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TRACK WEAR TESTS OF BAINITIC AND PEARLITIC RAILS: INTERIM RESULTS

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Summary

Tests of a range of rail steels in a 5-degree curve at the Federal Railroad Administration's Transportation Technology Center have demonstrated that cars equipped with improved suspension trucks lead to very low rail wear rates even with heavy axle loads. For the best premium rail studied, wear lives under the 315,000-pound cars are predicted to be 7,600 million gross tons (MGT) under partial lubrication, and 1,900 MGT with no lubrication. (These figures assume rail is replaced only for wear, and not for internal defects.) Six premium rail steels and one experimental bainitic steel have been tested for up to 224 MGT of heavy axle load traffic to date. Significant differences have been seen in the wear rates of premium rail, but evidence is that as wear rates rise, both by a change in lubrication conditions and by the introduction of standard trucks, the wear performance of the rails begins to converge.

The bainitic steel, although harder than the premium rails, has consistently shown higher wear rates. The steel has, however, shown resistance to surface fatigue and could be a candidate for service use if this expected fatigue resistance translates into significant reduction in the need for rail grinding.

Other results from the ongoing tests include:

- Even partial lubrication (achieving a wheel/rail friction of about 0.35) has a large effect on wear, reducing the fully dry (friction of about 0.5) wear rate by a factor typically between 3 and 4.
- For these premium high-hardness steels, there is no clear correlation between hardness and wear. The softest and hardest rails show the highest wear rates. The steel with intermediate hardness shows the lowest wear rate.
- Measured Brinell hardness of the rail appears to depend on the type of measuring machine used. An automatic machine consistently gave increased hardness, typically by about 16 points, as compared to manual machines. This may have ramifications for rail specifications.

Current premium rail steels are approaching their limit of development in terms of hardness, which is related to wear. Consequently the Association of American Railroads' Advanced Rail Steels project is examining the suitability of bainitic steel for rail manufacture. Bainitic steels allow much higher rail hardness to be achieved, and also offer increased toughness and weldability.

Suggested Distribution:
☐ Maintenance of Way
☐ Planning & Analysis
☐ Track Maintenance
☐ Safety

Work performed by TTCI Transportation Technology Center, Inc.
a subsidiary of the Association of American Railroads

INTRODUCTION

As traditional pearlitic rail steels approach their limit of development, attention has focused on the production of alternative microstructure steels that offer higher levels of hardness without complex heat treatments. Historically, increased rail hardness has led to improved wear resistance. As part of the AAR's Strategic Research Initiative, Transportation Technology Center, Inc. (TTCI) has worked with the Oregon Graduate Institute to develop a range of high strength, bainitic microstructure steels, which offer a combination of high toughness and strength. One of these, coded J6, was shown to have higher hardness and toughness than current pearlitic rail steels. Laboratory wear tests using rolling/sliding cylinders also indicated significantly better wear resistance than 340 Bhn hardness premium rail.[1] These wear tests were designed to simulate gage face wear of dry rail in severe curved track.

Consequently a commercial cast of J6 bainitic steel was made by Ellwood City Forge and rolled to American Railway Engineering and Maintenance of Way Association 136-RE section rail by Pennsylvania Steel Technologies. After testing to demonstrate they were safe for use in track, three test rails were installed in Section 7 (a 5-degree curve) of the high tonnage loop (HTL) at TTC. Two rails were installed in the high rail, and one in the low. Also installed were samples of six latest generation premium rail steels produced by five manufacturers. The test objective was to assess the comparative performance of the premium and bainitic rails under heavy axle loads. The data was collected as part of the FAST program, which is jointly funded by the AAR and FRA.

TEST CONDITIONS

Section 7 of the HTL is a reverse curve, and consequently under normal operation has only partial lubrication carried over from trackside lubricators elsewhere in the loop. In the first part of testing, this partial lubrication led to measured high rail gage face friction levels of about 0.35. In the second part of the test, all trackside lubrication was stopped and the loop was operated in fully dry condition, giving friction levels of about 0.5. Exhibit 1 gives details of tonnage accumulated by the test rails in the two test phases. (The J6 rails were installed after the premium rails, and hence show lower values of accumulated tonnage).

The test train on the HTL has four locomotives and approximately 75 gondola and tank cars with nominal loaded weight of 315,000 pounds. The train runs clockwise and counter clockwise at a nominal speed of 40 mph. This means that in Section 7 (4-inch superelevation) the train runs at 1.7 inch over balance speed. The train applies between 3 and 5 MGT of weekly traffic. All the cars had improved suspension trucks equipped with forms of cross bracing and shear pads between the bearing adapters and the sideframes. These trucks offer much better curving behavior than standard three piece trucks.

		Premium rails	**J6 rails**
Part 1	Start	0 MGT	0 MGT
	Finish	167 MGT	102 MGT
Part 2	Start	167 MGT	102 MGT
	Finish	224 MGT	159 MGT

Exhibit 1. Tonnages Applied to the Test Rails

TEST STEELS

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. All these hardness values were made using manually operated Brinell test machines. Another laboratory was asked to test the hardness of the steels using an automated Brinell test machine. This machine used an optical system to produce an average indentation size from 80 measurements of indentation diameter. This automatic system consistently gave higher hardness values, by an average

Manufacturer	**Rail**	**Hardness (BHN)***
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

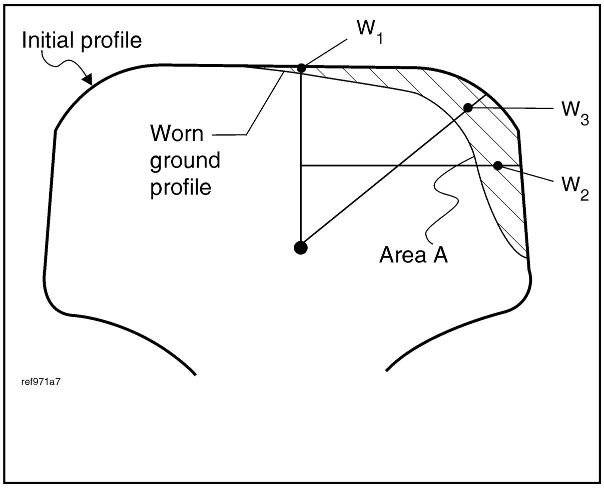

Exhibit 3. Measurements from Rail Profiles

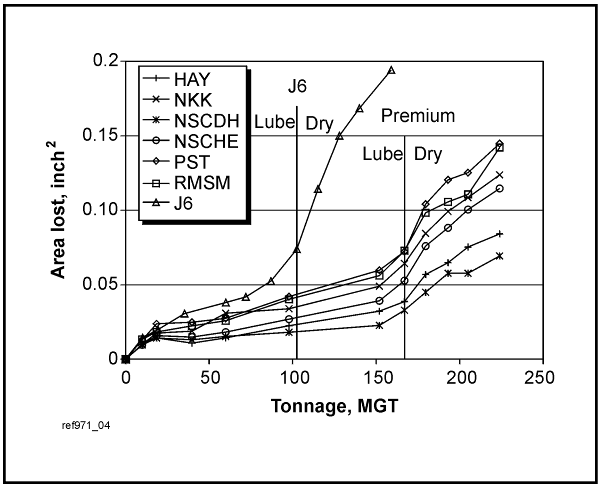

Exhibit 4. Effect of Tonnage on Wear

of 16 Bhn. 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 had a carbide free ferrite lath structure with hardness provided by a very fine lath size and a high dislocation density.

WEAR MEASUREMENTS AND RESULTS

Wear measurements were made after installation, and at intervals up to the final tonnage at the end of part 2. Snap gages measured high and low rail height loss, and high rail gage face loss 5/8 inch below the rail top. Measurements were also made of the high and low rail transverse profiles using a Miniprof™ machine. The Miniprof and snap gage measurements agreed well, and therefore only the Miniprof measurements are presented here. Exhibit 3 illustrates the measurements available from the Miniprof software. Exhibit 4 shows for all the test rails the amount of metal worn from the cross section (in square inches) with tonnage. To determine wear rates for all the steels (under partial lubrication and fully dry conditions) linear regression was used to relate area lost (A) to tonnage (MGT):

$$A = a(MGT) + b$$

High values of coefficient "a" indicate poor wear resistance, low values mean good resistance. In all cases, the correlation coefficient (R^2) was above 0.9. Exhibit 5 gives the relative wear rates (values of "a," normalized to the steel with the best wear resistance) found under partial lubrication and dry running. The NSCDH steel had highest wear resistance, while the J6 steel had lowest wear resistance. Exhibit 5 also shows for each steel the ratio of dry to lubricated wear rate.

Steel	Relative wear rate		Wear ratio (dry/lube)
	Lube	Dry	
HAYHH	2.31	1.24	3.24
NKKTH37N	2.91	1.72	3.59
NSCDH37	1	1	6.06
NSCHE	2.63	1.73	3.99
PSTHH	3.87	1.73	2.71
RMSMDHH	3.72	1.92	3.12
J6	4.81	3.5	4.40

Exhibit 5. Relative Wear Rates of Test Rails

There are a number of things to note from exhibits 4 and 5:

- The premium steels show wide variations in wear rate, especially in the partial lubrication regime, although performance tends to converge with dry running. (Note this convergence has continued as wear rates have increased by the recent introduction of standard three piece trucks on the test train.)

- Partial lubrication has a large effect on wear, reducing wear rates by a factor of 3 to 4.

- Under improved suspension trucks, wear rates are very low, even under dry running. For example, assuming rail is replaced when 35 percent of the head is lost, the NSCDH has estimated wear lives of 7,600 MGT and 1,900 MGT, under partial lubrication and dry running respectively.

- For these premium steels, there is no clear correlation between hardness and wear. The highest wear rates are shown by the softest and hardest rails. Note however that this conclusion holds for the low wear rates produced by vehicles with improved suspension trucks. The test train has recently been equipped with standard three-piece trucks, and this has led to significantly higher wear rates. At these higher wear levels, a rail hardness effect is evident and the softer rail steels appear to be wearing faster than the harder rail steels.

- Despite having high hardness, the J6 steel consistently shows the highest wear rate, as explained below.

EFFECT OF HARDNESS ON RAIL WEAR

For the premium rails, results show that wear resistance is not related to hardness. Although wear is linked to hardness over large hardness ranges, there is evidence of a decreasing effect at high hardness. One laboratory study concluded that increasing hardness above 350 Bhn had little effect on wear.[2] This is supported by this study. Wear performance is likely to improve as carbon content increases (raising the volume of hard carbides), and as pearlite spacing decreases (lowering the chance that carbides will fracture during rolling contact). Below a critical pearlite spacing, carbides are less likely to fracture during deformation.[3] Thus, for wear resistance, carbon content and pearlite spacing may be more important than simple hardness. The fact that both factors happen to increase hardness may account for the general effect of hardness on wear. All the premium steels under test have about the same carbon content (the NSCHE has slightly higher carbon), and, if a critical pearlite spacing exists, reductions in spacing below this value may have minimal benefit. Hence the present results may not be too surprising.

The J6 results confirm that bulk hardness is not always the best indicator of wear resistance. Low carbon bainitic steels work harden less than pearlitic steels. So, although bainitic steels have higher bulk hardness, they may not develop the same work hardened strength at the worn surface as do pearlitic steels. Because of this lack of work hardening, to exceed the wear properties of premium rail steel, bainitic steel is likely to need a bulk hardness at least 70 to 80 hardness points higher than pearlitic steels.

Rail life, however, is not simply related to wear resistance. Though most rails are replaced when wear limits are exceeded, in many cases much of the metal loss is caused by grinding to restore the rail profile and remove surface cracks, pits, and spalls. For premium rails, grinding is used to remove fatigue damaged surface material, aiding the natural wear. Bainitic steels, with their higher hardness (which should equate to better fatigue resistance) and higher natural wear, offer the possibility of longer rail life through a reduction in rail grinding. The J6 test rails show no evidence of head checks or spalls or internal defects after 159 MGT of heavy axle load traffic.

FUTURE WORK

The wear test in FAST Section 7 will continue through 2000. The cars have been equipped with standard trucks, and partial lubrication has been returned. The use of standard trucks has further increased wear rates, and, while differences are still seen between the various steels, relative performance is beginning to converge. J6 rails have also been installed in a 5.5-degree curve on Norfolk Southern track near Roanoke, Virginia, to assess performance in revenue service.

REFERENCES

1. K. Sawley and J. Kristan, “Evaluation of Bainitic Test Rails,” AAR TD-98-012, 1998.
2. J. Kalousek, D. Fegredo, and E. E. Laufer, Wear, Vol. 105, 1985, p. 199.
3. G. Langford, Met. Trans. A, Vol. 8a, 1977, p.861.

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