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Results of Thermite Railhead Repair Weld Testing at FAST

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Summary

Three sets of ten thermite railhead repair welds were installed at the Federal Railroad Administration's (FRA) Facility for Accelerated Service Testing (FAST) located near Pueblo, Colorado. Orgo-Thermit, Inc. submitted two types of welds, and Railtech Boutet, Inc. submitted one weld type. The following observations were made regarding the in-track performance of the railhead repair welds under heavy axle load traffic:

- The primary degradation mode was due to shelling, and the primary failure mode was due to vertical fatigue fractures.
- Fatigue fractures in thermite railhead repair welds initiated under the railhead and propagated transverse to the rail.
- Thermite railhead repair welds performance was comparable to wide-gap thermite welds at FAST with regard to shelling. The welds began shelling at similar tonnage levels as wide-gap welds.

The following observations were made concerning the installation of the welds in track:

- When fitting the weld mold to the rail, it must fit properly under the railhead. Failure to ensure a proper fit can result in significant flashing under the railhead, which can act as initiation sites for fatigue failures.
- Rubbing the molds against the rail to improve fit can result in the formation of a gap between the rail and the mold under the railhead. The best practice is file-to-fit rather than rub-to-fit weld molds when possible.
- All products tested required crowning of the rail in order to reduce the amount of dipping that occurred post weld. In order to achieve a satisfactory crown, the rail was unclipped for approximately five ties on each side of the weld and then lifted using a jack. The maximum crown achieved was 0.035 inch.
- All products tested had a greater sensitivity to environmental conditions, such as wind and temperature, compared to traditional full-section thermite welds. During in-track installation, shear times varied up to 1.5 minutes depending on conditions.

Thermite railhead repair welds were developed by Orgo-Thermit, Inc. and Railtech Boutet, Inc. in response to railway industry requests for welds that could be used to repair railhead defects without the need to cut the rail, thereby preserving the rail neutral stress temperature.

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INTRODUCTION

Railhead repair welds enable the repair of defects in the head of rails without severing the rail. This process eliminates the need for a plug rail and field welds otherwise needed to make repairs.

Transportation Technology Center, Inc., (TTCI) tested several thermite railhead repair welds in the laboratory. The welds met the applicable American Railway Engineering and Maintenance of Way Association (AREMA) requirements for thermite welds.[1] Arrangements were then made to begin in-track testing at FAST in the High Tonnage Loop (HTL). The railhead repair weld testing at FAST did not analyze the ability of the welds to repair defects, but rather analyzed the in-track installation and performance of the welds under heavy axle load conditions.

WELD INSTALLATION

Three sets of welds were installed at FAST. The first set of welds was the Orgo-Thermit 1 1/8-inch depth Railhead Repair Weld (OW-1 group) installed in February 2008. This set consisted of 10 welds installed throughout the high rail in HTL Section 31, which is a 5-degree curve with 4-inch superelevation. The second set of welds was the Orgo-Thermit full-head depth Head Repair Weld (OW-2 group) that was installed in April 2008. The OW-2 group of welds was also installed in HTL Section 31. The last set of railhead repair welds was the Railtech Boutet Head Wash Repair Welds (BW-1 group) with a 1-inch depth slot. The BW-1 group of welds was installed in October 2008 in HTL Section 3, which is also a 5-degree curve with 4-inch superelevation. Figure 1 shows the slot depths for the BW-1 and OW-2 group welds.

Figure 1. Ground Slots for Railhead Repairs. Railtech Boutet 1-inch Depth Slot (left) and Orgo-Thermit Full-Head Depth Slot (right)

Welds of each type were initially installed without lifting or crowning the weld. For each weld type, dipping of 0.050 to 0.090 inch occurred on either side of the welds after they had cooled. In order to minimize dipping, the rail had to be lifted (using a jack) about 4 inches at the weld. This resulted in approximately 0.035 inch of crown, as measured across the slot with a 3-foot straightedge. Because the rail to be welded was still a single piece, lifting the rail required unclipping approximately five ties on either side of the weld to prevent lifting the ties in track. Welds made with this procedure had reduced dipping that ranged from 0.005 to 0.015 inch on both sides of the weld. According to Railtech Boutet representatives, this dipping may be reduced further by future changes to the weld design or preheat procedures, which are currently being investigated by the weld manufacturer. Orgo-Thermit engineers recommend unclipping additional ties to achieve 0.050 inch of crown as a means to reduce dipping.

During the initial laboratory investigation of the OW-1 welds, significant cold lapping was observed under the railhead. Both OW-2 and BW-1 groups did not have any cold lapping under the railhead in the laboratory test welds. During installation at FAST, however, all three weld types experienced problems with cold lapping. This was determined to be a design issue for the OW-1 group and a procedural issue for both the OW-2 and BW-1 groups.

Molds from both manufacturers were designed to be used on head-worn rail. As a result, when installing the welds in newer rail, the molds must be filed to ensure they properly fit with the rail. A common practice in thermite welding is to rub the molds against the rail to achieve a good fit. When this occurs, the mold is rubbed away in areas under the railhead. It can create a gap between the mold and the rail that allows liquid metal to flow beyond the fusion zone and cold lap against the bottom of the railhead. Therefore, it is important that welders be instructed to minimize rubbing and use a file-to-fit practice when possible. Figure 2 shows the gap that may form if the mold does not fit properly under the railhead.

Both manufacturers have continued to improve their products since installation at FAST. Each now produces weld molds specifically designed for various rail sections. This will also reduce the occurrence of cold lapping under the railhead.

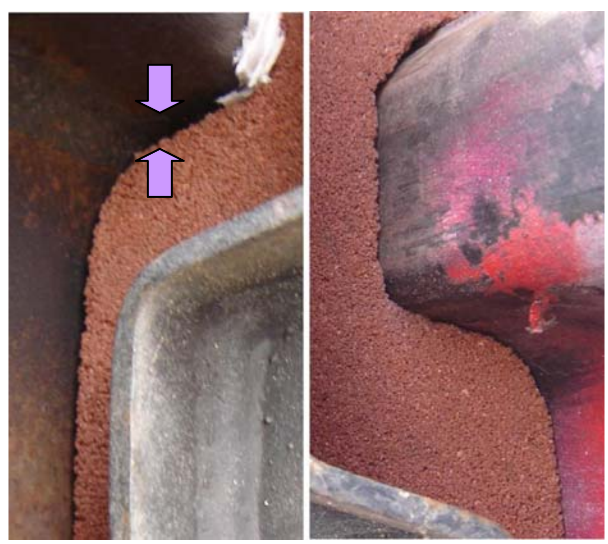

Figure 2. Fit under the Railhead Poor Fit (left) and Good Fit (right)

During installation for all three weld groups, environmental conditions affected the required weld shearing times. Thermite railhead repair welds appeared to be more sensitive to the cooling effects of wind and temperature compared to traditional full-section thermite welds. A decrease in shear time of up to 1.5 minutes from the time specified in the manufacturers' installation procedures was observed for welds from both suppliers.

WELD PERFORMANCE UNDER HEAVY AXLE LOADS

Several welds from the OW-1 group were installed directly over ties to observe the weld performance in reverse bending conditions. Two welds were installed over concrete ties with 24-inch center-to-center spacing, and two welds were installed over wood ties with 19.5-inch center-to-center spacing. The first railhead repair weld failure occurred at 20 million gross tons (MGT) in a weld located above a concrete tie. As with any weld or rail break that occurs over a tie, the rail break detection system may not activate due to the tie plate acting to maintain electrical continuity between the broken pieces of rail. This was the case for the railhead repair welds installed over ties at FAST, but both manufacturers do not recommend installing the railhead repair welds over ties.

Weld failures that occurred during the test were generally vertical fractures that initiated under the railhead. Shelling also occurred. Cold lapping under the railhead creates stress risers that promote the initiation of fatigue cracking. Figure 3 shows a fracture that started at the underside of the railhead at a flashing. All weld breaks that occurred during the test period fractured transverse to the rail with the breaks following the arc of the heat-affected zone to the bottom of the weldment and then fracturing vertically through the base of the rail. Figure 4 shows the fracture pattern for two Orgo-Thermit welds.

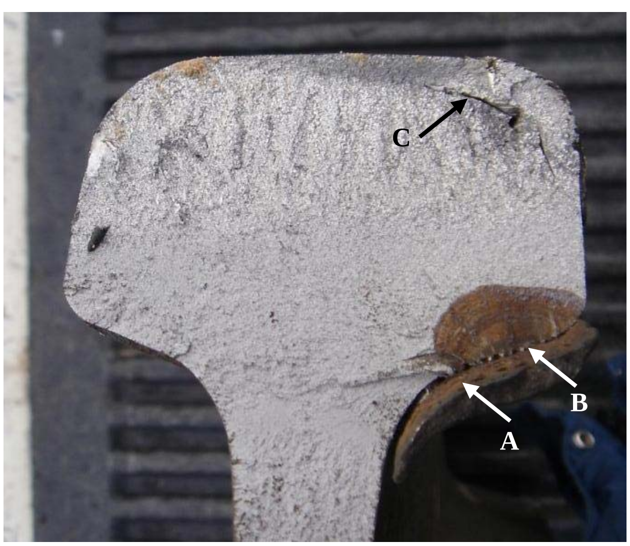

Figure 3. Fatigue Fracture of a Railhead Repair Weld. (A) Cold Lapped Weld Material under Railhead (B) Fatigue Fracture Initiation Site (C) Subsurface Shelling at Gage Corner

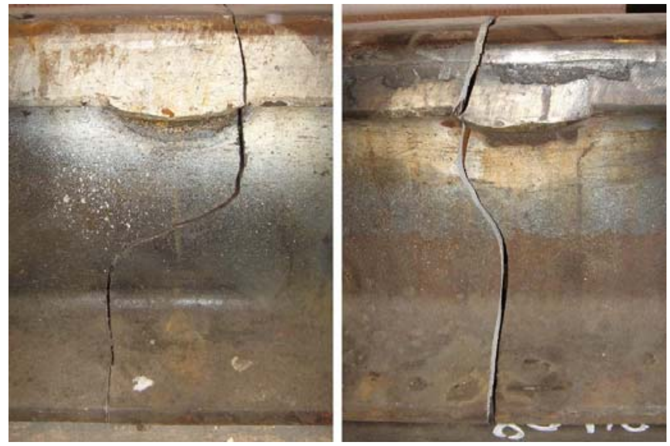

Figure 4. Photos Showing Typical Railhead Repair Weld Fractures

In research conducted previously by TTCI, cold lapping at the weld collar to rail transition in the web and base of the rail was identified as a stress concentrator.[2] Cold lapping acts as a preexisting crack that serves as an initiation site for fatigue cracking in welds. Cold lapping under the railhead can contribute to fatigue failures in a similar manner to cold lapping observed under the rail base.

As with all thermite welds at FAST, shelling is the major form of performance degradation; however, it does not necessarily result in weld removal. The entire group of OW-1 welds, with the exception of one weld that was removed due to fracture, has experienced shelling on the gage corner of the rail. For both manufacturers, initial shelling began at approximately 30 to 50 MGT. This is similar to the performance of wide-gap thermite welds installed at FAST, which begin to shell around 35 MGT.

Of the 10 OW-1 group welds, two were removed due to vertical fatigue fractures, and three were removed due to shelling at the gage corner of the rail. Both of the welds that failed due to fatigue had been installed above ties. The remaining welds from the OW-1 group accumulated approximately 132 MGT. The OW-1 group welds received maintenance grinding to reduce the impact of shelling on the gage corner of the rail. Manual grinding was performed at approximately 35 and 50 MGT on welds as needed using a standard post weld grinder.

Of the nine OW-2 group welds, two were removed due to vertical fatigue fractures, and one was removed due to shelling. Another weld in the OW-2 group, weld FHW-09-08, failed during installation. Weld FHW-09-08 was an alloy-hardened weld with around 380 Brinell hardness number. It cracked during post-weld grinding. A second alloy-hardened weld failed in a similar manner out-of-track in follow-up testing.

The BW-1 welds accumulated approximately 95 MGT as of June 2009. Two welds were removed at 85.9 MGT due to shelling. All welds experienced shelling degradation.

Table 1. Status of the Railhead Repair Welds as of June 2009

Weld ID	HTL Section	MGT	Status
Orgo-Thermit 1-1/8 inch Head Repair Weld (Group OW-1)			
OHW-01-08	30	132	In service, shelling
OHW-02-08	31	132	In service, shelling
OHW-03-08	31	82.9	Removed, shelling
OHW-04-08	31	85.5	Removed, VF under railhead
OHW-05-08	31	131	In service, shelling
OHW-06-08	31	131	In service, shelling
OHW-07-08	31	20.3	Removed, VF under railhead
OHW-08-08	31	128	In service, shelling
OHW-09-08	31	43.0	Removed, shelling
OHW-10-08	31	55.3	Removed, shelling
Orgo-Thermit Full Head Repair Weld (Group OW-2)			
FHW-01-08	3	27.7	Removed, VF under railhead
FHW-02-08	31	100	In service, shelling
FHW-03-08	31	36.4	Removed, VF under railhead
FHW-04-08	31	100	In service, shelling
FHW-05-08	31	97.4	In service, shelling
FHW-06-08	31	45.4	Removed, shelling
FHW-07-08	31	94.8	In service, shelling
FHW-08-08	31	85.0	In service, shelling
FHW-09-08	31	0	Removed, Failed during installation
Railtech-Boutet 1-inch Head Wash Repair Weld (Group BW-1)			
BHW-01-08	3	85.9	Removed, shelling
BHW-02-08	3	85.9	Removed, shelling
BHW-03-08	3	95.0	In service, shelling
BHW-04-08	3	95.0	In service, minor shelling
BHW-05-08	3	95.0	In service, shelling
BHW-06-08	3	95.0	In service, shelling
BHW-07-08	3	95.0	In service, shelling
BHW-08-08	3	95.0	In service, shelling
BHW-09-08	3	95.0	In service, shelling
BHW-10-08	3	95.0	In service, shelling
Note: "VF" refers to vertically oriented fatigue fractures			

CONCLUSIONS

- When fitting the weld mold to the rail, it must fit well under the railhead. Failure to ensure a proper fit can result in significant cold lapping or flashing under the railhead, which can act as initiation sites for fatigue failures.
- Rubbing of the molds against the rail to improve the fit can result in the formation of a gap between the rail and the mold under the railhead. The best practice is file-to-fit rather than rub-to-fit weld molds when possible.
- All products tested required crowning of the rail in order to reduce the amount of dipping that occurred post weld. In order to achieve crown, the rail was unclipped for approximately five ties on each side of the weld and then lifted using a jack. The maximum crown achieved was 0.035 inch.
- All products tested had a greater sensitivity to environmental conditions, such as wind and temperature, compared to traditional full-section thermite welds. During in-track installation, shear times varied up to 1.5 minutes depending on conditions.
- The primary failure mode was due to vertical fatigue fractures. Shelling was the primary form of performance degradation.
- Fatigue fractures in thermite railhead repair welds typically initiated under the railhead and fracture transverse to the rail.
- Thermite railhead repair welds performed comparable to conventional wide-gap welds at FAST with regard to shelling.

WAY FORWARD

- Shelling is a common problem at FAST for all thermite welds. TTCI is conducting metallurgical analysis of shelled welds to determine the root causes of shelling.
- TTCI is researching the effects of railhead repair welds on thermite weld residual stresses on the overall stress state of the rail. TTCI is also exploring the use of railhead repair welds as a means to repair head defects in flash-butt welds.
- Both manufacturers have made improvements to their products and procedures since the initiation of this test. TTCI began a second round of in track testing in summer of 2009.

REFERENCES

1. American Railway Engineering and Maintenance of Way Association. 2005. *Manual for Railway Engineering.* "Chapter 4 Section 3.14 Specification for the Quality Assurance of Thermite Welding of Rail," Lanham, Maryland.
2. Kristan, Joseph. December 2003. "Effects of Flashing and Alignment on Thermite Weld Performance." *Technology Digest* TD-03-026. Association of American Railroads, Transportation Technology Center, Inc., Pueblo, Colorado.