Testing of Innovative Rail Welds and Methods under Heavy Axle Load

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ABSTRACT

Transportation Technology Center, Inc. (TTCI) continually tests new weld products and weld technologies in the High Tonnage Loop (HTL) at the Facility for Accelerated Service Testing (FAST), Pueblo, Colorado, under the Association of American Railroads’ (AAR) Strategic Research Initiatives (SRI) Program. Current product testing includes thermite railhead repair welds, electric-flash railhead repair welds, and head-alloyed welds.

Weld manufacturers Railtech Boutet, Inc, Orgo-Thermit, Inc., and Holland LP have installed these types of welds in track at FAST, and TTCI is monitoring their performance in the heavy axle load (HAL) environment. Thermite weld heat affected zone (HAZ) mitigation techniques are also being investigated. This paper describes the performance of the welds since installation and the investigation of HAZ mitigation techniques.
INTRODUCTION

The AAR tests new and improved rail welding products and processes under its SRI Program for improved rail welding. Welds are first examined in the laboratory and then, in conjunction with the SRI for HAL implementation, are installed and tested in the HTL at FAST. Four different weld innovations are currently being tested. These include thermite railhead repair welds, electric-flash railhead repair welds, thermite welds with alloy strengthened heads, and thermite welds with a weld overlay of the adjacent heat-affected-zones (HAZ). Figure 1 shows the general locations of each of these tests within the HTL in relation to numbered track sections.

Sections 31 and 3 are 5-degree curves and section 25 is a 6-degree curve. TTCI operates a test train at FAST consisting of three locomotives and 110 cars, each weighing 315,000 pounds. The train runs at approximately 40 mph, which is about 7 mph overbalance speed for
the curves. Welds made in revenue service, where maximum car weight is typically 286,000 pounds, are generally expected to perform as well or better than welds at FAST.

**Thermite Railhead Repair Welds**

Both Railtech Boutet and Orgo-Thermit have independently developed thermite railhead repair welds in response to industry requests for portable, cost-effective means to repair railhead defects in rail without the need to completely cut the rail, thereby preserving the stress-free temperature of the rail and maintaining the strength and integrity of the web and base ([1](#)). The thermite railhead repair process involves grinding a slot in the railhead to remove the flaw and then restoring the railhead using a thermite weld.

In 2008, TTCI conducted a preliminary round of testing on railhead repair welds from both manufacturers. The test was ended after 1 year because of extensive shelling occurring on all test welds ([2,3](#)). Shelling is a problem generally experienced by thermite welds at FAST that do not receive maintenance grinding. TTCI made changes to the test plan to incorporate maintenance grinding similar to revenue service operations and the weld manufacturers made improvements to their products and processes ([3](#)).

TTCI started the second round of testing of both Railtech Boutet and Orgo-Thermit railhead repair welds in 2009. At the direction of SRI steering committees and input from a technical advisory group, both consisting of Class I railroad members, TTCI investigated three weld installation scenarios: (1) installation over cribs (between ties), (2) installation over electric-flash butt (EFB) welds, and (3) installation directly over ties. The welds were installed in sections 30, 31, and 32 of the HTL in three separate efforts. The first installation made over cribs occurred in June 2009 and consisted of five welds from each manufacturer. The second
installation in which repairs were installed on EFB welds was performed in March 2010 also consisted of five welds from each manufacturer. The last installation, where welds were made directly over ties in June 2010, was limited by space constrictions to two welds from each manufacturer made over concrete ties and two welds from each manufacturer made over wood ties.

Figure 2 shows the installation locations for each of the weld scenarios. Sections 30 and 32 are spirals on either side of section 31, a 5-degree curve with 4-inch superelevation. Test zone A, located in section 31, consists of 136RE rail over concrete ties. In this zone, the thermite railhead repair welds are located in the cribs between ties. Test zone B, also located in section 31, consists of 136RE rail over wood ties. Welds in test zone B were placed over EFB welds. Test zones C₁ and C₂ are located in HTL sections 32 and 30 respectively. Test zone C₁ consists of 136RE rail over concrete ties and test zone C₂ consists of 136RE rail over wood ties. Welds in zones C₁ and C₂ were installed directly over the ties.
Repairs over Cribbs

The welds installed over cribs have accumulated 272 MGT. Rail grinding was performed approximately every 25 to 30 MGT for the first 150 MGT after which no more grinding was performed until 260 MGT. All welds remain in track as of July 2012 with the exception of one Orgo-Thermit weld that was removed at 172 MGT for gage face shelling.

Repairs over Electric-Flash Butt Welds

TTCl was asked by members of several Class I railroads to investigate the potential for using thermite railhead repair welds to make repairs over EFB welds.

Repair welds made to EFB welds have accumulated 220 MGT to date. Two Railtech Boutet welds were removed at 102 and 132 MGT because of fatigue that initiated at flashing that
occurred under the railhead. Figure 3 shows a magnetic particle inspection of a fatigue crack that started at flashing under the railhead. Flashing occurred because of a poorly fitted mold under the railhead. For welds made on EFB welds, this test shows that extra care must be taken to grind the EFB weld collar flush to the railhead to ensure a good mold-to-rail fit under the railhead.

**Figure 3. Magnetic Particle Inspection shows Cracking that Started at Flashing under Railhead for a Thermite Railhead Repair Weld Made over an Electric-Flash Butt Weld**

**Repairs over Ties**

Railhead repair welds do not alter the base of the rail, and the weld itself is confined to the railhead and top of the web. As a result, it is possible to install the welds directly above ties. In order to determine any potential differences in weld performance over ties, TTCI and the rail weld vendors installed welds over both wood and concrete ties.
As of July 2012 the welds installed over ties have accumulated 176 MGT with two failures. Both of the two Orgo-Thermit welds installed over concrete ties experienced fatigue fractures that initiated under the railhead. The welds had accumulated 54 and 65 MGT at the time of failure. The two Railtech Boutet welds installed over concrete ties remain in track. Figure 4 shows a Railtech Boutet Head Wash Repair weld installed over a concrete tie.

All breaks observed in testing of thermite railhead repair welds (including the first round of testing), whether over ties or cribs, exhibit a gentle S-shaped fracture (2,4). This type of fracture can present problems if it occurs over a tie plate. The tie plate can electrically connect both sides of the fracture thereby preventing the signal system from indicating the broken rail.

![Image of a Railtech Boutet Head Wash Repair weld installed over a concrete tie.](image-url)

**Figure 4.** Railtech Boutet Head Wash Repair installed above a Concrete Tie

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Electric-Flash Railhead Repair Welds

Holland and EWI, who develops and applies manufacturing technology innovation within the manufacturing industry, jointly developed a railhead repair process using electric-flash technology. Two sets of Head Defect Repair (HDR) welds were installed in section 3 of the HTL by Holland. The first welds were made in the laboratory in short plugs (rail sections) that were later welded together into rail strings and then installed into track. The second set was made directly in track using the Holland mobile weld truck. Figure 5 shows the Holland mobile weld vehicle being prepared for welding at FAST.

Figure 5. Holland Mobile Weld Unit setting up to make a Weld at FAST
The rail flaw is cut from the rail using a rail saw jig that removes v-shaped wedges from the railhead. Figure 6 shows the rail with the railhead cut in preparation for a repair weld. The rail is crowned, a wedge shaped insert is set in place, and the welding unit is then lowered into position. The welding unit grips the rail and makes electrical contact similar to traditional mobile unit EFB welding. The welding unit then flashes the weld insert into place and shears the expelled material. The weld and insert is finish ground to match the transverse profile of the surrounding rail and made ready for service. During the installation at FAST, the entire process took approximately 45 minutes per weld. Figure 7 shows one of the laboratory-produced welds located over a crib.

![Figure 6. Railhead removed with V-shaped Saw Cut in Preparation for Electric-Flash Railhead Repair Weld](image-url)
The laboratory-produced welds have accumulated 268 MGT with no failures. The mobile unit produced welds have accumulated 155 MGT. Two of the mobile unit HDR welds have been removed from track. The first fractured after 94 MGT because of an internal defect located at the bottom of the railhead in the body of the weld insert material. The fractured weld exhibited a gentle “S” shape similar to fractures observed for thermite railhead repair welds. Figure 8 shows the fractured weld. The second weld was removed after a fatigue crack was found by rail flaw inspection. The crack initiated at a sharp geometry transition under the
railhead that was not ground during the weld production. The weld had 132 MGT at the time of removal.

Figure 8. Fractured Holland Head Defect Repair Weld

(The fracture initiated at an internal defect in the weld insert near the bottom of the railhead.)

TTCI is monitoring the rate of running surface wear and batter using longitudinal profiles and taper gage measurements. In general, the welds are exhibiting batter on both ends of the weld insert similar to standard EFB welds. The weld inserts are also exhibiting metal flow on the running surface. The weld inserts from the laboratory-produced welds are generally performing well; however, the welds produced in track are showing more batter across the entire weld insert. TTCI conducted a manual taper grind of three of the in-track welds to reduce
impacts. Since the initiation of this test, Holland has made changes to their in-track installation procedure to increase crowning prior to welding. Holland is also working with their suppliers to produce a weld insert with improved hardness properties and improved resistance to batter. TTCI has not conducted any testing of welds that incorporate these procedural and material changes.

**Alloyed Thermite Welds**

Rail hardness has steadily increased over the past couple of decades and now many rail manufacturers produce head hardened rails with a hardness in excess of 400 Brinell. However, in North America, thermite welds installed in these rails typically have hardness values near 320 to 330 Brinell at the time of installation. Figure 9 illustrates the hardness profile for thermite welds made in both high strength and standard strength rails. The difference in hardness results in weld running surface profile degrading faster than the rail in which they are installed. This in turn contributes to wheel impacts on the weld and reduction in weld fatigue life.

The reason for this disparity in rail and weld hardness is that higher hardness thermite welds generally cannot meet current AREMA recommended practices for deflection in slow bend tests. The AREMA *Manual for Railway Engineering* in Chapter 4 on rail requires a minimum of 0.6-inch deflection under 4-point slow bend testing for thermite welds in high strength rails. Slow bend testing as defined in Chapter 4 places the base of the weld in tension. Higher hardness welds have lower ductility than the intermediate hardness welds and therefore cannot generally reach the recommended deflection value.

Orgo-Thermit developed the Head Alloyed Weld (HAW) to address this disparity in the head of the rail without changing the properties of the base. The result is a weld that more
closely matches the hardness of the parent rail in the head of the weld and still retains the ductility in the base necessary to meet the deflection requirements in Chapter 4. This is achieved by selectively alloying the head of the rail by incorporating the alloying elements into a container on the bottom of the diverter plug.

![Running Surface Hardness for Newly Installed Thermit Weld](image)

**Figure 9.** Comparison of Running Surface Hardness Profiles for Welds made in Standard and High Strength Rail Steels — Dashed Line Indicates Potential use of High Strength Weld Portion

Orgo-Thermit and TTCI personnel installed 10 HAWs in the high rail in section 3 of the HTL at FAST. Seven of the welds were installed in a 390 Brinell head hardened rail. Two of the welds were installed in 345 Brinell hardness rail and one weld was installed at the junction of the two rail types. Welds in this portion of track do not receive periodic grinding. As of June
2012, these welds have accumulated 251 MGT with no failures. Figure 10 shows a HAW at 230 MGT. Throughout the duration of the test, the weld running surfaces of the HAWs were a minimum of 50 Brinell harder than the nonalloyed welds. The HAZs, which are located outside the weld metal in the parent rail and therefore do not get alloyed had reduced hardness similar to those in standard thermite welds.

![Figure 10. Orgo Head Alloyed Weld](image)

**Heat Affected Zone Treated Welds**

As the hardness of modern rail steels continues to increase, the disparity between HAZ hardness and rail hardness also increases. The soft HAZ in the rail adjacent to a thermite weld typically
has a hardness of about 260 Brinell. This is true whether the rail is standard or high strength. Figure 9 illustrates the difference in hardness between the rail and HAZ for a 310 Brinell rail and a 410 Brinell rail. The result is that welds made in higher strength rails experience a greater difference in batter and wear between the rail and HAZ. Therefore, welds made in higher strength rail may degrade faster than similar welds made in standard strength rail because of the impacts generated at the running surface of the weld.

TTCI investigated the possibility of applying a weld overlay across the soft region of the weld HAZ to reduce dipping. A stick (shielded metal arc weld) or wire (flux core arc weld) weld is made directly over the HAZ immediately after shearing the thermite weld head riser. The overlay weld is made using a weld material designed for rail end buildup. The weld is made over the HAZ at approximately 0.25 inch from the sheared weld material and has a width between 0.75 and 1 inch.

The primary benefit of the overlay process does not come solely from the hard overlay material but is more due to changes that occur in the overall shape of the HAZ under the weld overlay. The weld overlay pushes the soft part of the HAZ away from the weld body and reduces the width of the soft HAZ by up to 75 percent. This occurs as deep as 0.5 inch below the running surface, which means that periodic rail grinding should not eliminate the benefit gained once the weld material is removed. Figure 11 shows two etched surfaces of a thermite weld with HAZ overlay weld. Figure 11(a) is the top running surface. The weld metal is in the middle and the overlay weld material is visible on both sides. Figure 11(b) is a longitudinal cross section of the weld. The soft region of the HAZ is the dark etched area on the outside edges of the image. A typical HAZ profile has the dark area proceed straight up to the surface whereas under the overlay material it turns away from the weld and narrows significantly at the running surface.
TTCI has conducted initial testing of the weld overlay process at FAST. Figure 12 shows two welds made at the same time, one with weld overlay treatment of the HAZ and one without. Both welds have accumulated over 110 MGT of traffic. The weld with treatment has no visible batter at the running surface; whereas, the weld made without treatment shows typical batter at the running surface.
TTCI is conducting another more comprehensive test to quantify the benefits obtained by
the weld overlay treatment of HAZ. In addition to the testing done on standard thermite welds
TTCI is working with Orgo-Thermit to test the process on HAWs to achieve a running surface
with both hardened HAZ and weld metal. TTCI is currently working with Canadian National
Railway to begin in-track testing in revenue service conditions with focus on cold weather
implementation.

**Summary and Conclusions**

TTCI continues to test and evaluate new innovative weld processes developed by rail weld
manufacturers.

Thermite railhead repair welds in the current testing at FAST are generally performing
comparably with standard thermite welds at FAST in similar conditions. Extra care must be
taken when making thermite weld repairs on EFB welds to ensure that the electric-flash weld is
ground flush to the rail along the web and under the railhead to prevent flashing. Flashing under
the railhead acts as a stress raiser and may promote crack initiation. When installed over ties, S-
shaped fractures, as observed at FAST, can result in a lack of rail break indication from the
signal system because tie plates or clips may electrically short the rail break.

Holland mobile unit welds tested at FAST exhibited accelerated batter across the full
running surface of the weld insert in comparison to the original lab produced welds. Holland has
made material and procedural changes to the overall weld process since initial testing at FAST.
TTCI has not yet conducted testing on welds made with these modifications.

TTCI is working with Norfolk Southern to establish a revenue service test of railhead
repair welds. The welds will be installed at the eastern mega site near Bluefield, West Virginia.
All of the Orgo-Thermit HAWs remain in track with no failures in 251 MGT of traffic. The welds show an increased resistance to batter in the weld metal. The welds experience batter in the HAZ similar to standard thermite welds. The alloy process does not prevent batter in the HAZ since the HAZ occurs in the parent rail, outside the alloyed weld.

In addition to testing weld products described above, TTCI has also explored methods to improve the performance of weld HAZ. The weld overlay treatment of HAZ has shown strong initial in-track performance. Additional in-track testing of treated welds is underway including testing to determine if additional improvements in weld running surface performance can be achieved by combining the TTCI HAZ treatment with the Orgo-Thermit HAW. TTCI is working with Canadian National Railway to establish testing of wire weld HAZ treatments in revenue service.

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The following rail weld manufacturers contributed products and expertise in support of the testing; Holland, EWI, Railtech Boutet, Inc., and Orgo-Thermit, Inc.

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(The fracture initiated at an internal defect in the weld insert near the bottom of the railhead.)

Figure 9. Comparison of Running Surface Hardness Profiles for Welds made in Standard and High Strength Rail Steels — Dashed Line Indicates Potential use of High Strength Weld Portion

Figure 10. Orgo Head Alloyped Weld

Figure 11. (a) Etched Running Surface Showing Location of Weld Bead and HAZ, and (b) Etched Longitudinal Cross Section of Railhead showing HAZ

Figure 12. Running surface of HAZ (a) treated thermite weld and (b) untreated thermite weld
(Arrows indicate locations of HAZ.)
Testing of Innovative Rail Welds and Methods Under Heavy Axle Load

By Daniel Gutscher
TTCl weld testing overview

- Association of American Railroads Strategic Research Initiatives
  - Improved Rail Welding
  - Heavy Axle Load Implementation
- Weld and weld process innovations
- Facility for Accelerated Service Testing
Weld Testing at FAST

High Tonnage Loop

- Thermite Railhead Repair Welds
- Head Alloyed Welds
- Electric-Flash Railhead Repair Welds
- Treated HAZ Trials
Railhead Repair Welds

- Enable the repair of railhead defects without altering the stress-free temperature of the rail
- Thermite
  - Railtech Boutet
  - Orgo-Thermit
- Electric Flash
  - Holland and EWI
Thermite Railhead Repair Welds at FAST

- Orgo-Thermit Head Repair Weld
- Railtech Boutet Head Wash Repair

- 3 Installation scenarios
  - Over cribs
  - Over ties
  - On EFB welds

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In-Track Performance

• Welds over cribs
  – 10 welds (5 per manufacturer)
  – Installed 2009, 272 MGT to date
  – 1 Orgo-Thermit weld removed for shelling at gage face (172 MGT)

• Welds over ties
  – 4 welds over concrete ties (2 each)
  – 4 welds over wood ties (2 each)
  – Installed June 2010, 176 MGT to date
  – 2 Orgo-Thermit welds removed for fatigue fractures initiated under railhead (54 & 65 MGT)
• Repair welds on electric-flash butt welds
  – 10 welds (5 per manufacturer)
  – Installed March 2010, 220 MGT to date
  – 2 Railtech Boutet welds removed for fatigue fractures at flashing under railhead
Thermite repair on EFB
Electric Flash Railhead Repair

- Jointly developed by Holland and EWI
  - Head Defect Repair
Holland Head Defect Repair

- Eight lab produced welds
  - Installed at FAST, Jan 2011
  - 268 MGT, no failures
Holland Head Defect Repair

- Eight mobile unit welds
  - Installed at FAST, Aug. 2011
  - 155 MGT
  - 2 failures (94 and 132 MGT)
    - Initiated in insert under railhead
    - S-shaped fracture
Welds In High Strength Rail

Running Surface Hardness for Newly Installed Thermite Weld

Hardness - Brinell

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Weld Longitudinal Profile (not to scale)

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Orgo-Thermit Head Alloyed Weld
Weld HAZ In High Strength Rail

Running Surface Hardness for Newly Installed Thermite Weld

- **High Strength**
- **Standard**

Weld Longitudinal Profile (not to scale)

- Hardness - Brinell:
  - Rail: 250
  - HAZ: 300
  - Weld: 400
  - HAZ: 450

- Vertical differences:
  - 50 units
  - 150 units
Weld Overlay Treatment of HAZ

• Applied immediately after shearing thermite weld
• Alters shape of HAZ below running surface
Running Surface Performance

- Treated weld
- 70 MGT
- No visible batter

- Untreated weld
- 70 MGT
- Batter at HAZ
Testing Weld Innovations

- Thermite Railhead Repair Welds
- Electric Flash Railhead Repair Welds
- Alloyed Thermite Weld Heads
- HAZ Overlay Treatments