

Track Wear Tests of Bainitic and Pearlitic Rails: Final Results

by Kevin Sawley and Rafael Jimenez

Summary

Wear tests of six premium rail steels and one experimental bainitic rail steel in a 5-degree curve showed that the bainitic steel tested (coded J6) has superior resistance to rolling contact fatigue defects when compared to premium rails. If, as expected, this fatigue resistance translates into reduced need for grinding, bainitic rails may still offer improved service life over premium rails in curved rail sites where frequent grinding is now applied. Results also confirmed that pearlitic steels have naturally higher wear resistance than bainitic steels.

Tests were undertaken at the Federal Railroad Administration's Transportation Technology Center using heavy axle load cars equipped with standard three-piece trucks and with all rails partially lubricated. In the tests, 94 million gross tons (MGT) of traffic were applied, following earlier wear tests of the same rails under cars with improved-suspension trucks. Principal results from the tests include:

- Under heavy axle load cars with standard three-piece trucks, all the premium rails showed reasonably similar wear properties, although the harder rails showed the least wear.
- The expected relationship between bulk hardness and wear was seen for the premium pearlitic rails, in that wear rate fell as hardness increased.
- The J6 bainitic rails, despite being harder, wore approximately 48 percent faster than the average for the premium rails.
- At the end of tests, all premium rails showed cracks and spalls on the high-rail gage corner. The J6 rails showed no such damage.

The two goals of the tests were to establish the relative wear resistance of a range of commercially available premium pearlitic rails, and to establish the wear performance of experimental bainitic rail steel developed under the Association of American Railroad's Strategic Research Initiative. This high hardness bainitic steel is being studied since current premium rail steels are nearing their limit of development in terms of hardness. Past work has shown that, at least for pearlitic steel, high hardness equates to high wear resistance.

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INTRODUCTION

The wear performance of an experimental bainitic high-strength rail steel (J6) has been compared with six currently available pearlitic premium rail steels in Section 7 of the High Tonnage Loop (HTL) at the Federal Railroad Administration’s Transportation Technology Center. An earlier Technology Digest (TD00-003) summarized the relative wear performance of the rails under heavy axle load (315,000-lb) cars with improved-suspension trucks equipped with forms of cross-bracing and shear pads between the bearing adapters and the sideframes. In Part 1 of the tests, the rails were subject to partial lubrication. In Part 2, the rails were tested in the fully dry condition. It was noted that rail wear rates were very low with improved-suspension trucks, and that, probably because of the low wear, the expected effect of hardness on pearlitic rail wear was not observed.

This TD summarizes results from the next phase of testing (part three), in which wear of the same rails was measured under heavy axle load cars equipped with standard three-piece trucks. In Part 3, the rails again had partial lubrication. Exhibit 1 details the tonnage applied during all three parts of testing.

The first objective of the wear test was to examine the relative curved-track wear performance of current premium rail steels. Secondly, researchers wanted to assess the wear resistance of the experimental J6 bainitic rail steel developed by TTCI and Oregon Graduate Institute as part of the AAR’s Strategic Research Initiative.

This high-strength bainitic rail steel is under test since traditional pearlitic rail steels appear to

be nearing their limit of development. The bainitic microstructure offers higher levels of hardness than those achievable in pearlitic steels, without complex heat treatments. Historically, increased rail hardness has led to improved wear resistance.

TEST STEELS AND CONDITIONS

The rail steels in the test curve are listed in Exhibit 2 with their as-manufactured hardnesses. The values quoted are averages of measurements made by TTCI and two independent laboratories, and were taken 3/8 inch below the running surface using manually operated Brinell test machines. Note that an automatic Brinell machine consistently reported hardness values approximately 16 points higher.

Five of the premium rails were conventional head-hardened grades. The sixth, NSCHE, was a pearlitic hypereutectoid grade with increased carbide thickness. The J6 bainitic steel was rolled to American Railway Engineering and Maintenance of Way Association 136-RE section rail by Pennsylvania Steel Technologies from steel made by Ellwood City Forge. It had a carbide-free ferrite lath structure with hardness provided by a very fine lath size and a high dislocation density.

All rail steels were tested in both the high and low rails, but, even after 250-300 MGT, wear on the low rails was relatively low. Therefore, results reported here focus on high-rail wear performance.

	Truck Susp.	Lube	Premium rails MGT	J6 rails MGT
Part 1	Improved	Partial	167	102
Part 2	Improved	None	57	57
Part 3	Standard 3-piece	Partial	93	93

Exhibit 1. Tonnage Applied to the Test Rails

Manufacturer	Rail	Hardness (HB)*
Hayange	HAYHH	361
Nippon Kokan	NKKTH37N	369
Nippon Steel Corp.	NSCDH37	358
Nippon Steel Corp.	NSCHE	367
Pennsylvania Steel Technologies	PSTHH	342
Rocky Mountain Steel Mills	RMSMDHH	378
TTCI/PST	J6	412

* Values from manual test machine

Exhibit 2. Rail Steels Installed in the Test Site



Section 7 of the HTL is a reverse curve, and under normal operation has only partial lubrication carried over from trackside lubricators elsewhere in the loop. The test train has four locomotives and approximately 75 cars with nominal gross car loads of 315,000 pounds. The train runs at a speed of 40 mph, so that in Section 7 (4-inch superelevation) the train runs at 1.7-inch overbalance speed. The train applies between 3 and 5 million gross tons (MGT) of traffic weekly. In Part 3 of the wear tests, all cars had standard three-piece trucks.

WEAR MEASUREMENTS AND RESULTS

Wear measurements were made at intervals using “snap gages” and Miniprof™ profile measuring equipment. The Miniprof and snap gage measurements agreed well, and only Miniprof measurements are presented here. The Miniprof equipment allows three methods of describing wear:

- W_1 : the metal lost at the rail top center.
- W_2 : the metal lost from the gage face, 0.5-inch down from the new rail top.
- A: the total loss of cross-section.

Wear under the partial lubrication of part three testing is proportional to tonnage, and can be described by the equation:

$$A = a (MGT) + b \quad (1)$$

The coefficient “a” is found by linear regression and is a measure of wear performance. Rails with a low value of “a” wear slowly, and vice-versa.

Exhibit 3 lists the values of “a” found for all of the test steels, the correlation coefficients for equation 1, and the relative wear index, or RWI. (The RWI of a steel is the coefficient “a” divided by the lowest value of “a”.) Thus the most wear-resistant steel has an RWI of 1, and all other steels have an RWI greater than 1. The high correlation coefficients indicate that steady state wear has been achieved in these Part 3 tests.

Key points to note from Exhibits 3 and 4 are:

- Of the premium rails, the Hayange rail shows the lowest wear rate, followed closely by the Rocky Mountain Steel and NSCHE rails.
- However, apart from the Pennsylvania Steel rail, all the premium rails show very similar wear rates with the RWI values falling between 1 and 1.14.
- In these Part 3 tests, the premium steels show the expected correlation between hardness and wear, with the harder steels showing the least wear (Exhibit 4). This contrasts with the wear results of parts one and two, in which such an effect of hardness on wear was not observed.
- Despite having highest hardness, the J6 rail has the highest wear rate, 48 percent higher than the premium rail average.

It is believed that test results from Part 3 are a better indication of relative wear performance than the previously reported test results from Parts 1 and 2. Principally this is because the amount of wear in Parts 1 and 2 was so small that it is likely that wear performance was influenced by initial profile effects and by effects from the surface decarburized layers.

Rail steel	Hardness (BHN)	Part 3 results		
		a	R ²	RWI
HAY	361	1.444	0.997	1.00
NKK	369	1.632	0.999	1.13
NSCDH	358	1.643	0.997	1.14
NSCHE	367	1.557	0.996	1.08
PST	342	1.936	0.997	1.34
RMS	378	1.530	0.998	1.06
J6	413	2.409	0.999	1.67

* Units are in² per 1,000 MGT

Exhibit 3. Wear Rate Coefficients

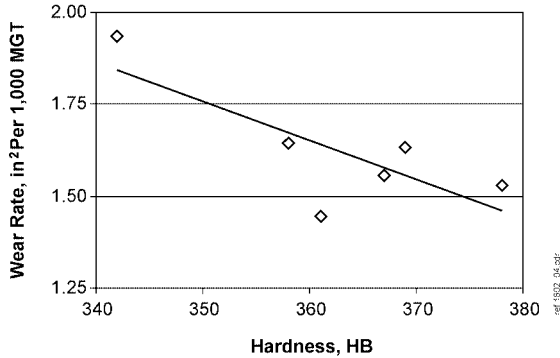


Exhibit 4. Effect of Hardness on Wear for Premium Pearlitic Rails

CONCLUSIONS FOR BAINITIC RAIL STEELS

The J6 rails were the hardest tested, but gave the highest wear rate. This shows that bulk hardness, while a good indicator of relative wear resistance for pearlitic rails, cannot alone be used to predict relative wear performance of steels with different microstructures. Other factors, as yet unknown, influence wear. It seems, however, that bainitic steels need to be harder than premium pearlitic steels in order to match their wear resistance – possibly by up to 70-80 hardness points.

The poorer wear resistance of bainitic steels need not inhibit their use. While most rails are replaced when wear limits are exceeded, much of the metal loss is often caused by grinding to remove surface cracks, pits, and spalls. At the end of these tests, all the premium high rails showed head checks and spalls on the gage corner. In contrast, the J6 rails showed no contact fatigue damage. The resistance of J6 steel to contact fatigue has been verified in unpublished laboratory tests. Bainitic steel rails may offer increased service life, despite their wear properties, if they need less grinding. This is illustrated in Exhibit 5 which is based on data from two grinding test sites, where measurements allow estimates to be made of the metal removed by natural wear and by grinding. Currently predicted lives (based on removal when

Life (in MGT) Assuming Failure by Loss of Cross-Section				
	7.1-degree curve		4.0-degree curve	
	High rail	Low rail	High rail	Low rail
Current prediction	465	426	576	468
Calculated*	612	718	778	717

* Assuming 50 percent more wear and 50 percent less grinding

Exhibit 5. Predicted Lives of Rails

35 percent of the head cross-section has been lost) range from 426-576 MGT. Assuming 50 percent more natural wear and 50 percent less grinding, calculated lives increase to 612-778 MGT. Note this value of 35 percent is for illustration. It should also be noted that the past rate of grinding at these sites might not continue in the future.

CONCLUSIONS

- Under heavy axle load cars with standard three-piece trucks, all the premium rails showed similar wear properties, with the harder rails showing the least wear.
- The J6 bainitic rails, despite being harder, wore approximately 48 percent faster than the average for the premium rails.
- At the end of tests, all premium rails showed cracks and spalls on the high-rail gage corner. The J6 rails showed no such damage.
- Bainitic rails may offer longer service life in sites where frequent grinding is now needed to control rolling contact fatigue damage.

REFERENCES

1. *Technology Digest* 00-003, “Track Wear Tests of Bainitic and Pearlitic Rails: Interim Results,” Feb. 2000.

Note: Please contact Kevin Sawley at (719) 584-0636 with questions or comments about this document.

E-mail: kevin_sawley@ttci.aar.com

Web site: www.ttci.aar.com

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