

The work described in this document was performed by Transportation Technology Center, Inc.,
a wholly owned subsidiary of the Association of American Railroads.

Testing of 1.5-inch Gap Thermite Welds at FAST

Daniel Gutscher

Summary

The Transportation Technology Center, Inc. (TTCI) tested thermite welds that incorporated several design improvements including increased weld gap. Four types of welds were tested in the Facility for Accelerated Service Testing (FAST) High Tonnage Loop (HTL) at the Transportation Technology Center in Pueblo, Colorado. Following are the test results at the conclusion of the testing after 117 million gross tons (MGT) of 39,000-pound wheel load traffic:

- Shelling occurred during the test as summarized below:
 - Advanced geometry (AG) welds – 50 percent experienced shelling
 - Orgo-Thermit 1.5-inch gap SKV welds – 60 percent experienced shelling
 - Head hardened 1.5-inch gap welds – 40 percent experienced shelling
 - 1-inch gap (standard field weld) used as the test control – 27 percent experienced shelling
- Several fractures occurred during the test as summarized below
 - AG welds: one horizontal fracture under the railhead at 43.6 MGT and one vertical fracture in the weld base at 104 MGT
 - Orgo-Thermit 1.5-inch gap SKV welds: one vertical fracture in the weld base at 97 MGT
 - No fractures occurred in the head hardened 1.5-inch welds or the standard 1-inch gap welds

The 1.5-inch gap thermite welds began experiencing shelling between 65 and 100 MGT, whereas the 1-inch gap thermite welds, used as control welds for the test, began shelling after 100 MGT. Additionally, a wide-gap weld located in the test zone began shelling at 53 MGT. These results correspond to the average tonnage to shelling for thermite welds at FAST. TTCI does not perform rail grinding in the FAST HTL. This may contribute to the rate of shelling. “Gap” refers to the gap between rail ends at the time of welding. Standard thermite welds have a 1-inch gap, whereas the welds tested at FAST had 1.5-inch gaps. In addition to increased weld gap, changes to weld collar geometry and alloy hardened weld heads were tested.

This work was sponsored by the Association of American Railroads and the Federal Railroad Administration as part of the FAST/Heavy Axle Load Implementation Program.



INTRODUCTION

As axle loads increase, rail welds experience an increasingly demanding environment. The need to improve thermite welds to meet heavy-axle-load demands has been the impetus for both research and development efforts. Research performed at the University of Illinois at Urbana Champaign (UIUC) proposed a number of possible improvements that could be made to existing thermite weld procedures and designs.¹ Of the proposed design changes, several were identified by TTCI for further testing based upon the greatest perceived improvement to overall weld performance.^{2,3} The research described in this *Technology Digest* focuses on two of the design modifications, increased weld gap and improved weld geometry.

Increasing the weld gap reduces the criticality of preheat for achieving good rail end melt back and thereby for achieving good fusion. In thermite welding, two sources of heat provide the energy necessary to melt back the rail ends and get proper fusion: (1) the weld preheat and (2) the thermal energy of the thermite portion. Of these two sources, preheat is the most susceptible to variation as it is highly dependent on operator experience and judgment. Increasing the weld gap provides additional energy through additional superheated thermite weld metal, making the preheat less critical to achieving proper melt back.³ Adequate melt back is necessary in order to eliminate cold lapping and to ensure that the weld fusion line is not immediately adjacent the weld collar to rail profile geometry transition. This serves to improve the fatigue performance of the weld by reducing or eliminating potential crack initiators.

Modifying the weld to optimize rail profile geometry reduces stress risers at critical areas where fatigue cracking is likely to initiate. The UIUC research showed that the weld collar to rail transition could be improved through changes to the collar flank angle and to the radius at the transition.¹ The optimum combination was determined to be a weld collar flank angle between 30 and 35 degrees and a toe transition radius of 1/8 inch (3 mm).³

Three different welds that incorporated one or both of the above modifications were tested in the laboratory and then in track at the HTL at FAST. Standard 1-inch gap welds were included in the in-track testing as the test control welds. The weld referred to herein as the advanced geometry (AG) weld incorporated both the increased gap and geometry modifications. The Orgo-Thermit high performance weld (HPW) incorporated the increased gap and head hardening that was accomplished through an alloyed plug insert.

LAB TESTING

Each of the test weld types, with the exception of the HPW weld, was tested in the laboratory under the Association of American Railroads’ (AAR) Strategic Research Initiatives Program: Improved Rail Welding. The HPW welds were tested in the laboratory separately under a proprietary commercial agreement between Orgo-Thermit, Inc. and TTCI.

The test welds were evaluated in the laboratory for compliance with the American Railway Engineering and Maintenance-of-Way Association (AREMA) *Manual for Railway Engineering* Section 2.5 “Specification for the Quality Assurance of Thermite Welding of Rail.” Laboratory testing included ultrasonic inspection, hardness testing, macro examination, microscopy, and slow bend testing. All welds tested met the applicable AREMA requirements.

Additionally, full-scale fatigue tests were performed on the AG welds in order to determine potential fatigue life benefits afforded by the improved weld geometry. Five AG welds were tested at different loads for comparison to standard thermite welds. Evaluation of the data indicated a 34-percent increase in thermite weld fatigue life for the AG welds when tested in the laboratory environment. Table 1 summarizes the welds tested.

Table 1: Summary of Welds Tested

Weld Type	Gap	Kit	Note
Orgo-Thermit 1-inch SKV	1-inch	two-piece	Commercial product
Orgo-Thermit 1.5-inch SKV	1.5-inch	three-piece	New product in North America
Orgo-Thermit HPW	1.5-inch	three-piece	Head hardened
AG Weld	1.5-inch	three-piece	Incorporates geometry modifications

TESTING AT FAST

Over a period of two weeks in January 2007, 41 welds, comprised of four different weld types, were installed in the HTL test zone. The Orgo-Thermit two-piece standard 1-inch gap thermite welds were used as the control for the test. The control welds were spaced throughout the weld test bed at 160-foot intervals. The three types of test welds were then spaced at 20-foot intervals between the control welds. Their order was cycled to eliminate any possible systematic effects of maintenance on the test should one or more weld types have shown earlier failure tendencies. Welds were installed in head-hardened (370 Bhn*) 136RE section rail.

The weld test bed was located in the HTL main line in sections 30, 31, and 32. The weld test bed started in the middle of the spiral in section 30 and continued through section 31 (a 5-degree curve with 4-inch superelevation) to the middle of the spiral in section 32. For the duration of the test, FAST operated with 315,000-pound cars running at approximately 5 miles per hour overbalanced speed through the curve. All test welds were installed in the high rail in order to take advantage of the higher loading environment and to reduce the overall time required to evaluate weld performance. Figure 1 shows the test layout. Longitudinal profiles of the weld running surface and hardness measurements were taken on select welds at periodic intervals throughout the test.

* Brinell hardness number

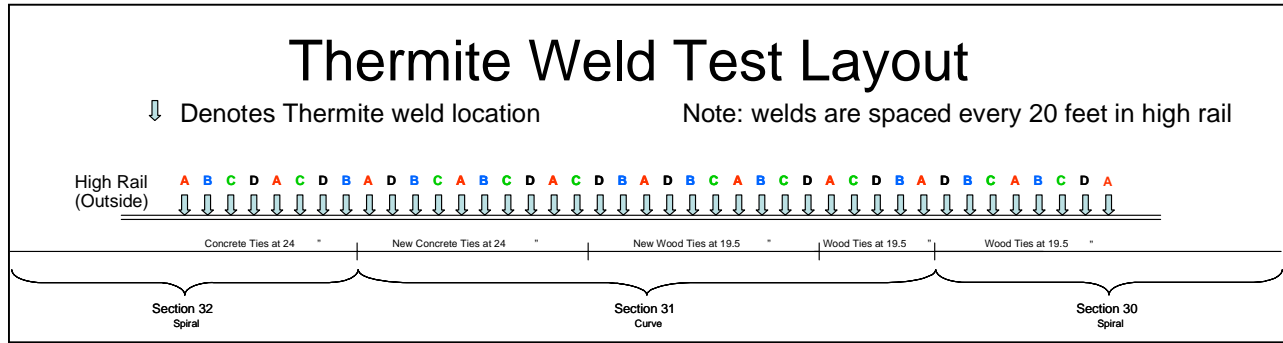


Figure 1: Layout plan for weld testing in FAST HTL Sections 30, 31, and 32. “A” designates Orgo 1-inch SKV welds (control), B, C, and D designate locations of the Orgo 1.5-inch SKV, Orgo HPW, and AG test welds, respectively.

RESULTS AND DISCUSSION

Shelling due to subsurface rolling contact fatigue occurred throughout this test. Table 2 details the weld types, their individual locations in the test, and associated performance, along with total tonnage achieved for each weld. A correlation between weld gap and tonnage to the onset of shelling was identified, which is confirmed by field weld performance at FAST.

The 1-inch gap welds began experiencing shelling after 100 MGT, whereas the majority of the 1.5-inch gap welds experienced shelling between 65 and 100 MGT. A wide-gap weld (2.75-inch gap) from a different vendor, which was placed in the test zone during the test period for maintenance purposes, experienced shelling at 53 MGT. A brief review of weld records at FAST revealed a similar relationship for the average tonnage to shelling for maintenance welds at FAST where shelling occurred. Wide gap thermite maintenance welds at FAST averaged 55 MGT to shelling, and 1-inch gap maintenance welds averaged 114 MGT to shelling. TTCI does not perform rail grinding in the FAST HTL. This may contribute to the rate of shelling.

Two AG welds experienced fractures during the test period. The first was due to a horizontal fracture that initiated under the railhead at a region of geometry transition not specifically addressed by the new geometry, and the second was a vertical fracture that initiated at a weld metal fin under the rail base. One of the 1.5-inch SKV welds and one of the AG welds were removed due to rail breaks that occurred near the welds. In this test, no welds experienced infant mortality; i.e., failure prior to 30 MGT.

Figure 2 presents the average running surface hardness values for each weld type in the parent rail, the weld HAZ, and the weld metal in the center of the weld. The HAZ hardness values for the various welds were all similar, with a standard deviation of 4 Bhn. Weld centerline hardness for the alloy hardened HPW welds was on the average 27 Bhn higher than the other welds in the test. This difference was maintained from installation through approximately 76 MGT.

Table 2: FAST Weld Performance Summary

Weld ID#	Location	MGT	Weld Performance
Advanced Geometry Welds			
AG-01-07	Sec 31, Tie 3	104	Shelling; Vertical break in base
AG-02-07	Sec 30, Tie 115	72.2	Shelling; Removed due to adjacent rail break
AG-03-07	Sec 31, Tie 39	77.9	Shelling
AG-04-07	Sec 31, Tie 183	117	Shelling
AG-05-07	Sec 31, Tie 75	43.6	Horizontal failure under railhead
AG-06-07	Sec 31, Tie 147	117	
AG-07-07	Sec 31, Tie 214	117	Shelling
AG-08-07	Sec 31, Tie 273	117	
AG-09-07	Sec 31, Tie 14	117	
AG-10-07	Sec 32, Tie 44	117	
Orgo-Thermit High Performance Welds			
HPW-01-07	Sec 30, Tie 127	72.2	Shelling
HPW-02-07	Sec 31, Tie 51	117	Shelling
HPW-03-07	Sec 30, Tie 162	117	
HPW-04-07	Sec 31, Tie 123	117	
HPW-05-07	Sec 31, Tie 224	117	
HPW-06-07	Sec 31, Tie 254	42.2	Shelling
HPW-07-07	Sec 31, Tie 87	117	
HPW-08-07	Sec 31, Tie 194	117	Shelling
HPW-09-07	Sec 32, Tie 24	117	
HPW-10-07	Sec 32, Tie 54	117	
Orgo-Thermit 1.5-Inch SKV Welds			
O1.5-01-07	Sec 30, Tie 138	92.2	Shelling; Removed due to adjacent rail break
O1.5-02-07	Sec 30, Tie 174	64.7	Shelling
O1.5-03-07	Sec 32, Tie 64	117	
O1.5-04-07	Sec 31, Tie 27	77.9	Shelling
O1.5-05-07	Sec 32, Tie 4	117	
O1.5-06-07	Sec 31, Tie 99	73.5	Shelling
O1.5-07-07	Sec 31, Tie 135	117	Shelling
O1.5-08-07	Sec 31, Tie 263	117	
O1.5-09-07	Sec 31, Tie 171	117	
O1.5-10-07	Sec 31, Tie 234	97.0	Shelling; Vertical break in base
Orgo-Thermit 1-Inch SKV Welds			
OSW-01-07	Sec 30 Tie 103	117	
OSW-02-07	Sec 30, Tie 150	117	
OSW-03-07	Sec 31, Tie 15	117	
OSW-04-07	Sec 31, Tie 63	117	Shelling
OSW-05-07	Sec 31, Tie 111	117	
OSW-06-07	Sec 31, Tie 159	117	Shelling
OSW-07-07	Sec 31, Tie 204	117	
OSW-08-07	Sec 31, Tie 244	115	Shelling
OSW-09-07	Sec 31, Tie 283	117	
OSW-10-07	Sec 32, Tie 34	117	
OSW-11-07	Sec 32, Tie 74	117	
Notes:			
<ul style="list-style-type: none"> Items shaded in blue were removed from the test as a result of weld failure. Items shaded in yellow experienced shelling during the test, but were not removed as a direct result of shelling. 			

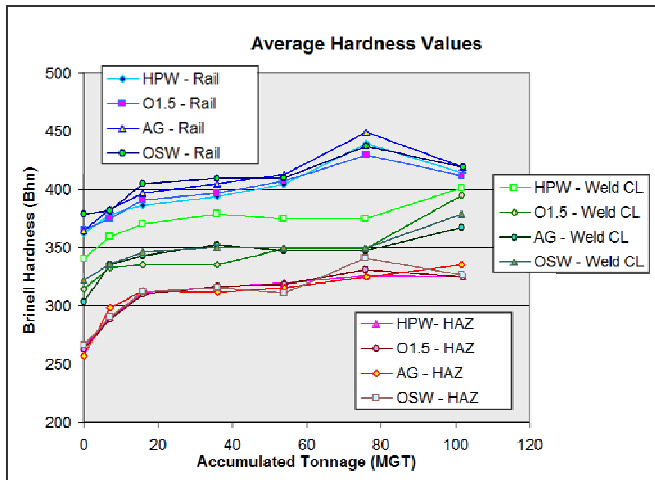


Figure 2: Average Bhn values for the test welds taken at the parent rail, the HAZ, and the weld centerline.

Longitudinal profiles of the test welds revealed typical dips in the weld HAZ regions adjacent to the weld centerline. The weld profiles correspond generally to the hardness values in which harder regions experienced less batter than adjacent regions of lower hardness. Figure 3 shows the longitudinal profiles for one of the test welds (top) and one of the control welds (bottom). The profiles shown are typical for all the welds in the test. The welds showed similar profile degradation when shelling occurred, regardless of weld type.

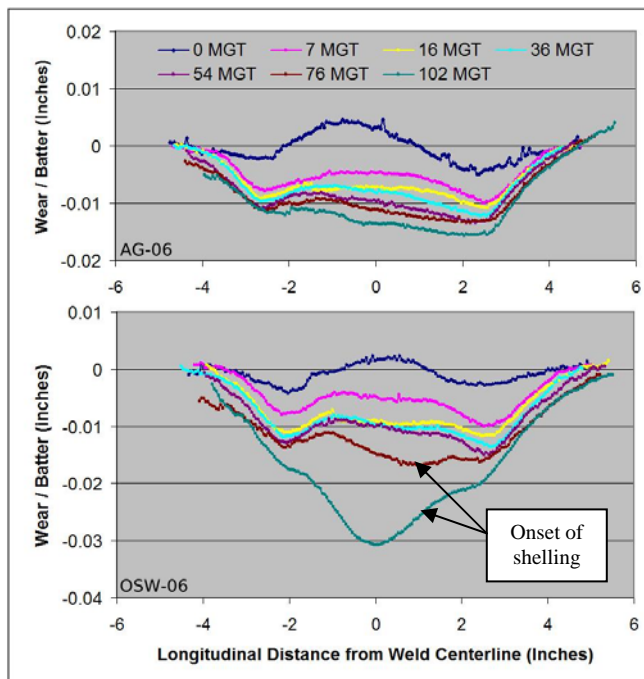


Figure 3: Longitudinal profiles on the running surface of two welds. Advanced Geometry Weld AG-06 (top), and standard 1-inch gap Orgo SKV weld OSW-06 (bottom).

CONCLUSION

Shelling was the dominant degradation mode experienced by all welds during the test period. Shelling for the 1.5-inch gap welds occurred primarily between 65 and 100 MGT. Shelling for the 1-inch gap welds occurred after 100 MGT.

Two fractures occurred in the AG welds and one in the 1.5-inch gap welds. Of the fractured AG welds, one was a horizontal fracture that initiated under the railhead at 43.6 MGT. The other was a vertical fracture that initiated under the rail base at a weld metal fin near the flange tip at 104 MGT. The 1.5-inch SKV weld that fractured experienced a vertical fracture in the base of the weld at 97 MGT. None of the 1-inch gap welds fractured. During the test, two rail fatigue breaks occurred at the edges of tie plates. One was adjacent to an AG weld and the other adjacent to an Orgo 1.5-inch SKV weld. For all the fractured welds and rail described above, with the exception of the horizontal fracture, shelling of the welds was advanced and may have resulted in vertical loads that contributed to the fatigue failures.

Fatigue performance improvement of the AG welds, as indicated by the laboratory testing, was not observed in testing at FAST. A quick analysis of the welds with base breaks revealed excessive rail end meltback beyond the geometry transition. This resulted in the formation of fins under the rail that initiated the base breaks. Reducing the preheat times may be a viable option for eliminating this occurrence and will need to be explored further.

FUTURE WORK

A comprehensive approach to improving weld performance must address HAZ hardness and strength in order to reduce batter and shelling that result in weld impacts. TTCI is conducting research aimed at improving the strength and corresponding performance of the weld HAZ. Additional studies are focusing on establishing a better understanding of weld degradation and shelling in the environment at FAST.

ACKNOWLEDGEMENTS

This work was sponsored by the AAR and the Federal Railroad Administration as part of the FAST/Heavy Axle Load Implementation Program.

Orgo-Thermit, Inc. produced the welds and provided materials in support of this testing program.

REFERENCES

1. Cyre, Jeffrey Paul. 2002. "Concepts for Improving the Fatigue Resistance of Thermite Rail Welds." Master of Science Thesis, University of Illinois at Urbana-Champaign.
2. Lawrence, F.V. et al. April 2003. "Increasing Thermite Weld Fatigue Life Through Improvements in Weld Profile." TD-03-005, AAR, TTCI, Pueblo, Colorado.
3. Kristan, J. October 2004. "Thermite Weld Progress." TD-04-015, AAR, TTCI, Pueblo, Colorado.

Visit our website at <http://www.ttc1.aar.com>