

"BAINITIC STEELS FOR RAILS"

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Summary

The Association of American Railroads, in cooperation with the Oregon Graduate Institute, has developed a new range of high strength rail steels that offer outstanding wear performance. They have outperformed current premium rail steels in small-scale tests designed to simulate severe gage face wear seen on high rails in sharp curves. These steels have microstructures, called bainitic, which are fundamentally different from those seen in conventional rail steels. Through the use of selected alloying elements, they can give high hardness and strength without the need for special heat treatments.

As well as wear resistance, the high strength of these steels confers good resistance to deformation in rolling contact. For this reason, rails made from these steels are expected to have excellent resistance to shelling and spalling, as well as improved overall fatigue performance.

The steels are made with much lower carbon contents than conventional rails, and are expected to be easily and reliably welded in the plant and in the field.

Full-size rails are planned for manufacture in 1997. When rail integrity has been assured by laboratory testing, trial rails will be installed under heavy axle loads at the Transportation Technology Center, Facility for Accelerated Service Testing, Pueblo, Colorado, for direct comparison with the best currently available rails.

Suggested Distribution:

- Maintenance of Way
- Track Maintenance
- R&T Dept.
- Safety Dept.



Association of American Railroads
Research and Test Department

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INTRODUCTION AND CONCLUSIONS

Working with the Oregon Graduate Institute, the Association of American Railroads has developed a new range of high strength rail steels that offer outstanding wear properties. The new steels have performed much better than current premium rail steels in small-scale laboratory tests designed to imitate severe gage face wear seen by high rails in sharp (5°) curves. Exhibit 1 illustrates this type of wear, which is a major cause of premature rail replacement in curved track.

The steels have structures, called bainitic, which are different from those seen in normal rail steels, and can give high hardness and strength without special heat treatments.

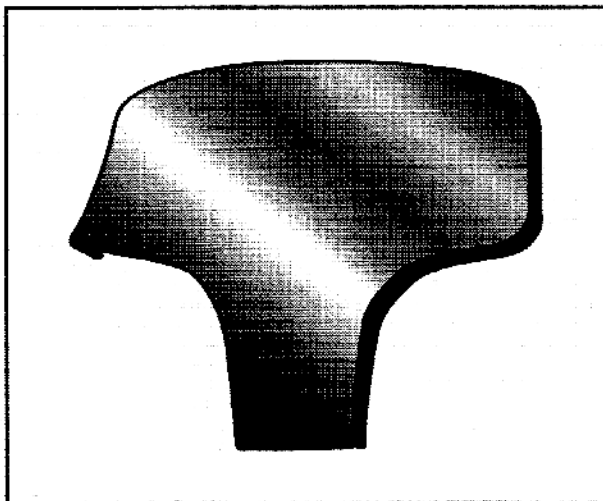


Exhibit 1. Type of Wear that Causes Premature Rail Replacement in Curved Track

As well as wear resistance, the high strength of the steels gives high resistance to the type of deformation caused by wheels rolling on the rail. For this reason, rails made from the steels should have good resistance to shelling and spalling, as well as improved overall fatigue performance.

Produced with lower carbon contents than usual, the steels are expected to be readily weldable in the plant and in the field.

The most promising bainitic steel studied is coded J6, and its chemistry is compared with premium rail in Exhibit 2.

Exhibit 2. Comparison of J6 Chemistry with Premium Rail Steel

Alloy Content (wt. percent)	Rail steel	
	Bainitic J6	Premium Rail
Carbon	0.26	0.79
Manganese	2.0	0.91
Silicon	1.81	0.66
Chromium	1.93	-
Molybdenum	0.49	-

Bainitic Steel

Discovered in the 1930s, bainitic steels have grown in use over the past 20 to 30 years as improvements in steel making have enabled routine commercial use. Though little known, they are not new to the railroad industry. Past work appeared to show they were not suitable for track work, but over the last few years evidence has mounted that they can offer benefits in heavy tonnage track.

Several manufacturers have sought to develop bainitic rails. In Scandinavian trials comparing bainitic and premium rails, one manufacturer has claimed a 40-percent reduction in wear after 100 million tons of traffic of iron ore traffic. The steel had a higher carbon level but lower alloy content than steel J6. Bainitic steels are also being adopted in Britain for use in frogs for high speed and tonnage (mainly passenger) track.



High-strength bainitic steels have been studied in detail in another Association of American Railroads project to develop improved frog steels (*Technology Digest* 96-026). Results are positive, and prototype frogs are in manufacture for testing under heavy axle loads at the Transportation Technology Center, Facility for Accelerated Service Testing, Pueblo, Colorado.

Normal rail steels derive their strength and wear resistance from the fine layers of iron and iron carbide (a structure called pearlite) of which they are made. In contrast, bainitic steels gain their strength from an ultrafine structure containing micro-defects, called dislocations, which are harmless but confer high strength and resistance to deformation.

Bainitic steels can be produced consistently by the use of simple alloy elements. The structure is most easily ensured by using small amounts of molybdenum and boron, which make the hardness fairly insensitive to cooling rate. Strength is imparted by adding carbon, which has the greatest effect, with chromium, manganese and nickel. At the carbon levels used in this project, silicon helps suppress the formation of carbides, which appears to be one factor leading to good wear resistance.

The weldability of the new steels has not been studied in detail, but no problems are foreseen. In general, welding becomes easier as the carbon content falls. The naturally low-carbon content of bainitic steel should give no problems for flash-butt, thermite or repair welding.

TEST PROGRAM

A range of wrought steels was made to examine the effect of the different elements on steel properties. All the steels made contained the ½Mo-B additions needed to ensure the bainitic structure; the other alloy additions are listed in Exhibit 3. The steels

were produced in the form of as-rolled 3-inch-square billets.

Exhibit 3. Range of Bainitic Steels Examined in the Development Program

Steel	Alloy content, weight percent				
	C	Mn	Si	Cr	Ni
J1	0.18	2.01	1.13	1.94	0.01
J2	0.12	3.97	0.27	0.02	0.02
J3	0.077	2.03	0.27	1.97	1.93
J4	0.023	2.02	0.27	1.96	1.93
J5	0.026	4.04	0.27	0.02	0.02
J6	0.26	2.00	1.81	1.93	-

A number of different tests were used to assess the performance of the steels. As well as conventional hardness, tensile and Charpy impact measurements, wear and deformation resistance were measured using small (35 mm diameter) rolling cylinders in an Amsler test machine.

To measure wear, test steel cylinders were rolled against cylinders made of Class C wheel steel. High contact pressures (177 ksi and 247 ksi) and creepage (35 percent) were chosen to simulate the type of severe wear seen on the rail gage face in sharp (5°) curves. Specimens were weighed throughout each test, to give weight lost per meter rolled per millimeter of contact width. Steels with good wear resistance should have good resistance to rolling contact fatigue, since both types of damage are caused by metal flow.

Further tests to assess deformation resistance were done at a contact pressure of 188 ksi and a creepage of 10 percent, with oil lubrication used to minimize wear. The cylinders were yawed to cause the steel at the cylinder surface to flow sideways, and this flow was measured to assess resistance to



deformation. In these tests, both the bottom and top rollers were made of the same bainitic material.

Exhibit 4 summarizes the hardnesses and wear rates (at 247 ksi) measured on the premium (HH) and six experimental bainitic steels. The bainitic steel coded J6 was the only steel that did not show severe wear under the test conditions used, and also showed high resistance to deformation. It is important to note, however, that the very high-wear resistance found using small test specimens (shown in Exhibit 4) is unlikely to be reproduced in revenue service.

Based on the results found, steel J6 has been chosen for further full-scale development through 1997.

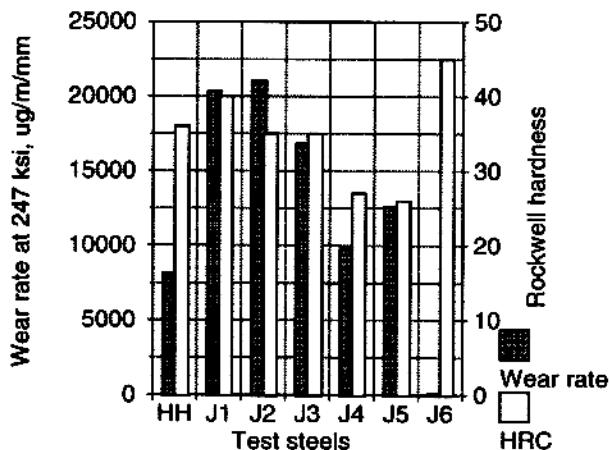


Exhibit 4. Hardness and Wear Rates Measured on the Premium and Six Experimental Bainitic Steels

FUTURE WORK

Small-scale laboratory tests have confirmed the potential of bainitic steel to give improved wear performance in highly curved track. The task now is to prove this in full-scale trials, and do the other work needed to implement bainitic steel safely and confidently.

Using a large commercial cast of as-rolled J6 steel, the 1997 goals are to:

- Demonstrate a significant increase in wear resistance under real wheel and rail conditions, using rails installed at FAST.
- Prepare plant and field weld procedures that mesh smoothly with current practices to ensure welds of consistent high quality.
- Give increased focus on other needed properties, such as toughness, crack growth and steel cleanliness, to ensure rails can be used safely.
- Test the rail residual stresses formed in manufacture and during service. These accelerate fatigue and need to be minimized. Particular attention will be given to ensure high strength bainitic rails are not susceptible to rail end "crocodile cracks," where the web cracks cause the head and foot to separate.

With positive results from this program, two further tasks are needed. First, the J6 steel has a fairly high alloy content, particularly chromium and molybdenum, and is more expensive than current premium rail. But J6 is intended as a demonstration, and once good field wear resistance is achieved, the task is to work with manufacturers to make the base alloy leaner and cheaper while maintaining its beneficial properties. Work with leaner experimental alloys suggests this can be achieved, especially if the higher cooling rates used by manufacturers to produce head hardened rail can be used.

Second the measured benefits and costs need to be weighed to make sure that the new rails produce a real bottom line benefit.

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