ABSTRACT
The evaluation of track components to enhance their safety and utility under heavy axle loads has continued at the Facility for Accelerated Service Testing (FAST), Pueblo, Colorado.

A test of premium rails developed to provide better wear and rolling contact fatigue (RCF) resistance that began in 2010 was concluded at the end of 2013. Rails produced in Europe, North America, and Asia were included. Differences among the various rail types in wear and in the development of RCF were evident. Intermediate strength rails are also being tested; one portion of the test was concluded earlier than planned due to shelling on the gage corner of the high rail.

Innovative rail welding methods developed by various suppliers are being evaluated. Electric-flash head repair welds have accumulated up to 449 MGT. Prototype welds made in-shop performed better than welds made in the field. Head-alloyed thermite welds and treatment of the heat-affected zones associated with thermite welds are also being evaluated.

Testing of wood ties has confirmed differences in performance based on tie type (hard or soft wood) and fastener type (cut spike or elastic) after 800 MGT. Concrete ties being tested in the same curve provide a basis for comparison. Enhanced design concrete ties are also being tested as part of an effort to evaluate improved performance track.

INTRODUCTION
The evaluation of track components and structures at the Facility for Accelerated Service Testing (FAST) has been a major part of the Association of American Railroads’ Strategic Research Initiatives Program, but testing at FAST continues to evolve to meet the changing needs of the industry. The experiments and tests that are conducted at FAST are regularly reviewed by industry research committees to ensure that they are meeting current needs and are preparing the way for future requirements. Though the types of components being tested may be similar to those that were tested several years ago, current tests reflect industry needs as railroads continue to improve the safety and efficiency of their businesses.

The 315,000-pound gross rail load operating train at FAST is currently comprised of 110 aluminum coal cars and three EMD SD 70M/MAC locomotives (Figure 1).

Figure 1. Test Train at FAST
The test train at FAST is operated on the High Tonnage Loop (HTL), a 2.7-mile track made up of tangents, short spirals, and 5- and 6-degree curves (Figure 2). Train operating speed is 40 mph, which results in overbalanced speed operations; the curves are balanced at about 33 mph. Operation is bi-directional, with approximately 50 percent in each direction.
EXPERIMENTS AT FAST
Rail Performance Evaluation

Rail tests have been an important part of the FAST program since its inception. These tests provide information that railroads can use in purchasing and utilization decisions, and that suppliers can use to improve their products. Because U.S. railroads are spending more than $3 billion per year (Class I Railroad Annual Reports) to renew and maintain rail, increasing the service life and decreasing the life-cycle costs of modern rail steels is very important. Testing in the controlled and well-maintained environment of FAST allows for accelerated testing while minimizing test variables.

Premium Rail

A test of premium rails that began in 2010 and ended in 2013 included nine high-hardness (413 HB average) premium rails from manufacturers in North America, Europe, and Asia. Table 1 lists the suppliers and types of premium test rails. The premium rails were installed in a 5-degree nonlubricated curve (Section 7 in Figure 1).

Table 1. Premium Test Rails

<table>
<thead>
<tr>
<th>Supplier</th>
<th>Rail Type(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corus Rail Mill (France)</td>
<td>MHH HE Mill Head Hardened Hypereutectoid</td>
</tr>
<tr>
<td>ERMS Rail Mill (USA)</td>
<td>OCP 1-Percent Carbon</td>
</tr>
<tr>
<td>JFE Rail Mill (Japan)</td>
<td>SP2, SP3 Super Pearlite 2 &amp; 3</td>
</tr>
<tr>
<td>Mittal Rail Mill (USA)</td>
<td>HC High Carbon</td>
</tr>
<tr>
<td>Nippon Rail Mill (Japan)</td>
<td>HE-X Hypereutectoid X</td>
</tr>
<tr>
<td>Panzhihua Rail Mill (China)</td>
<td>PG4 Panzhihua Iron and Steel (Group)</td>
</tr>
<tr>
<td>Voestalpine Rail Mill (Austria)</td>
<td>VAS 1, VAS 2, voestalpine 1 &amp; 2</td>
</tr>
</tbody>
</table>
Primary performance metrics during the test were wear performance, development of rolling contact fatigue (RCF), and fatigue defects/rail breaks. Figure 3 shows rail wear (area loss) for the rails on the high rail of the curve after 559 MGT.

![Figure 3. Premium Rail Wear](image)

Statistical analysis of rail wear indicates that three rail types, VAS-2, PG4, and ERMS, wore more than the HEX control rail. None of the rails wore less than HEX rail. The VAS-1 rail wear results are not shown in Figure 3 because all of the VAS-1 rail wear measurement sites, except one, were lost during the test due to rail and weld breaks. As a result, wear for this rail type could not be compared statistically to the HEX rail. Figure 4 shows typical rail wear in the premium rail test curve. The wear is predominantly on the gage face because the curve does not receive gage face lubrication.

![Figure 4. Typical Premium Test Rail Profile after 559 MGT](image)

All rail types developed RCF, but some rails developed it earlier and more extensively than other rails. Previous studies have postulated that there could be a correlation between the amount cementite (Fe₃C) at the grain boundaries of rail steel, and the development of RCF [1]. Rail condition (amount and severity of RCF) was assessed visually during the test. Figure 5 shows the results of that assessment and the relationship to the amount of cementite in the rails.
This preliminary and limited analysis supports the hypothesis that increased cementite at the grain boundaries can increase a rail’s susceptibility to develop RCF, but more study is needed and is planned. A more accurate and less subjective (machine-based) quantification of RCF will be related to cementite content.

There were no railhead shells or railhead fatigue defects resulting in rail breaks. There were three rail breaks that initiated at the base of the rail. All of the base defects initiated at contact points between the field side of the high rail of the curve and tie plates. There were not enough breaks to say whether any of the rail types was more susceptible to breaks than the other types.

A new premium rail test began in early 2014. Six rail types from six suppliers (Table 2) were installed in the same test curve as for the previous test. These rails have only accumulated 84 MGT as of June 5, therefore it is too early to report meaningful results.

### Table 2. New Premium Rails Being Tested

<table>
<thead>
<tr>
<th>Supplier</th>
<th>Rail Type</th>
</tr>
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<tbody>
<tr>
<td>Panzhihua China</td>
<td>PZH</td>
</tr>
<tr>
<td>Tata Steel France</td>
<td>MHHP</td>
</tr>
<tr>
<td>voestalpine Austria</td>
<td>UHC</td>
</tr>
<tr>
<td>JFE Steel Japan</td>
<td>JFE-C</td>
</tr>
<tr>
<td>Nippon Steel Japan</td>
<td>HE-X</td>
</tr>
<tr>
<td>ArcelorMittal USA</td>
<td>AHH</td>
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</tbody>
</table>

**Intermediate Strength Rail**

Intermediate strength and hardness (340 HB average) rails from several manufacturers were installed for testing in a lubricated 5-degree curve (Section 3 in Figure 2) in 2010. Table 3 lists the types of the intermediate strength test rails and the suppliers. These rails are intended to provide satisfactory performance under moderately demanding conditions, but at a lower cost than premium rail.
### Table 3. Intermediate Strength Test Rails

<table>
<thead>
<tr>
<th>Supplier</th>
<th>Rail Type(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corus Rail Mill (France) – 1 grade: MHH HE (as rolled)</td>
<td>MHH HE (non-head hardened) Mill Head Hardened Hypereutectoid</td>
</tr>
<tr>
<td>ERMS Rail Mill (USA)</td>
<td>IH, IH HS, SS Intermediate Hardness, Intermediate Hardness High Strength, Standard Strength</td>
</tr>
<tr>
<td>Lucchini Rail Mill (Italy)</td>
<td>IH Intermediate Hardness</td>
</tr>
<tr>
<td>Mittal Rail Mill (USA)</td>
<td>ML Mittal's Grado MicoAleado AM Asturias</td>
</tr>
<tr>
<td>Panzhihua Rail Mill (China)</td>
<td>PG4 (non-head hardened) Panzhihua Iron and Steel (Group)</td>
</tr>
<tr>
<td>Trinecké Zelezárny Rail Mill (Czech Republic)</td>
<td>TZ Trinecké Zelezáry</td>
</tr>
</tbody>
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The test of these rails ended in 2012 after numerous shells developed in the high rail between 340 and 380 MGT. Figure 6 shows the number of shells that each rail type developed, the typical shell type, and the railhead location where the shells developed.

![High-Rail Gage-Corner Shelling in Intermediate Strength Rails](image)

Microstructural analysis of the shell origin cross-sections did not reveal microstructures at the shell initiation points different from the bulk rail microstructure. No discontinuities (e.g., inclusions, porosity, cracks) that might have contributed to shell initiation were detected.

Rail wear was low in the test curve because of effective gage face lubrication; the maximum area loss was approximately 0.22 square inches after 340 MGT. And, the rail was not ground after tonnage accumulation began. Because the rail profile remained relatively consistent over time, the railhead was subjected to a consistent stress environment (location and magnitude). TTCI researchers believe that the consistent stress environment led to the development of the shells. Detailed results of the intermediate strength (IS) rail test can be found in TTCI’s Technology Digest TD14-010 [2].
A new IS rail test started in 2012 in the same curve. Mechanical properties of these rails are similar to those in the first test; some of the same types that were in the first test are included. The primary difference between the first and second test is the implementation of preventive grinding every 50 MGT to manage wheel/rail contact conditions to inhibit the development of gage corner shelling, and to more closely represent current railroad grinding practices. Current tonnage accumulation is 260 MGT, and no shelling has been observed.

Rail Welding

Electric-Flash Railhead Repair Welds

Current methods for repairing railhead defects in North America generally involve cutting out the section of rail containing the defect and replacing the removed section with either a rail plug and two welds, or a single weld if the defect is narrow enough. This practice typically alters the rail stress-free temperature and introduces weld material into the full-rail cross section. Railhead repair welds, however, enable the repair of narrow head defects in rail by removing the head defect without cutting through the full-rail section. This preserves the rail stress-free temperature and leaves the web and base of the rail intact. Thermite head-repair welds were tested at FAST during the previous decade [3].

In December 2010 and January 2011, Holland Company and EWI produced electric-flash head-defect repair (HDR) welds in-shop. The welds were made in short rail plugs that were then sent to the Transportation Technology Center for installation at FAST. Six HDR welds were installed in the high rail of a 5-degree curve (Section 3) and two were installed in the low rail. In September 2011, Holland sent a mobile weld truck with a prototype HDR welder head to install test welds in the HTL. Eight welds were installed in Section 3 — five in the high rail and three in the low rail. Figure 7 shows a railhead with a notch removed for repair; and the rail after the repair was complete.

Figure 7. Electric Flash Head Defect Repair (HDR) Weld

After installation, the shop welded inserts had running surface hardness values near 410 Brinell hardness (HB), and the mobile unit weld inserts had hardness values near 360 HB. The difference in hardness affected the rates of surface degradation and metal flow. Figure 8 shows the profiles for one of the welds made in the shop, and Figure 9 shows the profiles for one of the mobile unit in-track welds.
Dipping of the mobile unit weld inserts was more than twice that of the shop-produced welds after approximately 100 MGT of traffic. None of the original lab generated welds failed in service through 449 MGT of traffic. Two of the eight mobile-unit produced welds were removed for non-test related maintenance on the track, and three were removed because of fatigue fractures that developed while in service. One weld was identified by rail flaw detection to have a fatigue crack and was removed from service. Of the four welds that had fatigue cracking, three of these initiated at geometry transitions under the railhead, which produced stress concentrations. The bottom of the railhead is a high
stress region in standard rail weld types, thermite railhead repair welds, and rails. This makes it more critical that stress concentrations in the bottom of railheads be minimized or eliminated. The fourth fatigue crack initiated under the railhead at a defect near the center of the insert. Detailed results of the HDR weld test can be found in Technology Digest 14-002 [4].

A new test of Holland HDR welds started in March 2014 with in-track welds. The hardness of the insert was increased, the heat input from the weld head was modified, the weld shear was improved to better match the shape of the railhead, and extra care was given for providing a smooth grind under the railhead. These steps are intended to address the failure modes that were identified during the first test.

**Heat-Affected Zone Treatment and Head Alloyed Thermite Welds**

Under heavy axle load (HAL) service conditions, the running surface of thermite welds can rapidly degrade, resulting in weld failures or extra maintenance. The degradation occurs both in the softer (relative to premium rail) weld material and in the heat affected zones (HAZ) of the rail that are adjacent to the weld. TTCI investigated several methods of reducing HAZ softening. The method judged to be the most practical and effective is a HAZ overlay treatment. The treatment consists of applying a weld bead with commercially available rail-repair electrodes to the rail adjacent to the weld, over the region where the soft HAZ forms. This is done while the thermite weld is still hot in order to make use of the thermite weld heat as preheat for the overlay welding. The result of the treatment was a modified HAZ shape near the running surface of the rail that reduced the size of the softened HAZ by 44 percent.

TTCI installed 21 test welds in the high rail of Section 31, a 5-degree curve, in the HTL in July 2012. The test welds included treated and untreated thermite welds from two different manufacturers. Additionally the test included a group of head alloyed thermite welds that were treated. The head-alloying process produces welds with hardness at the center running surface of the weld of approximately 390 HB, closely matching the hardness of premium rail, and about 50 HB harder than standard thermite welds.

Two welds had been removed as of April 2014 when the welds had accumulated 130 MGT. The first weld, a HAZ-treated weld, was removed because of an unrelated nearby rail break. TTCI replaced the weld with a new weld and applied HAZ treatment. The second weld was an untreated weld that broke from a fatigue crack that initiated in the base/web radius near the edge of the weld collar.

Longitudinal profiles at the centerline of the rail over the weld were measured. Figures 10, 11, and 12, respectively, show a standard thermite weld without HAZ treatment, a standard thermite weld with HAZ treatment, and a head-alloyed thermite weld with HAZ treatment.
Figure 10. Standard Thermite Weld without HAZ Treatment

Figure 11. Standard Thermite Weld with HAZ Treatment
Figures 10 and 11 show that the HAZ-treated weld developed less batter in the HAZ and in the weld. The HAZ overlay does not directly affect the thermite metal properties; however, from the two sets of profiles, it is apparent that the overlay does affect the rate of batter at the weld centerline. This is likely due to a reduction in dynamic forces experienced by the weld because of a smoother transition across the weld running surface. Figure 12 shows that the combination of the two processes produced welds with the least amount of overall batter at the running surface. Detailed results of the weld HAZ treatment test can be found in *Technology Digest* 14-003 [5].

The effects of higher hardness head-alloyed welds and HAZ treatment on long-term weld life has not yet been quantified, but early results are promising. Tests at FAST and in revenue service will continue.

**Improved Strength Track**

The trend toward heavier, faster, and longer trains is demanding more of the track structure. Passenger trains and their attendant track-geometry requirements are sharing tracks with freight trains in increasing numbers. Maintenance windows will become even shorter as traffic increases. Improved types of track structures and improved tie and fastener systems are needed to meet the increased demand. New-design, heavy-duty concrete ties and state-of-the practice conventional concrete ties were installed at FAST as part of a test of improved strength track. The half-frame ties (Figure 13) have larger vertical and lateral footprints than conventional ties and have integral under-tie pads.
Figure 13. Improved Strength Track with Heavy Duty Ties

These ties have been in track at FAST for almost 700 MGT. The track surface degradation rate for the half-frame tie track is approximately 20 percent of the rate for conventional concrete tie track. Preliminary testing also showed less ballast degradation under the half-frame ties. A more detailed analysis of ballast gradations under the various tie types is under way. Earlier testing showed that the half-frame tie track is very stable laterally. Single tie push tests showed that it takes more than two times the force to push the half-frame ties laterally through the ballast compared to conventional ties. Positive results of testing at FAST led to revenue service testing. Adoption of this innovative design will likely be driven by economics, availability, and maintenance issues. Performance has been good.

Ties and Fasteners

Over 1,000 hardwood, softwood, and concrete ties were installed at FAST in 2009. The ties have now accumulated over 800 MGT. Track gage strength was recently measured using the Light-Weight Track Loading Fixture (LTLF). The LTLF applies a 9,000-pound load, typically at the web of the rail just below the head. For this test, both web- and head-applied loads were used. The test confirmed previous results [6]. Gage restraint provided by hardwood ties with elastic fasteners is still similar to that provided by concrete ties. Both provide about three times the gage restraint of ties with AREMA 14-inch cut-spike plates and twice as much as ties with AREMA 18-inch cut spike plates. There are over 20 configurations of tie and fastener type. Figure 14 shows several representative results.
Figure 14. Gage Strength of Selected Tie and Fastener Combinations

CONCLUSION

Railroads, suppliers, and researchers are continuing their collaborative efforts to develop cost-effective ways to safely increase capacity. FAST provides the industry with a valuable facility for the development and evaluation of innovative track components. It provides a facility for testing components with the unproven potential to provide improved performance. Tests are regularly updated at the direction of railroad committees to ensure that the SRI program meets the changing needs of the industry.

REFERENCES


Figure 1. Test Train at FAST
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Figure 5. Premium Rail RCF Assessment
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Figure 9. Longitudinal Running Surface Profiles of In-Track Weld
Figure 10. Standard Thermite Weld without HAZ Treatment
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Figure 12. Head-Alloyed Weld with HAZ Treatment
Figure 13. Improved Strength Track with Heavy Duty Ties
Figure 14. Gage Strength of Selected Tie and Fastener Combinations

Table 1. Premium Test Rails
Table 2. New Premium Rails Being Tested
Table 3. Intermediate Strength Test Rails
Field Evaluation of Improved Track Components Under Heavy Axle Loads

Joseph A. LoPresti
Transportation Technology Center, Inc.
Heavy Axle Loads

Why HAL:
• Increased demand for rail transportation will increase need for additional capacity
• Heavier axle loads, and improved track reliability are ways to increase capacity
• Heavy axle loads decrease operating costs but increase demands on track

FAST

Why FAST (Facility for Accelerated Service Testing):
• FAST/HAL objective: Investigate performance of improved track components for HAL
  – Controlled, accelerated test environment
  – Provide information to help RRs increase capacity; and improve safety, reliability, and efficiency
• Current and future axle loads

FAST High Tonnage Loop

• 3 SD70 M or MAC locos and ≈ 110 cars
• 7.5 MGT/week
• 134 MGT in 2013, 108 currently, expect 135 in 2014

Rail Evaluations

• 8 intermediate strength (IS) rail types 2010 – mid 2012
• 6 IS rail types, mid 2012

Premium Rail

• Pearlitic microstructure
• 413 HB average hardness

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<td>Mittal Rail Mill (USA)</td>
<td>HC High Carbon</td>
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</tbody>
</table>
**Premium Rail - Wear**

- **Quartiles:** Min, 1st, 2nd, 3rd, Max
- **Medians:** Softest to hardest, left to right

**Quantitative Assessment of Fe3C**

- Lab work showed that grain boundary cementite could reduce resistance to RCF crack growth
- Picral etch to reveal cementite boundaries
- SEM at NS to quantify cementite

**Premium Rail - RCF**

- Fe3C at Grain Boundaries
- No Fe3C at Grain Boundaries

**Intermediate Strength Rail**

- Pearlitic microstructure
- 340 HB average

**IS Rails – Gage Corner Shells**

First test of IS rail ended in 2012

- 18 high-rail, gage-corner shells
- 800 track feet, 340 – 380 MGT

**IS Rail – Gage Corner Shells**

Shelling Mechanism

- Analysis did not reveal a root cause
  - No discontinuities, similar microstructure
  - Gage face lubrication, low wear rates, consistent stress field
  - Material properties (premium rail in the same curve did not develop shells at the same rate)
  - Mitigation: Preventive grinding every 50 MGT (current test)
Railhead Repair Welds

- Defect in railhead removed, web & base remain intact
- Thermite railhead repairs welds previously tested and reported
- Electric flash head repair welds currently being tested
  - HDR (Head Defect Repair) Developed by Holland Company and EWI

EF Railhead Repair Welds (HDR)

- Notch removed for repair
- Completed repair

- Three tests at FAST
  - 6 shop-made welds 2011
  - 8 in-track welds 2011
  - 10 in-track welds 2014

EF Railhead Repair Welds (HDR)

- 2011 welds
  - Shop welded inserts 410 HB
  - In-track inserts 360 HB

- 2011 welds
  - 0.01 ace (in)
  - Longitudinal Running Surface Profiles | HDR 10
  
  - Distance from Insert Centerline (in)
  
  - Variation from Rail Running Surf

EF Railhead Repair Welds (HDR)

- 2014 welds
  - Harder inserts, modified heat input, shearing and grinding to minimize stress concentrations
  - 85 MGT, no problems

Thermite Weld Hardness

- Thermite welds and associated heat affected zones (HAZ) can be softer than parent rail
  - Difference is greater in high-hardness premium rail
Thermite Weld Optimization

- Head-alloyed welds to increase head hardness – ductility of web and base maintained
- Weld overlay to minimize HAZ

Orgo-Thermit Head Alloy Plug
Results in weld hardness = 390 HB
Made after shearing while weld and rail are still hot
HAZ weld and thermite weld ground

• One treated weld removed due to unrelated rail
• One untreated weld removed by minimizing deformation HAZ and HAZ lateral footprint

Thermite Weld Optimization

- Reduction in deformation by minimizing HAZ and hardening weld

HAZ Overlay Treated and Untreated Welds at 108 MGT

Thermite Weld Optimization

- Reduction in deformation by minimizing HAZ and hardening weld

Improved Tie/Fastening Systems

- Ties are among the most basic, yet most important parts of the track structure
- Tests at FAST in 5- and 6-degree curves

Improved Tie/Fastening Systems

- Heavy-duty, half-frame ties increase vertical and lateral footprint
  – Increased lateral strength
  – More than 2x force to push laterally compared to conventional concrete tie
Improved Tie/Fastening Systems

• Reduced ballast and geometry degradation

• Hardwood ties with elastic fasteners gage strength similar to concrete ties after 650 MGT
• Less gage restraint with 18-inch cut spike plates

Summary

• Wear life for best performing premium rail ≈ 19% better than for worst performing rail
• Preliminary analysis shows some correlation between cementite at grain boundaries and RCF development
• IS rails when not ground developed numerous high rail gage corner shells by 380 MGT

• Weld overlay of HAZ at thermite welds reduced batter of HAZ
• Head-alloyed thermite welds batter less than standard welds
• Elastic fasteners on wood ties continue to provide better gage strength (than cut spikes), and similar to concrete ties after 650 MGT