the base. The second and third fractures of the pearlitic rail occurred in the RMSM rail, which again each initiated at the edge of the base due to mechanical damage, at 138 MGT and 167 MGT, respectively. The fourth and fifth fractures occurred in the ISG rail at the center and edge of the base at 274 MGT, and 303 MGT, respectively. The single 80-foot, J6 bainitic control rail has sustained three fractures during the course of the test. Two detail fractures occurred in the head of the rail at 95 MGT and 214 MGT with a base fracture due to mechanical damage occurring at 108 MGT.

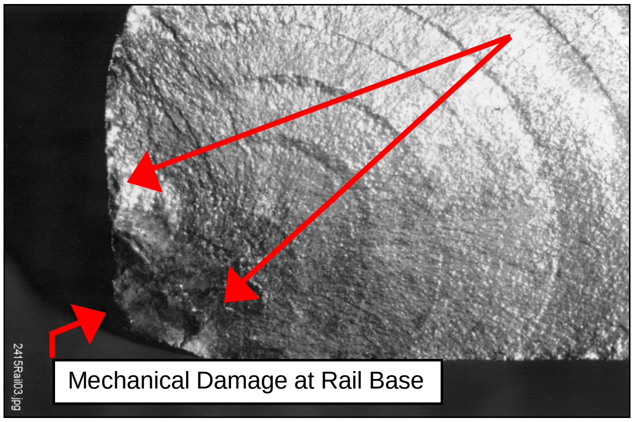

**Figure 2. Fatigue Fracture at Rail Base Corner, Corus Test Rail, 91 MGT**
The two long arrows indicate the approximate primary and secondary fatigue initiation sites that resulted.

In general, the fracture resistance of a steel decreases inversely to the strength and hardness of that material. The average hardness of the current pearlitic rail in test is 395 Brinell (HB) while that of the previous test was 365 HB. The installation practices employed for this test did not vary from those used previously. No fractures occurred in the previous rail wear evaluation with duration of 517 MGT. The mechanical properties of the high hardness rails will be evaluated to establish their performance in comparison to conventional (370 HB) rail. The fracture toughness of the steels — an indication of the propensity of a crack to propagate within the steel — will be quantified. This data may explain the fracture performance of the current test rail at FAST.

## RAIL WEAR AND STATISTICAL ANALYSIS

The rail wear is 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. 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. Another method employed to ensure accuracy is the use of Profile Master 2003™ software, developed by TTCI, which allows precise manipulation of the comparison profiles for optimum alignment. Precise alignment renders accurate wear measurements of $mm^2$ area lost as well as W1 (head height loss), W2 (gage face loss), and W3 (gage corner loss) parameters in the worn rail compared to the new or 0-MGT rail profile. The wear measurements are plotted against tonnage to allow calculation of wear rates needed to estimate rail life and allow scheduled maintenance. Under consistent FAST operating conditions, 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 excludes the 15 and 30 MGT wear measurements to ensure bias resulting from the possible transient break-in of the rail at the initiation of the test is not included. Transient performance could result from variations in oxide thickness and/or decarburization layer.

Figure 3 shows the high rail area loss wear data at 281 MGT. The high rail data was used for the preliminary analysis due to the low rail having sustained appreciably less wear. The high and low rail data will both be included in the final test analysis. The wear rate data was analyzed to establish statistical significance. The data from each rail type was first examined to ensure normality and equal variance. Passing these criteria, the One-Way Anova test was used to statistically determine if a difference between the test means existed with 95 percent certainty. 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, the 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, NSC, and ISG rails 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.

Test results thus far are preliminary and therefore emphasis should not be placed or inference drawn from the interim analysis. There may prove to be differences and/or transient variations in wear performance between the test rails that will not be concluded until test completion.

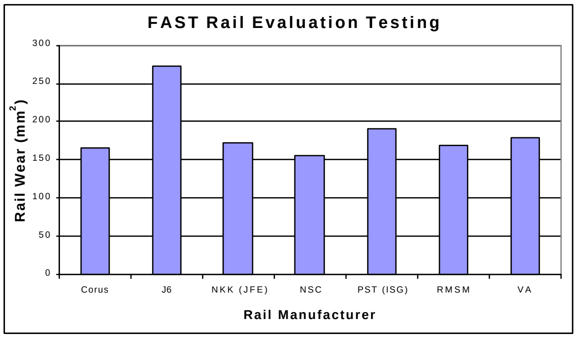

Figure 3. Total High Rail Wear in FAST Rail Evaluation Test in mm$^2$ at 281 MGT of Traffic Accumulation

## PRELIMINARY RESULTS

The results of this testing are most valuable when compared to previous rail tested at FAST under similar conditions. The data between this and the previous test were normalized using the control 136 RE J6 bainitic rail. These results show a 12.5 percent reduction in rail wear for the current test rail in comparison to the previous generation rail. This superior wear performance is likely due to the increased strength (hardness) of the current rail. The correlation coefficient for the current wear versus hardness data is still poor ($R^2 = 0.29$) for this analysis. However, the correlation has been improving during the course of the test and may prove to be appreciable by test completion. A better correlation between rail steel strength and wear will establish the previous assertion that rail wear decreases with increased rail hardness (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. As stated, the surface performance of the rails is acceptable with no need for remedial maintenance or grinding. Thus, assuming this trend continues along with the preliminary wear rates established at 281 MGT of FAST traffic, the number of years of rail life based on 30 percent head area loss for both 141 RE and 136 RE profile rail were calculated. The same calculation was performed on the previous generation FAST test rail. The preliminary estimate of rail lives for the current rail in test is shown in Figure 4 with an average 141 RE rail life of 11.8 years at 150 MGT per year (assuming no grinding). The previous generation rail would have an approximate average service life of 10.3 years. The average rail life of the current 136 RE rail in test will be 10.6 years while that of the previous generation is 9.2 years.

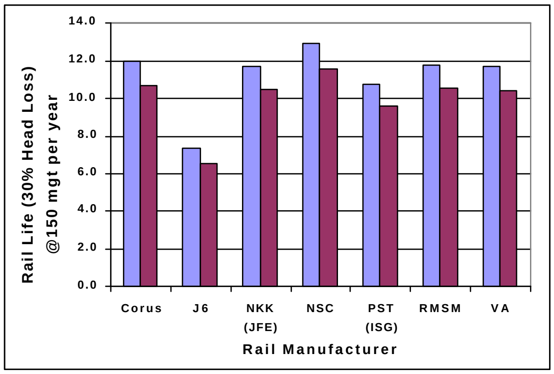

Figure 4. Extrapolated Rail Life Based on Preliminary High Rail Wear Rates to 281 MGT for each of the Rails Currently in the Rail Evaluation Test at FAST

## FUTURE WORK

The current rail performance evaluation is scheduled to continue through 2005 with the final results based on a minimum of 500 MGT of FAST traffic. Continual improvements in rail metallurgy will likely necessitate the initiation of a new test incorporating the state-of-the-art material subsequent to this test.

## PRELIMINARY CONCLUSIONS

- 12.5 percent reduction in average high rail wear (average 395 HB) compared to previous generation rail (average 365 HB) — data normalized between tests using J6 control rail.
- Surface performance is good throughout (no RCF).
- Five rail fractures have occurred in the pearlitic test rail by just over 300 MGT with zero failures having occurred in 517 MGT with the previous rail evaluation.
- Statistically significant difference in high rail wear rate (cross sectional area loss per MGT) exists between the J6 bainitic, ISG, and NSC rails in comparison to the mean of the six pearlitic rails in test.
- Estimated average rail life is 11.8 years (141 RE rail) at 150 MGT per year (in the absence of grinding).

## Acknowledgements

TTCI would like to thank Union Pacific Railroad, Progress Rail, and each of the rail manufacturers that donated rail for this research endeavor.

## Bibliography

Sawley, K. and R. Jimenez; October 2000, "The Comparative Wear Performance of Premium and Bainitic Rail Steels Under Heavy Axle Loads," Report No. R-941, Association of American Railroads, Washington, D.C..