TECHNOLOGY DIGEST

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Performance Evaluation of Candidate Frog Materials: Track Laboratory Tests

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Summary

Transportation Technology Center, Inc., working in conjunction with Oregon Graduate Institute, has evaluated potential frog materials and selected the best candidate steels for both tread-bearing and flange-bearing frogs. The best candidates for conventional tread bearing frogs were steels that minimized deformation yet were tough enough to survive, including austenitic manganese steel (AMS), J7 experimental bainitic steel, and martensitic steel. Test results for candidate flange-bearing frog materials suggest that J9 bainitic steel, A1SI 4340, and AMS are good performers, as these steels showed the least deformation and no cracking during testing (*see* Exhibit 1 for a list of the proporties of candidate frog materials.)

The initial screening involved literature review and small-scale fatigue and wear tests. Promising candidates were then selected for coupon tests under full-scale traffic in TTCI's Track Laboratory at the Federal Railroad Administration's Transportation Technology Center. Evaluations of both tread-bearing and flange-bearing frog materials were conducted simultaneously with gapped and flange-bearing coupons. The following types of steel were the candidate frog materials evaluated in the Track Laboratory:

- Hadfield's austenitic manganese steel
- Head-hardened rail steel and laser-hardened rail steel of pearlitic composition
- Bainitic steel with 0.25 carbon, molybdenum composition
- High-strength martensitic steels with 450-500 Bhn hardness
- High-alloy nickel maraging steel
- Cast iron for flange-bearing applications

The need for increased speeds and axle loads is driving the research and development effort for improved performance frog steels. The currently used material, AMS, can experience significant large deformations and degradation from frequent weld repairs. The issues are economic, as the railroads wish to increase frog life (maintenance cycles), operating speeds, and track capacity. Based on the initial results of the laboratory and track lab testing, turnout and crossing diamond frogs have been made using J9 bainitic steel castings and J6 bainitic steel rails. The full-scale tests are being conducted at the Facility for Accelerated Service Testing (FAST) under 39 kip wheel loads. Full-scale testing of other promising materials is planned.

Suggested Distribution:

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

Work performed by TTCI Transportation Technology Center, Inc.
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INTRODUCTION

Working with Oregon Graduate Institute (OGI), TTCI has evaluated potential frog materials. A multi-level process was employed. The initial screening involved literature review and small-scale fatigue and wear tests. Promising candidates were then selected for coupon tests under full-scale traffic in the Track Laboratory at the FRA's Transportation Technology Center. Evaluations of both tread- and flange-bearing frog materials were conducted simultaneously with gapped and flange-bearing coupons. The following types of steel were the candidate frog materials evaluated in the Track Laboratory:

- Hadfield's austenitic manganese steel (AMS)
- Head-hardened rail steel and laser-hardened rail steel of pearlitic composition (Rail Steel HH, LH-1075)
- Bainitic steel with 0.25 carbon, molybdenum -boron composition (J7, J9)
- High-strength martensitic steels with 450-500 Bhn hardness (A1SI 4340, NS-450 and 12-S)
- High-alloy nickel maraging steel (Aeromet-100)
- Cast iron for flange-bearing applications

The best candidates for conventional tread bearing frogs were steels that minimized deformation yet were tough enough to survive. These included: AMS, J7 bainitic steel, and a 12-S martensitic steel. The results are based on a 60,000 car (approximately 8 million gross ton (MGT) test period in the Track Lab. These materials had the lowest initial deformation and good long-term wear rates. No cracking was observed in these materials. A 4340 (martensitic) steel also performed well. A dispersion-hardened AMS, a nickel maraging steel, Aeromet 100, and a martensitic steel, NS-450, had higher wear and flow rates than the best performers.

Test results for candidate flange-bearing frog materials suggest that J9 bainitic steel, 4340, and AMS are good performers. These steels showed the least deformation and no cracking during testing. The projected wear lives of these three steels, after 10 MGT of operation, are 705, 628 and 532 MGT, respectively, for a 0.25-inch wear life. Less successful materials were laser-hardened rail steel, a martensitic steel, and cast iron with wear lives of less than 200 MGT.

Frog materials tests are conducted using test coupons in a special facility developed by the Association of American Railroads (AAR). The Track Laboratory, now owned by TTCI, uses a self-propelled freight car with 33-kip wheel loads to apply tonnage to a 40-foot-long test track. Frog material test coupons are installed in track in two coupon holders. One resembles a 90-degree crossing diamond, complete with flangeway gaps. The other simulates a low-speed flange-bearing frog diamond.

CANDIDATE MATERIALS

Candidate materials were selected for testing on the basis of somewhat arbitrary requirements. We know from experience the properties of materials that are at least moderately successful in the field. Yet, we have not accurately defined the frog loading environment; nor have we developed (and verified) a reliable model that will predict the performance of a material in revenue service frogs. Until that is accomplished, testing provides the best approach.

OGI's work with small-scale roller specimens appears to provide good relative comparisons of material wear/deformation performance. This is the first level of testing for candidate materials. The TTCI Track Laboratory provides full-scale testing of materials without the costs of making an actual frog. Exhibit 1 lists the properties of candidate materials evaluated in the Track Laboratory.

Material Name	Steel Type	Nominal Hardness (HB)	Tensile Strength (ksi)	Toughness (Charpy V@70F)
AMS (EDH) Explosively hardened	AMS	380 (surface) 200 (internal)	106	120
Rail Steel (HH)	Pearlitic	370	175	5
AMS (DH) Dispersion-Hardened	AMS	250	120	120
J7	Bainitic	430	220	20
J9	Bainitic	450	220	30
NS-450	Martensitic	450	210	14
4340	Martensitic	500	235	10
12-S	Martensitic	450	230	15
Aeromet-100	Maraging	500	290	5
Cast Iron	Cast iron	600	N/A	N/A
Laser-Hardened 1075	Pearlitic	600	140	5

Exhibit 1. Properties of Candidate Frog Materials

MATERIAL PERFORMANCE EVALUATION

The performance of each frog material is shown in Exhibits 2 and 3 under tread-bearing and flange-bearing conditions. Each material is compared to explosively hardened AMS, the current standard frog material.

For tread-bearing applications, toughness, and resistance to deformation under impacts are important. Wear and deformation were measured by comparing a time series of longitudinal and transverse profiles on each coupon. Flow was defined as material that appeared outside of the original profile. Wear or metal loss was defined as metal loss within the original profile. Exhibit 4 shows the metal loss and flow of each coupon at 30,000 cycles.

Material Name	Steel Type	Initial Hardness (HB)	Cross Metal Loss Rate (sq.mm/mgt)	Relative Performance (100=AMS)	Cracking Occurence
AMS (EDH)	AMS	380	3.87	100	N
AMS (DH)	AMS	250	14.47	27	N
J7	Bainitic	430	2.41	161	N
J9 weld	Bainitic	410	7.48	52	N
NS-450	Martensitic	450	14.38	27	N
4340	Martensitic	500	8.16	79	Y*
12-S	Martensitic	450	4.91	37	N
Aeromet-100	Maraging	500	10.43	47	N

*After 30,000 additional cycles

Exhibit 2. Relative Performance of Candidate Tread-Bearing Frog Materials at 30,0000 cycles (8 MGT)

Material Name	Steel Type	Initial Hardness (HB)	Projected Wear Life (0.25" mgt)	Relative Performance (100=AMS)	Cracking Occurrence
AMS (EDH)	AMS	380	532	100	N
Rail Steel (1050)	Pearlitic	300	318	60	N
Laser Hrdned. 1075	Pearlitic w/ glass surface	700	72	14	Y
J9	Bainitic	450	705	133	N
4340	Martensitic	300	94	18	N
4340	Martensitic	500	628	118	N
12-S	Martensitic	450	179	34	N
Cast Iron	Cast Iron	650	175	33	N

Exhibit 3. Relative Performance of Candidate Flange-Bearing Frog Materials at 30,000 cycles (8 MGT)

For flange-bearing applications, impact resistance is not as important as rolling load deformation resistance. Under these conditions, Bainitic J9, Martensitic 4340 (hardened to 500 Bhn) and AMS have been the best performers. The softest and hardest materials have inferior performance compared to these three. The softest materials have flowed significantly and will have a short wear life. The hardest materials have surface fatigue. The LH-1075 steel had considerable deformation below the thin hardened layer. The surface treatment also began to crack. Exhibit 5 shows the average height loss of each coupon.

Keep in mind that the Track Laboratory flange-bearing test results provide a relative ranking of the performance of candidate materials. The test conditions are not as severe as the likely field conditions

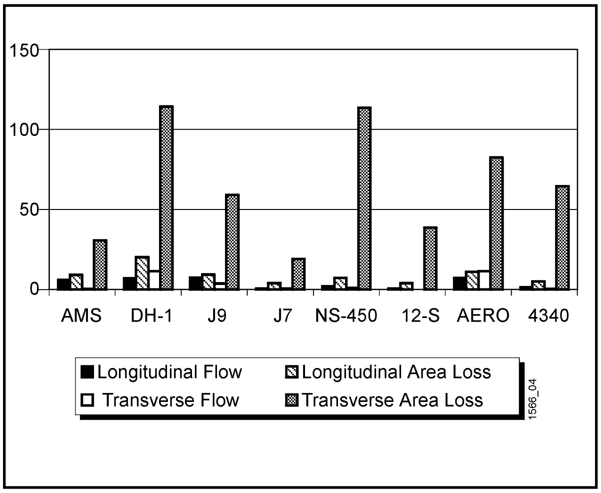

Exhibit 4. Tread-Bearing Coupon Wear and Flow Performance

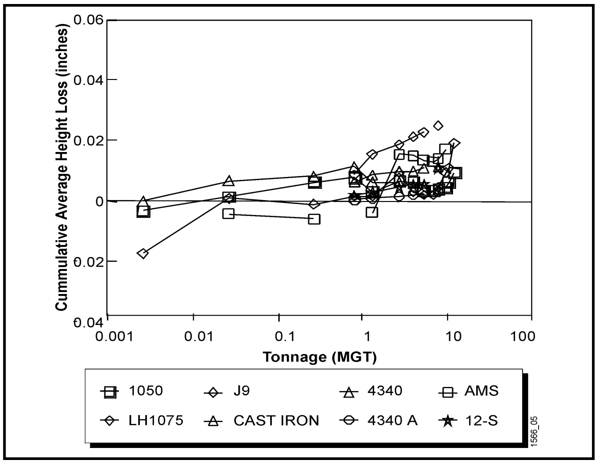

Exhibit 5. Deformation Performance of Flange Bearing Coupons

because the single track vehicle's wheels deform to become conformal to the test coupons, thereby lowering the contact stress in the running surfaces.

TEST CONFIGURATION

Tests were conducted using coupons and fixturing developed by AAR for frog materials evaluation. Test coupons were 24 inches long and roughly the shape of a railhead, with a flat base. The coupons have grooved sides, which allow them to be clamped to a base. The base has a structure similar to a 90-degree crossing diamond. Four coupons can be tested at one time. Each coupon has a flangeway cut into the running surface and is placed where flangeway gaps would be in a conventional 90-degree diamond.

To compensate for the relatively low speeds attainable in the Track Laboratory, the flangeway gaps were widened from the conventional 1 7/8 inch to 2 1/2 inch. NUCARS analysis of a 33-kip wheel load freight car suggested that a 2 1/4-inch gap would produce dynamic forces at 10 mph equivalent to the forces seen on a 1 7/8-inch gap at 40 mph (i.e., about 60 kips).

TRACK LABORATORY

The Track Laboratory is a self-contained track testing facility at TTC. The facility consists of a powered 263,000-pound freight car and a 40-foot track testing area. Loading can be applied by stationary load jacks or by the test car. The test car, powered by end-of-axle hydraulic motors, moves back and forth over the test track, changing direction of travel on vertical ramps at both ends of the test track. The car is configured to represent the axle spacing of the ends of two 100-ton hopper cars coupled together. With axle spacing of 70, 80, and 70 inches, this is the most severe loading condition encountered by the track for conventional 4-axle freight cars.

The vehicle has standard freight car components, such as three-piece trucks, with the exception of the truck bolsters. These are modified to allow the trucks to pivot as the car enters and exits the ramps. A maximum speed range of 0 to about 12 mph is possible under normal operations. The speed varies from 0 (at the highest point on each ramp) to the maximum (at the far end of the flat test track section) on each cycle. The optimal maximum speed for maximizing load cycles per hour is about 9 mph. At higher speed the car simply spends more time on the ramps.

The track lab materials evaluations described above have contributed to the three-stage process of evaluating frog materials for HAL service under the AAR research program. The track lab provides the middle stage of evaluation — subjecting test coupons of promising materials to full-scale traffic. This allows AAR to evaluate more materials under real loading conditions without the expense and delay of having to make frog castings.

FUTURE WORK

Full scale crossing diamond and turnout frog tests are planned for revenue service and/or FAST. These include J6 and J9 bainitic steels and NS-450 in tread bearing applications. An AMS flange bearing frog diamond will be tested in FAST.

Note: Please contact Dave Davis at (719) 584-0754 with questions or comments about this document.

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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.