TECHNOLOGY DIGEST

Timely Technology Transfer — 98-031

BAINITIC FROG PERFORMANCE IN HEAVY-AXLE-LOAD SERVICE

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Summary

Initial results from field testing of medium-carbon, bainitic-steel frogs suggest potential for good performance in heavy-axle-load (HAL) service. The frogs were produced from J9 bainitic steel alloy developed by the Association of American Railroads (AAR), and were tested by Transportation Technology Center, Inc. (TTCI). The wear/deformation rates in the severe loading areas of the frog wing and point were about 20 percent of the wear rates on a comparison austenitic-manganese-steel (AMS) frog. AMS is the steel most widely used to produce frogs for North American mainline service.

Although the reduced wear rate suggests good potential for J9 frogs, the testing demonstrated significant problems, including:

- The prototype No. 10 bainitic frog lasted 93 million gross tons (MGT) under the 39-kip wheel loads at the Facility for Accelerated Service Testing (FAST). The AMS casting control frog survived 150 MGT before extensive weld repair was performed to restore the running surfaces. The AMS frog remains in service.
- The bainitic frogs tested also had significant deficiencies that must be remedied before implementation on a large scale in revenue service. Both a No. 10 turnout casting and a "solid"-design, 76-degree crossing-diamond casting had significant manufacturing defects which led to their removal from service.
- The bainitic frog castings, poured from molds designed for producing AMS frogs, are oversized due to the lower shrinkage rate of J9. AMS molds also contribute to the high amounts of warpage in the heat-treated castings. Manufacturers will need to change their processes, currently optimized for AMS, to account for the differences between J9 and AMS.
- Initial attempts at weld repair of J9 frogs were unsuccessful. TTCI is working with suppliers to develop a J9 weld consumable with sufficient strength to survive under HAL service.
- Experience gained in making bainitic castings for AAR-sponsored tests is helping the industry climb a steep "learning curve." The next series of test frogs will be larger and more complex.

The tests compared wear and deformation rates of a No. 10 turnout frog with J9-alloy, bainitic-steel casting made by Rail Products and Fabrications against a standard rail-bound-manganese No. 10 frog installed in a turnout that has 98 percent mainline traffic at FAST.

Suggested Distribution:

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

Work performed by TTCI Transportation Technology Center, Inc.
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INTRODUCTION AND CONCLUSIONS

Field tests of medium-carbon, bainitic-steel frogs initially suggest good performance potential in heavy-axle-load (HAL) service. The wear/deformation rates in the severe loading areas of the frog wing and point were about 20 percent of the wear rates on a comparison austenitic-manganese-steel (AMS) frog. However, there are a number of practical problems to overcome before the technology is ready for full implementation.

The J9-alloy frog tested was developed to address the need to improve performance of high-angle frogs — both turnouts and crossing-diamonds — to counteract the effects of increased wheel loading. The industry goal is to increase frog life to the tonnage levels seen on the rail adjacent to the turnout or crossing diamond. After an initial screening of candidate frog materials, the Association of American Railroads (AAR) selected a medium-carbon alloy steel with a bainitic microstructure.

The bainitic-steel composition developed is designed to provide the following improvements over AMS, the most widely used frog material in North American mainline service:

- Higher surface hardness
- Higher bulk strength
- Improved casting quality
- Repairable
- Inspectable by ultrasonic methods

BACKGROUND

Approximately 120,000 frogs (100,000 turnouts and 5,000 crossing diamonds consisting of four frogs each) are in use on North American railroads. An estimated $400 million is spent annually on replacement and maintenance of both turnouts and crossing diamonds. Special track work (and frogs in particular) affect service reliability and line capacity. High-angle frogs have very short lives (100-200 million gross tons [MGT]) relative to conventional track or even mainline turnout frogs. In addition, frequent frog-maintenance operations require permanent or temporary slow orders causing disruptions to train service. Special track work, with lower design speeds and more frequent repairs, frequently causes traffic bottlenecks on high-tonnage lines. These delay costs can easily exceed the actual maintenance costs.

An estimated additional $450 million annually in train delay due to slow orders and track outages can be attributed to special track work. These slow orders are often imposed due to the impact loading and related damage caused by the unsupported flangeway gaps in the diamonds. The life expectancy of conventional crossing diamonds operating under HAL traffic is dramatically shortened compared to 100-ton or mixed-freight operations. Testing at the Facility for Accelerated Service Testing (FAST), under 39-kip wheel loads, has shown that conventional diamonds have very short lives (5-15 MGT). Unlike turnouts, the use of premium components in conventional-design diamonds does not restore the average life to what it was under 33-kip wheel loading.

FIELD-TEST RESULTS

A No. 10 turnout frog was installed in the FAST high-tonnage loop "frog farm" for evaluation. The test frog had a conventional rail-bound design. The casting was made to the AAR's J9 bainitic-frog-steel composition. Exhibit 1 shows the composition of the frog.

The performance of the No. 10 rail-bound frog and the 76-degree crossing-diamond corner installed in FAST will be compared to similar AMS components in similar service conditions. The five areas of improvement cited will be used to gauge performance. The J9 No. 10 frog survived 93 MGT of 39-kip wheel load traffic. AMS frogs of comparable design typically survive about 150 to 200 MGT under the same loading. The 76-degree diamond frog test was suspended after one of the AMS frogs failed in 4.6 MGT.

SURFACE HARDNESS/ BULK STRENGTH

The frogs were designed to have a higher initial surface hardness and higher internal strength than the currently used AMS. Initial deformation

Element	Specification (weight %)	#10 Frog Casting	76-Degree Casting
Carbon	0.24 - 0.27	0.24	0.27
Manganese	1.70 – 2.00	1.68	2.00
Chromium	0.00 - 0.25	0.14	—
Nickel	2.80 - 3.20	3.18	3.15
Silicon	1.60 - 1.90	2.38	1.90
Molybdenum	0.45 – 0.55	0.53	0.55
Boron	0.002 – 0.006	0.007	0.003

Exhibit 1. Bainitic Frog Composition

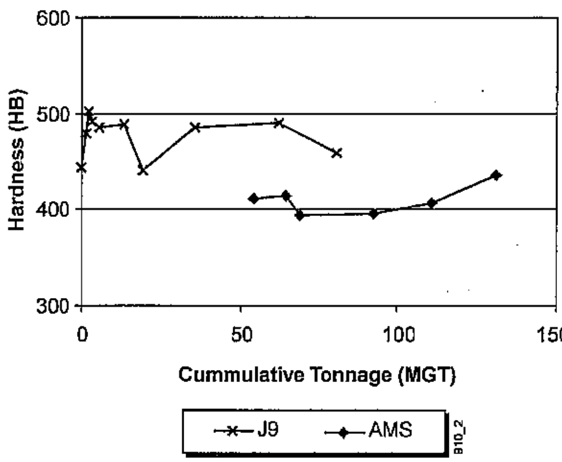

Exhibit 2. No. 10 Frog-Surface Hardness vs. Cumulative Tonnage

should be reduced as a result. Exhibit 2 shows the hardness vs. tonnage plots for the No. 10 frogs and a comparison AMS frog. The bainitic frogs did indeed start harder than the typical AMS frog, at 450 Brinell (HB) vs. about 380 HB for AMS. The rate of work hardening under the FAST train has been fairly rapid, with the frogs approaching 500 HB after 5 MGT.

Measurements of the height of the point on each No. 10 frog show that the bainitic frog is more resistant to deformation. Exhibit 3 shows the height loss vs. location for various tonnages on each frog. The bainitic frog nose is holding its shape remarkably well compared to the typical AMS frog. This improved shape retention will reduce impact loading on the frog and vehicles, as well as reduce the number of weld repair "build-ups" required over the life of the frog.

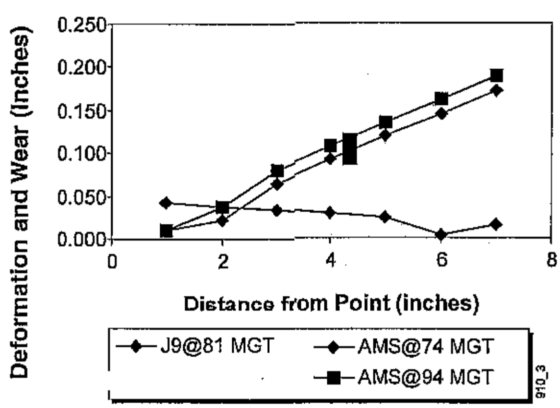

Exhibit 3. Comparison of FAST Bainitic and AMS No. 10 Frog-Point Wear

CASTING QUALITY

The soundness of the first prototype castings made of J9 has been disappointing. This alloy, with a wider freezing range, should be easier to cast than AMS. We attribute this to the inevitable learning curve associated with a new process.

The overall surface of the castings have been good. Autopsy of the No. 10 frog casting showed that it had some defects prior to placement in track. The heel areas in particular appear to have some voids, as shown in Exhibit 4. Evidence of circular areas in the heel, indicative of repair welds, was visible in several places on the casting's running surface. The crossing-diamond casting, as received, had a good surface condition. However, 2 MGT of traffic polished the running surface enough to reveal a web of interconnected surface cracks.

Magnetic particle inspection of the casting showed these cracks to be present on all surfaces of the casting. Subsequent sectioning and metallography showed that the cracking was internal as well. The cracks are tight, indicating that they are not caused by cooling shrinkage. We have concluded that the cracks are due to impact shock, such as might occur from explosive hardening.

REPAIR WELDING AND AUTOPSY

Electrode arc welding was used to repair cracks at the heel end. The J9 bainitic steel is unique and there was no commercial welding consumable available to match either its chemistry or its mechanical properties. We selected a common rail-repair welding electrode and an AWS E12018-type electrode for trial experiments because their relatively high strengths compare to other com-

Exhibit 4. Heel Cracking on No. 10 Bainitic Frog

mercially available structural steel electrodes. But the strengths were still much lower than that of J9.

The cracks were removed by grinding. During the grinding process more casting defects were found; therefore, more metal had to be removed. The repair area was preheated to prevent cracking during the welding process. The welding itself was successful. However, to no surprise, the weld metal was not strong enough to withstand the heavy wheel loads at FAST. The weld metal deformed rapidly and created new cracks. The frog was then sectioned to study its cast integrity. Recently a welding-consumable manufacturer has specially developed an electrode for J9 to match its hardness (strength). If it were available earlier, the frog might have been successfully repaired.

The autopsy of the frog revealed that numerous cracks and casting voids existed, as shown in Exhibit 5. Some cracks were initiated from the bolt holes and apparently the bolt holes were "cleaned" by arc gouging or gas cutting. Gouging and gas cutting are not the best ways to clean bolt holes. AMS is crack resistant enough to allow this practice with minimal damage. High-strength steels, however, are less forgiving. Cracks were also initiated from sharp corners or cast voids. The pattern used to make the J9 frog was designed to make AMS frogs. The excellent toughness of AMS made the very small radii forgivable; but, when a material like J9 is used, a modification of the design is probably needed. Improvement of casting integrity is also essential to fully utilize the excellent properties of J9 bainitic steel as a frog material.

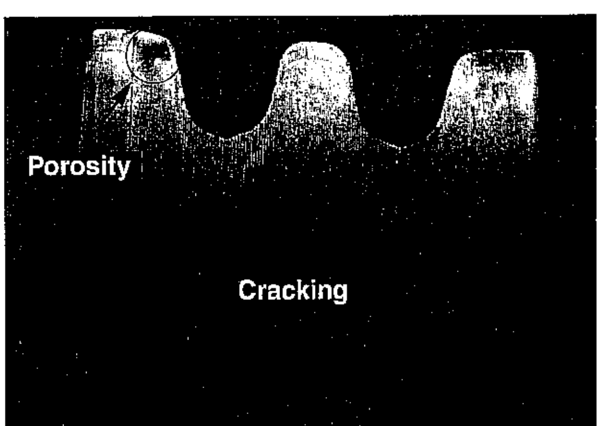

Exhibit 5. Frog Cross Section showing Porosity and Cracking

Transportation Technology Center, Inc. (TTCI), rail-inspection experts inspected the frog and bainitic test (calibration) bars before testing and, subsequently, during testing at 5 MGT intervals. The pretest inspections confirmed that the bainitic steel was inspectable. Consistent length measurements were obtained from the test bars and frogs.

Personnel who had not seen the radiography reports inspected the frog ultrasonically for defects. During this unbiased test, the ultrasonic inspections revealed the most-severe casting defects shown on the radiographs.

FUTURE WORK

Experience gained in the previous studies of bainitic frogs will be applied to the next series of test frogs for FAST. A No. 20 rail-bound frog as well as flange-bearing crossing-diamond castings in J9 steel will be tested in 1999. These products will provide suppliers with valuable experience in making large castings. The use of bainitic rail in special track work appears promising. Testing of J6 rail in crossing diamonds and switch points will continue in 1999.

ACKNOWLEDGMENTS

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A MORE DETAILED REPORT, WHICH MAY CONTAIN REVISED INFORMATION, MAY BE AVAILABLE AT A LATER DATE THROUGH AAR/TTCI, PUBLICATIONS, P.O. Box 79780, BALTIMORE, MD, 21279-0780.