

### DEVELOPMENT OF BAINITIC FROGS FOR HEAVY-AXLE-LOAD SERVICE

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TD 97-049

#### Summary

An improved bainitic frog steel for heavy-axle-load applications has been developed after a decade of collaborated work by the Association of American Railroads (AAR), Oregon Graduate Institute, member railroads, the supply industry, and AAR-affiliated research laboratories. This frog steel offers some significant benefits over the existing frog steels, such as improved deformation resistance, and ease of casting, repair, and inspection.

Turnouts and crossing-diamond frogs bear the brunt of any increase in wheel loading. In addition to the increase in static loading, the frog typically sees the highest dynamic wheel loading of any section of track. Dynamic loading of two to five times static loading has been measured on mainline turnouts and crossing diamonds.

Bainitic frogs can be made to the AAR composition by commercial foundries and shops that produce track work. Frogs tested by the AAR at the Federal Railroad Administration's Transportation Tehnology Center (TTC) were produced by suppliers of track work. These frogs meet the composition specification, have the expected hardness of 450 Brinell (HB), and meet the AREA specification for casting integrity.

Initial trials suggest that the bainitic frog steel is inspectable by ultrasonic methods. This is an important advantage over austenitic-manganese steel. Repeatable length-measurement results have been obtained on the frog. Some of the larger casting flaws such as gas pockets are detectable as well, suggesting that inspection resolution will be equal to the level accomplished with rail steel.

Field trials of this new frog steel are now in progress under 39-ton axle loads at the TTC's Facility for Accelerated Service Testing, where two No. 10 turnout frogs and a solid-design, 76-degree crossing diamond corner are currently being tested in track.

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#### Suggested Distribution:

- Research and Test
- Maintenance of Way
- Planning and Analysis
- Track Maintenance

Association of American Railroads  
Railway Technology Department

December 1997



## INTRODUCTION AND CONCLUSIONS

An improved bainitic frog steel for heavy-axle-load applications has been developed by the Association of American Railroads (AAR), Oregon Graduate Institute, member railroads, the supply industry, and AAR-affiliated research laboratories. This frog steel offers some significant benefits over the existing austenitic-manganese steels (AMS), including improved deformation resistance, ease of casting, and ease of repair.

Turnout and crossing-diamond frogs are the shortest-lived track components in the freight railroad system. Operating costs are also very high as approximately \$300 million is spent on special track work annually. Approximately 6,800 frogs are installed each year.

The simple rigid-point (gapped running surface) frog functions well in most cases because of the material used. Austenitic manganese steel (AMS), the current choice for frog materials, is an extremely tough and durable steel. AMS takes impacts well without catastrophic failure. However, it is also a relatively low-strength steel. Despite this, frog failures are seldom the cause of derailments and usually are low on the Federal Railroad Administration's list of reportable track-caused derailments.

However, as wheel loads, train speeds, and/or frog angles increase, the dynamic loading increases to the level where AMS cannot perform satisfactorily and economically. The Facility for Accelerated Service Testing (FAST) Heavy Axle Load (HAL) experiment has shown the industry the areas in which increasing axle loads from 33 tons to 39 tons will have the largest detrimental effect upon the economics of the track structure. Crossing diamond frogs are one area that has been identified. Load-measuring wheel sets at FAST have measured vertical loads that are two to five times the static load on 33- and 39-ton axle load cars, measured at speeds of 40

mph. Measurements at FAST and in the field show dynamic forces on mainline turnout frogs are from one-and-one-half to three times static load when measured at track speed. The difference in dynamic load is related to the frog angle, and to a lesser extent, speed. Above the 60-degree angle, the wheel must jump a gap and will always have an impact load caused by landing on the other side of the gap.

These high dynamic loads result in a significant foreshortening of life for the turnouts and crossing diamonds as compared to rail in open track. Additionally, the increase in wheel load from 33 kips to 39 kips caused a large decrease in lives of standard turnout frogs in tests at FAST. While no high-angle crossing diamonds were tested under the 33-kip wheel load train at FAST, testing of standard-quality high-angle diamonds under the 39-kip wheel load train produced intolerably short lives ranging from 5 to 15 million gross tons (MGT). (See TD 93-005). The average life of a high-angle diamond in revenue service is estimated to be 140 MGT.

By using premium materials and manufacturing techniques, such as elastic fasteners and high-integrity castings, the lives of turnout frogs under 39-kip wheel loads was restored to what it had been under 33-kip wheel loads. However, the lives of high-angle crossing diamonds has not been restored using these methods. Premium diamonds have lived only 15 to 30 MGT under 39-kip wheel loads (see TD 96-015). Under 39-kip wheel loads the AMS frogs are deforming much more rapidly. The deformation also extends much more deeply into the castings; well below the work-hardened layers of the material.

Thus, there appears to be a fundamental difference between the performance of turnout frogs and high-angle crossing diamonds under heavy axle loads. The low-



angle frogs can be upgraded to perform successfully, but the high-angle frogs are approaching, or have passed, an economic threshold with conventional designs and AMS. The maintenance required to keep the frogs repaired exceeds the time available for such repairs. Here, the inherent disadvantages of AMS become apparent.

The bainitic steel composition developed is designed to provide the following improvements over the currently used AMS frog material:

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

Two bainitic frogs were installed in the FAST high-tonnage loop for service evaluation. One frog is of conventional #10 rail-bound turnout frog design. This frog was produced by Rail Products. The second frog is a solid integral-base design 76-degree diamond frog. It was supplied by Cleveland Track Material. The castings were made to the AAR's J9 bainitic frog steel composition. Exhibit 1 shows the composition of the frogs.

The frogs were poured at 2,650 degrees Fahrenheit. Heat treatment consisted of a normalizing at 1,650 degrees F with fan cooling.

#### HARDNESS

The frogs were designed to have a higher initial surface hardness and higher internal strength than the currently used AMS. The AMS used in frogs has a relatively soft internal hardness of about 250 HB. The running surfaces are usually prehardened to about 380 to 400 HB by explosion hardening. This process creates a shallow layer of hardened material that rapidly decreases with depth to the bulk hardness. In contrast, the bainitic steel achieves its hardness through heat treatment. Thus, the frog will be consistently hard at any depth. The J9 steel is designed to produce a hardness of 450 HB.

Initial surface hardness measurements made on the Rail Products frog show that it is indeed in the intended range of hardnesses. Surface hardness measurements across the frog averaged 450 HB, with a range of values from 418 to 460.

#### INSPECTABILITY

AMS frogs are non-magnetic and extremely difficult to inspect ultrasonically due to their microstructure. The bainitic frogs have been

Element	Specification Minimum	Specification Maximum	#10 Turnout Frog	76-Degree Diamond Frog
C	0.24	0.27	0.24	0.25
Mn	1.70	2.00	1.68	1.92
Ni	2.80	3.20	3.18	3.20
Si	1.60	1.90	2.38	1.90
Mo	0.45	0.55	0.53	0.52
B	0.002	0.006	0.007	0.006

Exhibit 1. Bainitic Frog Composition



inspected ultrasonically by TTC personnel, and radiographically by the supplier. The bainitic frog met all AREA casting integrity specifications as confirmed by the radiographs.

TTC rail-inspection experts inspected the frog and bainitic test bars before testing and, subsequently, during testing at 3-MGT intervals. The pretest inspections confirmed that the bainitic steel was inspectable. Consistent length measurements were obtained from the test bars and frogs.

The frog was inspected for defects by personnel who had not seen the radiography reports. During this "blind" test, the ultrasonic inspections were able to find the most severe casting defects shown on the radiographs. Periodic inspections will be used to monitor the behavior of any defects found.

### BAINITIC FROG PRODUCTION

Some changes from the standard AMS frog-production process are required to efficiently produce bainitic frogs. Besides the obvious changes in chemistry, heat treatment, and pattern dimensions, the following items should be considered in changing from AMS to bainitic frog production.

**Casting patterns:** The patterns used for AMS frogs have square (sharp) corners. These corners are large stress raisers in the castings. AMS is an extremely tough material and can tolerate these stress raisers, although it is not advisable to have them. These stress raisers will cause fatigue failures in the less-tough bainitic frogs. Therefore, the patterns should be revised to eliminate the large stress raisers.

**Reduction of thermal distortion:** Reduction of warping during heat treatment is needed because, unlike AMS, the J9 casting cannot be easily bent. Development of fixturing to hold the casting straight during heat treatment is one approach. Another approach would be to redesign the cross-sectional shape of the casting to minimize warpage.

**Straightening of castings:** Due to the reduced ductility of J9, as compared to AMS, straightening frogs by bending is not advisable. With a yield strength of 145 ksi, an ultimate tensile strength of 222 ksi and the current sharp-cornered castings, it is likely that applied forces high enough to bend the casting will also crack it. Making oversized castings to allow for machining away of warpage is an interim solution.

**Machinability of castings:** AMS is difficult to machine as it rapidly dulls tools. As a result, AMS frogs are ground as needed and custom fit to rails and platework. J9 castings will be much easier to machine and should have much tighter dimensional tolerances. Use of bainitic steels will move the industry much closer to the goal of having "footprint" (interchangeable) frogs.

**Mechanical surface hardening:** Explosion hardening of castings may be eliminated. The J9 bainitic steel will have an initial hardness of approximately 450 HB after heat treatment as opposed to 380 to 400 HB for explosively hardened AMS. Explosion hardening as done for AMS would damage a bainitic frog.

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