TECHNOLOGY DIGEST

Timely Technology Transfer

"AN IMPROVED BAINITIC STEEL FOR FROGS"

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Summary

Working with the Oregon Graduate Institute, the Association of American Railroads (AAR) has developed a new, high-strength bainitic steel with the potential to offer better performance over the austenitic manganese steel (AMS) normally used in frogs. Bainitic steels are already used for frogs in the United Kingdom (UK), but the new steel has been developed for superior strength and hardness, making it more suitable for the higher axle loads seen in North America.

The new steel:

- has naturally high strength and hardness,
- shows very high resistance to deformation and wear in laboratory tests,
- is much tougher than rail steel, but not as tough as AMS,
- is easier to cast than AMS, thereby reducing the chance of casting defects,
- is easily inspectable by ultrasonic and magnetic particle methods, unlike AMS, and
- is easily repaired by welding.

Two full-size frogs have been produced for the next phase of development. The first frog will be sectioned to ensure that the properties generated in small-scale casts have been achieved in the large casting. The second will be tested against an AMS frog under heavy axle loads at the AAR, Transporation Technology Center, Facility for Accelerated Service Testing, Pueblo, Colorado.

Suggested Distribution:
- ❑ Bridges & Roadway
- ❑ Track Maintenance
- ❑ Planning & Analysis
- ❑ Maintenance of Way

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INTRODUCTION AND CONCLUSIONS

The Association of American Railroads (AAR) is working with the Oregon Graduate Institute to develop improved cast frog steels capable of meeting the increasing axle loads used on North American railroads. The steels are intended to be more durable, easier to cast, and easier to inspect and repair than the cast manganese steel commonly used in rail-bound frogs.

Railroads replace about 6,800 frogs annually at a cost of $120 million. An additional $120 million per year is spent on maintaining turnouts and crossing diamonds. A large share of this maintenance is expended on the frogs.

Over 1,000 bainitic frogs with a typical hardness of about 39 to 43 Rockwell C hardness (HRC) (360 to 400 Brinell) are now in use in Britain. While this low-carbon cast bainitic steel has been successful in Britain, it provides insufficient strength to resist the heavier North American axle loads. Thus, AAR work has focused on developing higher hardness bainitic steels to meet the North American requirements. The result of this effort is a medium carbon bainitic steel, for which chemistry and properties are described in Exhibit 1.

Compared to conventional austenitic manganese steel, the new bainitic steel gives the following benefits:

- Increased hardness and strength
- Better resistance to deformation
- Better wear resistance
- Fewer casting defects
- Improved weldability
- Inspectable by ultrasonic and magnetic particle techniques

Bainitic steel — though much tougher than rail steel — is not as tough as AMS. Because of this, bainitic frogs will not endure the large cracks that AMS frogs can tolerate. However, the improved castability and strength should make fatigue cracks less likely to develop in bainitic frogs.

Exhibit 1. The Chemistry of the Bainitic Frog Steel and its Properties Compared to Unhardened AMS

Bainitic alloy content, wt%						
C	Mn	Cr	Ni	Si	Mo	B
0.26	1.81	0.14	3.02	1.73	0.47	.002

		Steel	
		Bainitic	AMS
Initial hardness (Brinell)		470	170
Toughness (ft.lbs, 23°C)		19	90
Wear rate (μg/m/mm^2)	177 ksi	48	95
	247 ksi	98	236
Deformation (thousandths of an inch)	2000 cycle	0.114	29
	15000 cycle	0.150	44

BAINITIC STEEL

With microstructures midway between the relatively soft but ductile pearlite found in rails and the hard brittle phase called martensite, bainitic steels offer an attractive mixture of high strength and toughness. By alloying with molybdenum (Mo, about ½ percent) and boron (B, in trace amounts), bainitic steels can be produced in a wide range of sections by air cooling. This allows consistent properties to be obtained in large castings of complex shape, such as frogs.

Strength and toughness are controlled by the alloying additions. High strength is promoted by carbon, manganese, nickel, and chromium, though carbon has the biggest effect by far. Nickel is also used to promote toughness, which increases as sulphur and phosphorus are reduced. Silicon is used to prevent carbides and increase ductility. Some of the alloying elements are costly, but they are used in small amounts and have a minor effect on the final cost.

TEST PROGRAM

A range of wrought and cast steels were 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. Their compositions are listed in Exhibit 2.

Exhibit 2. The Range of Bainitic Steels Examined in the Development Program

Steel	Alloy content, wt%				
	C	Mn	Si	Cr	Ni
J1	0.18	2.01	1.13	1.94	0.008
J2	0.12	3.97	0.27	0.017	0.015
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	0.018	0.019
J6	0.26	2.00	1.81	1.93	0
J7	0.27	1.87	1.87	2.02	0.21
J9	0.26	1.81	1.73	0.14	3.02

A number of different tests were used to assess the performance of the steels. In addition to conventional hardness, tensile and Charpy impact measurements, wear, and deformation resistance were assessed using rolling cylinders in an Amsler machine.

For the wear tests, test steel cylinders were rolled against cylinders made of Class C wheel steel. The contact pressures (177 ksi and 247 ksi) and creepage (35 percent) were chosen to mimic the type of wear seen on the rail gage face in sharp curves. Wear was measured by weighing the specimens throughout the test, to give weight lost per meter rolled per unit area of contact. Steels with good wear resistance also should have good resistance to rolling contact fatigue because both problems result from severe flow of the metal surface.

Tests to assess deformation resistance were done at a contact pressure of 188 ksi and a creepage of 10 percent, with oil lubrication. The cylinders were yawed to cause the steel at the cylinder surface to flow sideways. 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 3 illustrates some of the wear properties measured. The wear rates of the cast bainitic steels J6, J7, and J9 are compared with rates measured for cast AMS. (Note, the AMS specimens had not been explosively hardened.)

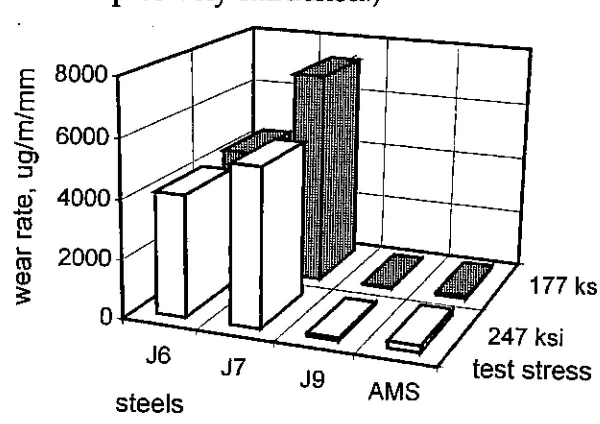

Exhibit 3. A Comparison of the Wear Rates of Cast Bainitic Steels and AMS

Although bainitic steels are not as tough as AMS, Exhibit 4 shows that the impact energy of steel J9 is broadly acceptable at the range of temperatures seen in North American service.

Steel J9, which was judged to have the best combination of properties, according to results of the laboratory testing, was chosen for full-scale development.

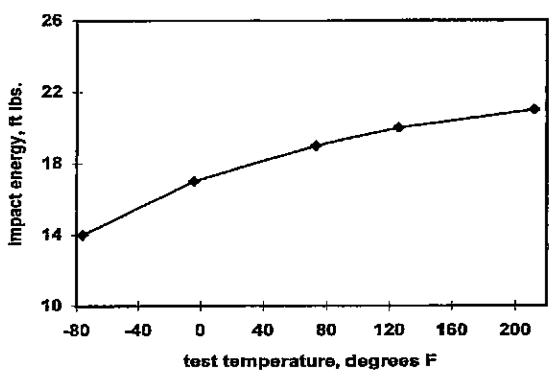

Exhibit 4. The Effect of Temperature on the Impact Energy of Steel J9 (The impact energy of rail steel at 70°F is about 3-4 ft.lbs.)

FULL-SCALE TESTS

Two rail bound frogs, with inserts cast in bainitic J9 steel, have been ordered from a supplier. The castings have been produced, and will be ultrasonically inspected and radiographed.

After inspection, one casting will be sectioned and tested to ensure that the properties achieved in small-scale casts have been reproduced in the large casting. Once the integrity of the casting is assured, the second frog will be installed at the AAR Transportation Technology Center's Facility for Accelerated Testing, Pueblo, Colorado, where its performance will be compared with a standard rail bound manganese frog.

To gain a better understanding of the properties of bainitic steels potentially suitable for rails and frogs, further large-scale laboratory work continues. In the rolling load machine, steel wear and deformation is measured under realistic wheel/rail conditions at loads up to 78 kips. Data on standard and head-hardened rail steels has been generated for comparison. Further tests with AMS are planned.

Other work uses rail coupons with gaps designed to simulate the impacts that occur when the wheel crosses the flangeway gap at a crossing diamond. Each coupon in the running rail is 24 inches long, and a four-axle, 100-ton car rolls backwards and forwards at a speed of 10 mph to 15 mph. Longitudinal and transverse profiles measure deformation.

These tests on smaller coupons allow us to evaluate frog material candidates economically. The knowledge gained from these tests is used in making full-sized frogs.

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A MORE DETAILED REPORT, WHICH MAY CONTAIN REVISED INFORMATION, MAY BE AVAILABLE AT A LATER DATE THROUGH THE AAR, PUBLICATION ORDER PROCESSING, 50 F STREET, NW, 5TH FLOOR, COG, WASHINGTON, D.C.,20001