

Preliminary Results of the AAR Developed “J6” Bainitic Rail Tested in Revenue Service

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Summary

Preliminary evaluation of “J6” bainitic rail steel, developed by the Association of American Railroads (AAR) and installed at a Norfolk Southern (NS) Railway revenue service test site, shows that the surface condition of the J6 rail, especially on the low rail, is superior to the head hardened pearlitic rail (control rail) also in test. Accordingly, the outside (high) rail wear of the J6 is comparable to the head hardened pearlitic (0.2 percent less wear on J6), and the inside (low) rail has sustained significantly less wear (49.9 percent less wear on the J6) subsequent to 110 million gross tons (MGT).

Preliminary analysis of bainitic (J6) rail on the NS line after 110 MGT of revenue service traffic under 286-kip cars shows:

- Surface condition of the J6 rail is superior to the head hardened pearlitic control rail, particularly on the low rail.
- Wear on the outside J6 bainitic rail is 0.2 percent less than on the pearlitic control rail.
- Wear on the inside J6 bainitic rail is 49.9 percent less than on the pearlitic control rail.
- J6 rail is performing exceptionally well in special track work and at the NS test site; e.g., J6 lasted three times longer than pearlitic in a three-rail crossing diamond test at FAST.

The wear results from the NS test site contrast with those from previous tests at the Facility for Accelerated Service Testing (FAST), Pueblo, Colorado, when the J6 outside rail wore 48 percent more than the pearlitic rail in test. The wear on the inside (low) rail at FAST was extremely low for each of the rails in test and thus was not analyzed. The major differences affecting the results between the two tests is the relative loading between the high and low rails and the track lubrication. The lubrication at the revenue service test site is probably better than the carryover lubrication at the FAST rail wear test section which may have altered relative wear performance.

The NS site has a nominal curvature of 5.5 degrees with 4 inches of superelevation. Testing at FAST was conducted in a 5-degree curve, with 3.4 inches of superelevation. The line originally received 60 MGT per year of 286-kip per car coal traffic traveling at 35 mph. Recently, however, the tonnage on the line has been reduced to 44 MGT per year. Comparatively, the consist used at FAST has 315-kip cars traveling at 40 mph and accumulates an average of 150 MGT per year. Overall, the test at FAST had a 1.7-inch cant deficiency while that at the NS site is 0.7 inch. Thus, the loading on the high and low rails on the NS site is more evenly distributed than at FAST, which has higher loading on the high rail, which leads to more wear on the high rail.

Suggested Distribution:

- Maintenance of Way
- Planning & Analysis
- Track Maintenance
- Safety



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INTRODUCTION AND CONCLUSIONS

The wear and mechanical performance of rail has continually improved over the years to the current steel, which now typically last several hundred or even in some instances over 1,000 MGT, depending on track curvature and operating environment. The improved performance is due to newly developed thermal treatments (head hardening) and alloying, which produce a very fine pearlitic microstructure with a higher percentage of the hard, wear resistant cementite carbon rich phase. Improved steel manufacturing processes also produce cleaner steel. The improved steel, fewer inclusions, has reduced the steels propensity for fatigue, which allows the rail to provide additional wear that in the past may have required premature removal due to fatigue defects. The newest rail developments have produced very hard rail steel (400+ Brinell hardness or Bhn) while still maintaining a fully pearlitic microstructure that retains the necessary mechanical properties and weldability.

Rail steel will likely continue to improve in the near future, but at some point metallurgical limitations will limit additional reductions in the pearlitic interlamellar spacing and/or hardness increases, without deleterious effects to the resultant mechanical properties or weldability of the steel.

The foresight of several railway researchers to the likely approaching limitations in pearlitic steel brought about an AAR metallurgical study to produce alternative rail steel microstructures that would possibly surpass the ultimate performance capabilities of the pearlitic rail steel. From this research, a single promising alloy was chosen with a bainitic microstructure. This particular steel (415 Bhn), designated "J6," surpassed several other developmental alloys in laboratory wear tests as well as the pearlitic rail steel available at that time (TD 98-012).

The J6 test alloy was manufactured into rail and tested at FAST under a 315-kip per car consist. The test section in which the J6 rail was tested was not directly lubricated, but only received carryover from adjacent curves. In this particular test, the bainitic steel sus-

tained approximately 50 percent more high rail wear than the adjacent head hardened (HH) pearlitic rail steels. However, the surface performance of the rail (absence of rolling contact fatigue cracks) appeared superior to the pearlitic counterparts. For further evaluation of the apparent surface performance of the J6 rail, several lengths of test rail were installed on a Norfolk Southern (NS) revenue service line.

Results from the wear measurements and visual inspections of the rail at the NS test site show that the outside (high) rail wear rates between the J6 and HH pearlitic rail are comparable while the wear on the inside (low) rail is significantly less on the J6. The surface condition of the J6 on the low rail is also significantly better with no cracking, spalling, or pitting observed while there is significant spalling on the HH pearlitic test rail.

TEST CONDITIONS AND TEST RAIL PERFORMANCE

The rail test site is at the Norfolk Southern Blue Ridge Beverage location in Roanoke, VA. The site has a nominal curvature of 5.5 degrees with 4 inches of superelevation. The line receives mainly coal traffic, which initially accumulated 60 MGT per year of 286-kip per car service traveling at 35 mph, but now accumulates 44 MGT per year. The rail has accumulated about 110 MGT to date with measurements taken at 0, 60, 85, and 110 MGT.

The evaluation of test rail performance consists of both monitoring the condition and wear of the rail as well as the performance of the flash-butt and thermite welds joining the test rails. Exhibit 1 shows the wear rates of both steels at the test site. The wear rate of the two rail steels is evident in Exhibit 2, which shows that the slopes of the outside rail wear plots are nearly identical for the two steels (similar wear rates). The J6 inside rail appears to have a lower wear rate than that of the HH rail. The final wear rate of the two steels will require additional test data to confirm, though a definite trend has emerged in the performance of the test rail from preliminary measurements.

Exhibit 1. Wear Rates of J6 Bainitic and Head Hardened Pearlitic Test Rails at the Norfolk Southern Blue Ridge Beverage Test Site

Tonnage at Measurement Cycle (MGT)	J6 Bainitic Rail Wear, in ²		Head Hardened Pearlitic Rail Wear, in ²	
	Outside Rail [High]	Inside Rail [Low]	Outside Rail [High]	Inside Rail [Low]
60	0.0773	0.0408	0.0718	0.0533
85	0.136	0.0454	0.128	0.0749
110	0.191	0.0582	0.192	0.116

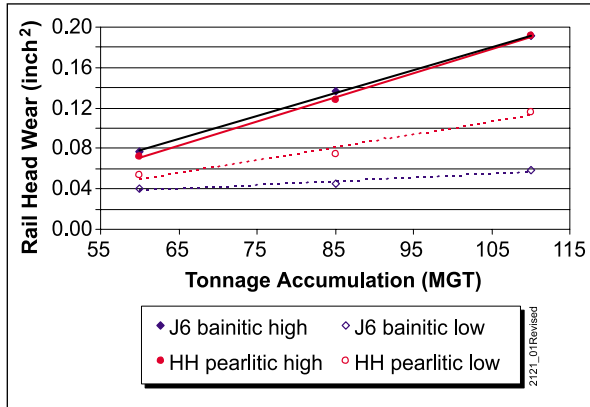


Exhibit 2. Rail Wear Data from the Norfolk Southern Blue Ridge Beverage Test Site

The most impressive characteristic of the J6 bainitic rail is its resistance to rolling contact fatigue as Exhibits 3 and 4 show. The bainitic rail shown in Exhibit 3 has no visible sign of rolling contact fatigue (RCF) cracking as opposed to the HH rail shown in Exhibit 4, which has substantial spalling. The superior resistance of the J6 rail to RCF is due to the bainitic microstructure, which is nonlamellar (as opposed to the lamellae structure of pearlite) but contains the same metallurgical phases as that of pearlite. The bainitic rail (415 Bhn) also has a much higher hardness than that of the HH pearlitic rail (350 Bhn), which was available at the time of test installation. The HH control rail used at the NS test site consequently showed a 24 percent higher wear rate compared to the other pearlitic rails in test at FAST. However, the wear rate of the control rail was not known at the time of the J6 NS test installation, and the HH rail was commonly used by the railroad. The surface performance of the NS control rail, as evaluat-



Exhibit 3. J6 Bainitic Rail from the Inside of the Curve (low rail) Shows No Evidence of Rolling Contact Fatigue on the Rail Surface
Rail surface shown at 110 MGT

ed at FAST, was consistent with each of the pearlitic rails also in test. A more direct comparison using the same hardness steels of the different rail microstructures was not possible. However, newly developed pearlitic rail steels are available with 400+ Bhn hardness, which would allow direct comparison of the microstructures without differences in hardness if the superior performance of the J6 rail persists.

The ability to join the newly developed J6 bainitic rail steel is of utmost importance as the rail is not practical for mainline curves, if it cannot be continuously welded in track. Laboratory test results have shown that properly modified flash-butt and thermite processes both produce welds that meet respective specified minimum requirements.

However, neither the flash-butt nor the thermite welding processes have been optimized for the J6 rail, but only initial experiments performed to allow test installation at the NS site. Consequently, one flash-butt weld fracture occurred. A second one was also removed after being located by a detector car. Two thermite weld fractures have also occurred at the test site. The specific weld failure causes are being studied and addressed to allow further improvements to the welding of the J6 rail. Welding improvements should not be a significant task as the J6 rail has a relatively low-carbon content in comparison to the pearlitic rail. The carbon content of the steel greatly influences its weldability with higher carbon content material typically requiring additional attention to produce a satisfactory weld.

Another advantage of the J6 bainitic rail steel is fracture toughness performance. The J6 steel has fracture toughness approximately 23 percent above that measured in premium rail steel.¹ The critical crack



Exhibit 4. Head Hardened Pearlitic Rail from the Inside of the Curve (low rail) Shows Substantial Spalling on the Rail Surface
Rail Surface Shown at 110 MGT



size, size of crack within rail from which fracture occurs, rises as the square of the toughness. Thus, the J6 rail should be able to sustain larger cracks than premium rail before failing by sudden brittle fracture.

SIGNIFICANT RESULTS

The preliminary (110 MGT) NS bainitic rail test results are extremely encouraging, with the J6 rail performing superior to the pearlitic control rail in test. However, an increase in rail costs is a factor that needs to be considered with utilization. Additionally, J6 may find wide application in special track work, where the benefits of its superior deformation resistance and toughness outweigh the expected first cost premiums. In a three-rail crossing diamond application, the use of J6 rail has tripled the service life under 39-kip wheel load operations at FAST.²

The additional capital cost for the rail could be offset by its use at locations that require substantial preventative or maintenance grinding to maintain an acceptable rail condition. Eliminating a consistent need for grinding would offset the additional cost of the bainitic rail.

As an example, the relationship between natural wear, grinding, and rail life can be illustrated using data from AAR grinding test sites on Canadian National.³ Two of the test sites were ground at 11 MGT intervals. Assuming that the test rail will require replacement after 35 percent of the head section has been lost, the high- and low-rail life in a 7.1-degree curve is 465 and 426 MGT, respectively. However, grinding 50 percent less, even with 25 percent higher wear, increases the high and low rail life by 44 and 76 percent to 670 and 749 MGT, respectively. Thus an approximate 50 percent increase in rail life could be obtained for a likely 10-percent cost premium.

FUTURE WORK

The current test in place on the NS will continue to be monitored until replacement of the rail is required. This will allow a full-life performance evaluation to ensure the rail performs consistently throughout its utilization. If the superior performance of the J6 bainitic rail persists, additional laboratory investigation of the

alloying will allow further enhancements of the bainitic microstructure for rail performance and cost reduction.

The J6 rail also has been added to a recently initiated rail evaluation test at FAST in which the bainitic rail is being compared to the newest super premium pearlitic rail from six manufacturers, with hardness in excess of 400 Bhn. Though the FAST site again does not receive direct lubrication, this test will allow comparison of the J6 to the current and previous pearlitic rail.

A cooperative university research study has also begun at the University of Illinois at Urbana-Champaign sponsored by the AAR and the Federal Railroad Administration. This research is to investigate the localized plastic deformation (shear yielding) at the rail surface due to wheel/rail interaction. The results from this research are intended to accelerate the development of rail steel metallurgy by providing an increased knowledge of thin layer rail deformation processes. This knowledge will allow enhancements to the rail steel to inhibit plastic deformation of the critical surface layer that performs differently than the bulk deformation of the steel.

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