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# Evaluation of Frog Steels for Flange-Bearing Applications

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## Summary

Transportation Technology Center, Inc. (TTCI) is evaluating steels in an effort to extend the service life of flange-bearing frog (FBF) ramps. This *Technology Digest* describes the full-scale evaluation of three candidate materials under heavy axle load service at the Facility for Accelerated Service Testing (FAST) near Pueblo, CO. The three frog materials were all commercial formulations of abrasion resistant steels. The predominant degradation mode for all materials was wear/metal flow, with little rolling contact fatigue (RCF) observed. Of the three, the superior toughness of the best performer in wear makes it less likely to fail in service from cracking. The lowest strength material had a significantly higher wear rate. The third material experienced fatigue cracking while having wear performance similar to the first material. Further evaluation of additional steel candidates is needed. A better performing steel is needed to unlock the economic potential of improved flange-bearing frog designs.

Additional information was discovered about design improvements for flange-bearing frogs. This included finish details for running surface cross section profiles. Treatment of running surface profiles at ramp entry flares should mimic the lateral flares used on guard rails.

Steels were evaluated in flange-bearing ramps using 4-foot long coupons on each rail in a specially built track panel. This allowed for a simple rectangular bar test coupon. The track panel had flange-bearing ramps at each end of the test coupon. The plate work, fasteners and guard rails were similar in design to those used in flange-bearing frog crossing diamonds used in revenue service. Cars totaling 315,000 pounds rode over the coupons at 40 mph during testing.

This *Technology Digest* is one in a series on research, development and evaluation of potential improvements to FBF crossing diamonds. The series will include frog steels, foundation designs and transverse running surface profiles. This project was conducted by TTCI under the Association of American Railroads Strategic Research Initiatives Program.



## INTRODUCTION

Flange-bearing frog (FBF) crossing diamonds and turnout frogs have proven to be beneficial for heavy axle load freight operations. The improved dynamic performance of these designs is significant in reducing required track surface and frog bolt maintenance. Reductions in crossing diamond condition-related slow orders also have been significant in locations where full FBF crossing diamonds have been implemented.

The industry is in the early stages of learning how to maximize the efficiency of flange-bearing ramp, frog, and crossing diamond system designs. This is evident in the high initial wear rates of flange-bearing ramps and frogs, and in the uneven wear and dynamic loading observed on some diamonds.

This *Technology Digest*, one in a series on the current flange-bearing research and development work, describes some of these issues and the design improvements developed in response.

### FBF Diamond Performance Issues

While FBF crossing diamonds perform well dynamically as compared to conventional tread-bearing frog crossing diamonds, there remain areas for improvement. These can include relatively rapid changes in wheel/rail contact conditions, running surface grade, track stiffness, and track alignment. Mitigating the potential deleterious effects of these necessary transitions is the goal of this project.

The train and track form a complex, dynamic system that is subject to changes in the static and dynamic properties of each. Variations in dynamic performance are manifested as uneven wear and deformation of track and running surfaces.

### Candidate Frog Materials

The goal of flange-bearing frogs is to reduce the dynamic loading for both vehicles and track. This can be accomplished through long-lived materials for the frog and no significant degradation to wheel flanges. Wheel/rail contact stress calculations suggest that contact stresses at frogs will be significantly higher than those in open track.<sup>1</sup> Thus, materials that can resist high dynamic loading, and high contact stresses, are needed for either tread-bearing or flange-bearing frog applications. The advantage of tread-bearing frogs, in this regard, is that the distribution of wheel/frog contacts likely is spread laterally over a larger area.

As with wheel/rail contact in open track, it is unlikely that a material can be found which will be both economic and strong enough to eliminate plastic deformation in frogs. Thus, a large amount of plastic deformation is expected in this application. The performance of the steels at joints and unsupported edges also will be of interest.

The FAST HTL service setting represents an accelerated test environment for track components. The car weights are mostly 315,000 pounds, with some overloads up to 340,000 pounds. However, the dynamic load environment is closely controlled, with out-of-round and tread defect wheels being removed in a timely manner. With respect to this evaluation, the small population of wheels (1 train of ~1,000 wheels) vs. revenue service (potentially ~10 million wheels) makes the evaluation less rigorous than revenue service. FAST train wheel flanges become conformal to the flange-bearing test surfaces much more quickly than in revenue service. Thus, the wear rates seen in the HTL will be about one-third of what they are currently in revenue service. Figure 1 shows a comparison of wear rates on the same steel in revenue service and at FAST. In revenue service, grooving the running surface decreased the wear rates to 60 percent of what they were with flat running surfaces. The full implementation case describes the FAST test condition where all wheels encounter flange bearing frogs frequently enough for flanges to become conformal.

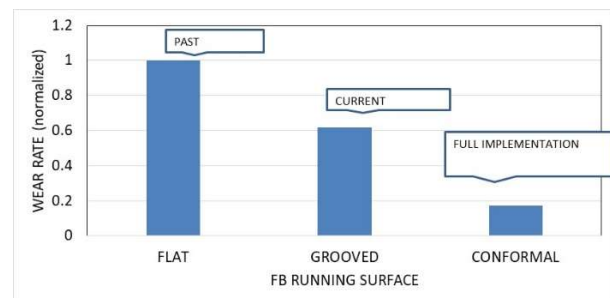


Figure 1. Flange-bearing surface wear rates for various test conditions

The FAST test is useful in making relative comparisons of materials in flange-bearing applications. This initial screening limits railroad risk in evaluating untried materials and reduces the viable candidates to a manageable number for revenue service evaluation.

The evaluations done at FAST included 4-foot long test coupons designed to simulate the running surfaces of frogs. The coupons are level in elevation with a mechanical joint at each end. The running surface has a cross sectional groove that is roughly conformal to a new wheel flange. Figure 2 shows some of the test coupons. They were roughly 2"×6"×48". Additional materials were evaluated using the flange-bearing ramps on either side of the test coupons. The design of the ramps was such that a short section of level running is present on the top end of each ramp. This zone of level running allowed evaluation of additional materials during coupon testing.



Figure 2. Flange-bearing coupon for FAST evaluation of frog materials

Three materials were tested in the level running surfaces of the track panel. This includes three sets of ramps and two sets of test coupons. The results of the tests were determined by measuring the vertical height loss of each material. Table 1 shows the engineering properties of the materials evaluated. These materials were donated by special trackwork suppliers and approved by the railroad steering committee overseeing the project. Additional candidate materials will be tested when space becomes available.

Table 1. Frog materials properties

	A	B	C
Surface hardness (BHN)	470-530	450-500	360-410
Yield Strength (ksi)	190	187	145
Tensile Strength (ksi)	225	247	181
Elongation (%)	10	11	10
Charpy v-notch at -40F	22 ft.-lbs.	18 ft.-lbs.	29 ft.-lbs.

Figure 3 shows a wear vs. tonnage plot for the two coupons tested on the same rail of the track panel. Because of differences in vehicle performance and track conditions, significant differences in dynamic wheel loading and wear were measured between the inside and outside rails of the HTL. Note that the wear rate is approximately linear, indicating there is little change in the materials shapes or hardness over time. This is confirmed by running surface hardness measurements made at the same time the profiles are measured. Figure 4 shows the running surface hardness of each material during the tests. Hardness was measured with an Equotip® device. All materials tested showed an early rise in hardness, likely due to removal of mill scale. After that they remained in a small range of hardness for the duration of the test.

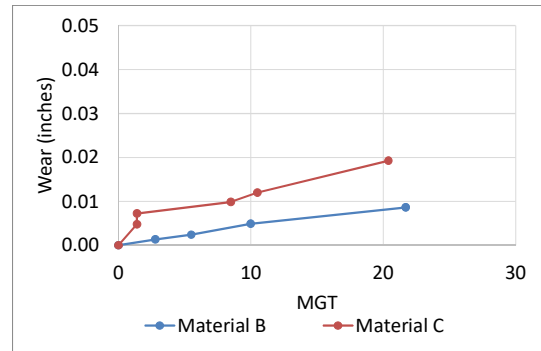


Figure 3. Height loss vs tonnage for flange-bearing coupons at FAST

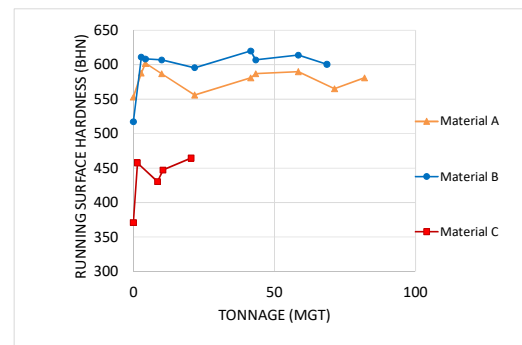


Figure 4. Running surface hardness vs. tonnage

Accounting for wear differences between locations in the test panel, a summary comparison of materials performance is presented as Table 2. Since the wear rates are fairly linear, the table also shows a projected wear life to 0.25 in. of height loss. Depending on the design used, this is a typical wear limit used in the field. This comparison shows that Material A is the best wear performance under heavy axle loads. Material B has similar performance with slightly higher wear. Material C had more than double the wear rate of the other two materials.

Table 2. Wear performance of candidate frog materials

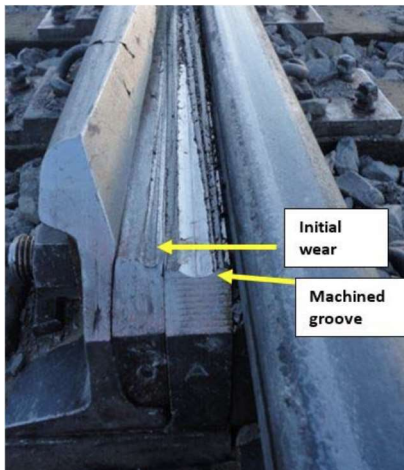
	Wear Rate (in./MGT)	Wear Rate Normalized	Wear Life (0.25 in.) MGT
Material A	0.0097	100%	652
Material B	0.0101	105%	621
Material C	0.0240	248%	263

Additionally, component failures were recorded during testing. Material B was used to build three of the six ramps used in testing. Two of the three ramps made with Material B had cracking severe enough to require replacement of the components. No other running surface components had cracking failures.

In assessing the engineering properties that contributed to the performance differences seen, the high hardness and sufficient impact toughness of Material A accounts for its better performance. Material C had lower strength and significantly higher wear rates.

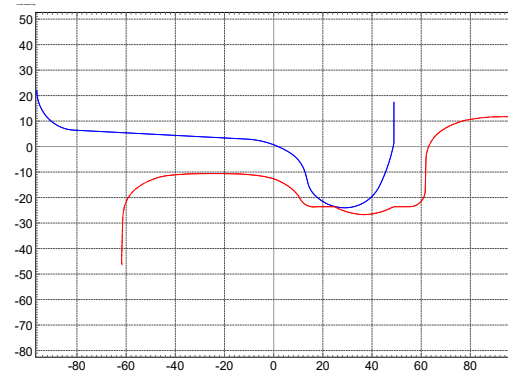
**Additional Observations**

Treatment of the ramp ends requires a running surface “funnel” that widens in correspondence with the lateral guard flare. This is best accomplished by adding a flat segment in the flangeway floor cross section profile. This will allow the guard rail to guide the wheelset to the desired path without putting larger stresses on the wheel flange tip. Figure 5 shows the wear pattern seen at FAST at the beginning of the flange-bearing ramp, where some wheelsets were not centered on the track prior to entering the flange bearing ramps.



**Figure 5. Flange bearing ramp entry wear pattern**

The edges of the cross section groove, where they meet the flat surface of the flange-bearing bar, should be chamfered to remove any sharp corners. The experience at FAST was that wheelsets that do not steer well or that have wider wheel back-to-back spacing, can have high contact stresses with the wheel flange riding on this relatively sharp corner. This condition, illustrated in Figure 6, can lead to flange tip shelling. The alternative to chamfering these groove edges is to “shelter” them out of the expected flange running band (e.g. close to guard rail) so that wheel flanges cannot reach.



**Figure 6. Potential adverse contact between flange and flange bearing ramp running surface groove edge.**

**CONCLUSIONS**

A purpose - built track panel allows the safe and efficient evaluation of candidate frog steels using simple rectangular bar test coupons. The test conditions at FAST are, however, less severe than revenue service because of the lack of wheel flange shape variations that result from a single train operating on the test track, with frequent flange-bearing.

Three high-strength steels were evaluated. From the evaluation, the best performer showed a combination of high strength and good impact resistance. Further evaluation of additional steel candidates is needed. A better performing steel is needed to unlock the economic potential of improved frog designs.

Additional lessons were learned about design improvements for flange-bearing frogs. These include finish details for running surface cross section profiles. Treatment of running surface profiles at ramp entry flares should mimic the lateral flares used on guard rails.

**ACKNOWLEDGEMENTS**

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**References**

1. Huimin Wu, David D. Davis, Rafael Jimenez, and Duane Otter, November 2016, Evaluation of Wheel-Rail Contact Stresses at Crossing Diamonds, *Technology Digest* TD16-054, TTCI, Pueblo, CO.

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