TTCI TECHNOLOGY DIGEST

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

Full Section, High Hardness Thermite Welds

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Key Findings:

- All the welds were tested using 0-degree, 45-degree, and 70-degree probes. No indication of flaws was found.
- The Brinell hardness results for all 10 welds at the weld center ranged from 341 BHN to 363 BHN.
- The microstructural variation from the weld center to the parent rail was comparable to the microstructural variation of other standard thermite welds.
- Four welds were tested for slow bend tests and three of them passed American Railway Engineering and Maintenance-of-Way Association (AREMA) specifications for deflection and modulus of rupture.
- Seven full section hardness thermite welds were installed on a 5-degree curve in late 2016. Five were installed on the high rail and two were installed on the low rail of the curve.

Transportation Technology Center, Inc. (TTCI) is evaluating a thermite weld design that provides high hardness throughout the full section (from head to base) of the weld. In October 2016. this new weld design was installed on the High Tonnage Loop (HTL) at the Transportation Technology Center (TTC), Pueblo, CO. As of November 2018, there have been no weld failures after accumulating 157 MGT heavy axle load traffic. TTCI engineers have tested head alloyed thermite welds at TTC's Facility for Accelerated Service Testing (FAST) that also were developed by Orgo-Thermit, Inc.[1]

Both the head alloy welds and full section high hardness welds are installed using the welding procedure and tools for a standard thermite weld. However, the head alloyed welds have the alloying elements attached to the plug of the mold so that, when melted, the alloys are dispersed in only the head of the weld. The full section high hardness welds have the alloys contained in the thermite charge portion that is poured into the crucible and therefore provides alloying elements through the full section of the weld.

Orgo-Thermit developed a new type of thermite charge mixture containing alloying elements to improve wear resistance and longevity of aluminothermic (thermite) welds. These welds utilize the same crucible, molds, and installation procedures as standard thermite welds. The only difference is the thermite charge material. In early 2016, TTCI was contacted by Orgo-Thermit to complete a metallurgical analysis and other associated tests to qualify the welds. After laboratory tests were completed in late 2016, seven welds were installed on the High Tonnage Loop (HTL) at FAST for further in track testing. This report discusses TTCI's analysis of results obtained from different laboratory tests including hardness, metallography and four-point slow bend as well as initial data obtained from in track testing.

LABORATORY TESTING

Orgo-Thermit supplied test welds for laboratory testing at TTCI. The shipment consisted of seven 136RE premium head hardened rails with the welds present at the centers as shown in Figure 1. These welds were poured at the Orgo-Thermit manufacturing facility in New Jersey and then shipped to TTCI. The objective of the metallurgical analysis and other tests were to qualify the performance of the welds in comparison to results obtained for previously tested aluminothermic welds and standards mentioned in the *AREMA Manual for Railway Engineering*, Chapter 4, Rail.

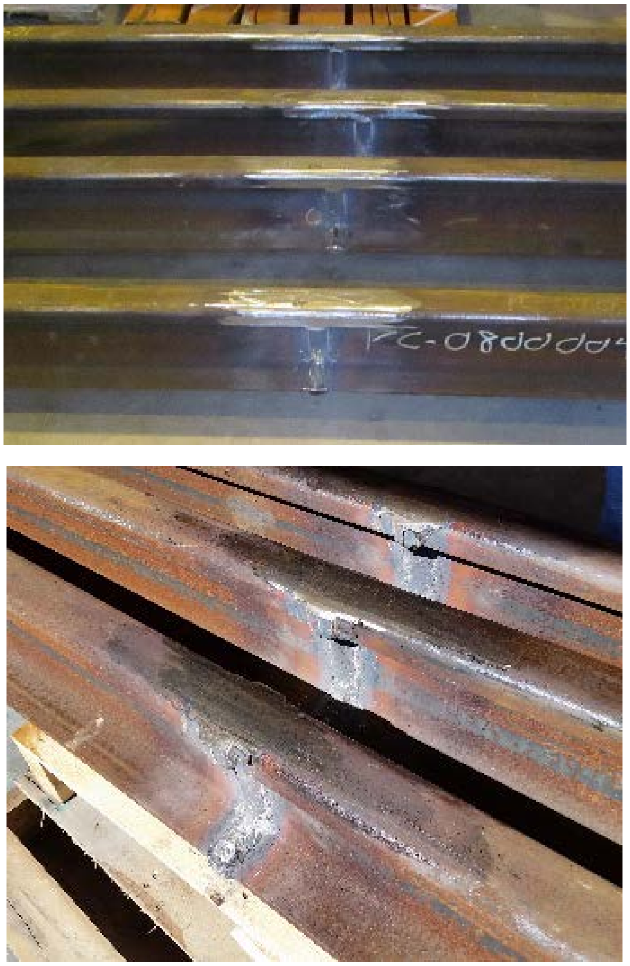

Figure 1. Seven 136RE premium head hardened rails with the welds present at the centers that were sent for laboratory analysis.

Ultrasonic Testing and Surface Hardness

All welds were ultrasonically tested for defects and tested for surface hardness values using 0-degree, 45-degree, and 70-degree probes. No indication of flaws were found. Surface hardness was measured using a top-of-rail hardness tester having a tungsten carbide ball indenter. The hardness results for all seven welds at the weld center ranged from 341 BHN to 363 BHN and neither any weld or parent rail had hardness above 388 BHN.

Slow Bend Tests

Two test welds were tested using a four-point bending fixture at an external laboratory following the guidelines mentioned in AREMA Manual Article 3.10.3.6 of Chapter 4, Rail. Since these welds were present in high strength rails having hardness more than 341 BHN, the AREMA recommended modulus of rupture value of 120,000 psi and a deflection of 0.60 inch were the minimum conditions for qualification. One weld provided values above the AREMA limits but the second weld failed to qualify the minimum limit for deflection even though the modulus of rupture limit was reached. Since one weld did not pass the AREMA specification, two more welds were put through the slow bend test apparatus and both passed.

Residual Stress Tests

Three additional welds were tested to evaluate residual stresses within the alloyed welds. Strain gages were installed at seven locations from head to base as shown in Figure 2. Two of the welds were cut through the center of the weld while weld the third weld was cut at 0.25 inch from the widest part of the weld. In both methods, strain gages were installed at 0.25 inch from the cutting axis.

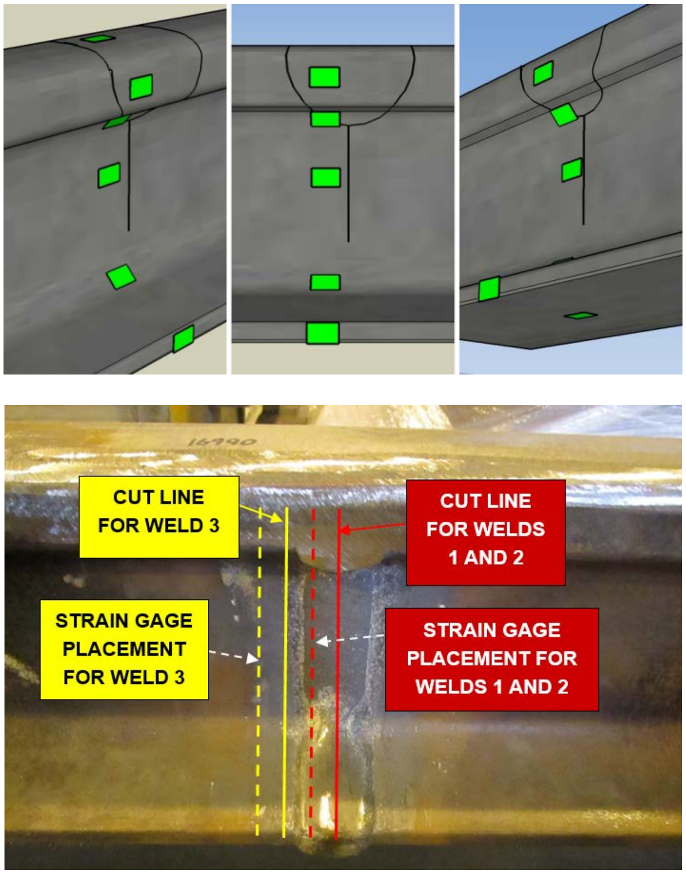

Figure 2. Strain gage locations and cutting locations for residual stress measurements.

Measurements were taken before and after cutting to calculate the changes in strain due to stresses generated during cutting. The differences in strain values were converted to stress values and plotted against the vertical position of the gages to generate profiles of the longitudinal residual stresses.

The results show that the cut through the center of the weld generates higher compressive stresses at the head and the base of the rail compared to the cut made at 0.25-inch away from the boundary of the weld. Compared to a standard thermite weld, the three full section high hardness welds generated higher tensile stresses at the web region at a height of 5 inches from the base. Also, the compressive stresses at the head of all full section high hardness welds are higher than the compressive stress at the head of a standard thermite weld.

Metallography

The microstructure was analyzed before and after etching with 2 percent Nital reagent. Both optical microscope and scanning electron microscope (SEM) were used to examine the microstructures. The microstructure revealed some dark spots which appeared to be small porosity voids. One sample, un-etched and viewed with a SEM showing examples of connected voids, can be seen in Figure3.

The microstructural variation from the weld center to the parent rail was comparable to the microstructural variation of standard thermite welds. The near heat affected zone (HAZ) had fine pearlite while the far HAZ had a mixture of spheroidized cementite and some amounts of fine pearlite. The drastic change in the grain size of pearlite from the weld metal to the near HAZ was comparable to other standard thermite welds.

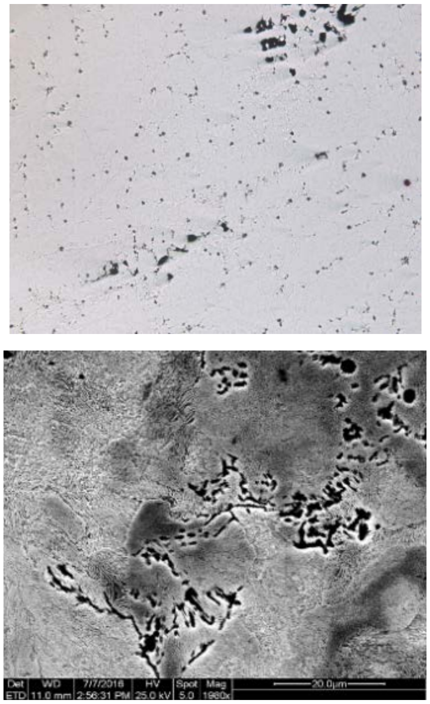

Figure 3. Left: Un-etched microstructure of weld center of the web. Right: Interconnected voids near heat-affected zone region at the top of the rail.

In-Track Testing at FAST

In October 2016, seven test welds were installed on a 5-degree curve with 4 inches of superelevation. Five full section high hardness thermite welds were installed on the high rail and two of the test welds were installed on the low rail of the curve.

The operation was performed by TTCI's weld team and pre-heating and all operational parameters were kept the same as a standard Orgo-Thermit thermite weld process. Special attention was given to pre-heating time and temperature to ensure that the data was correlated to the performance of the welds. TTCI engineers conducted visual inspection, hardness measurements, and longitudinal profiles of all the weld running surfaces as soon as the welds were installed. These measurements were taken and will continue to be taken at varied intervals throughout the test.

As of November 2018, the welds have accumulated 157 million gross tons (MGT) of traffic. Running surface hardness measurements are shown in Table 1.

Table 1. Running Surface Hardness Measurements at Installation and at 152 MGT. Negative and positive designates the direction of decreasing (negative) and increasing (positive) mile post numbers.

Running Surface Hardness at Installation (BHN)							
Weld #	Hardness Measurement Location						
	Parent Rail (Negative)	Heat Affected Zone (Negative)	Weld Material (Negative)	Weld Center	Weld Material (Positive)	Heat Affected Zone (Positive)	Parent Rail (Positive)
01	400	283	330	304	294	329	337
02	398	274	300	346	288	340	374
03	373	280	312	368	290	355	373
04	360	290	370	331	294	368	377
05	335	245	301	330	266	288	320
06	330	289	365	315	272	310	336
07	345	235	345	266	228	252	349

Running Surface Hardness at 155 MGT (BHN)							
Weld #	Hardness Measurement Location						
	Parent Rail (Negative)	Heat Affected Zone (Negative)	Weld Material (Negative)	Weld Center	Weld Material (Positive)	Heat Affected Zone (Positive)	Parent Rail (Positive)
01	420	369	420	401	360	418	421
02	421	374	424	411	317	394	417
03	421	358	426	398	356	413	430
04	441	325	411	386	356	400	413
05	432	318	398	404	332	429	420
06	429	387	408	404	360	423	435
07	423	387	401	421	369	411	433

Profiles of a test weld located on the high rail and a test weld located on the low rail are shown in Figure 4.

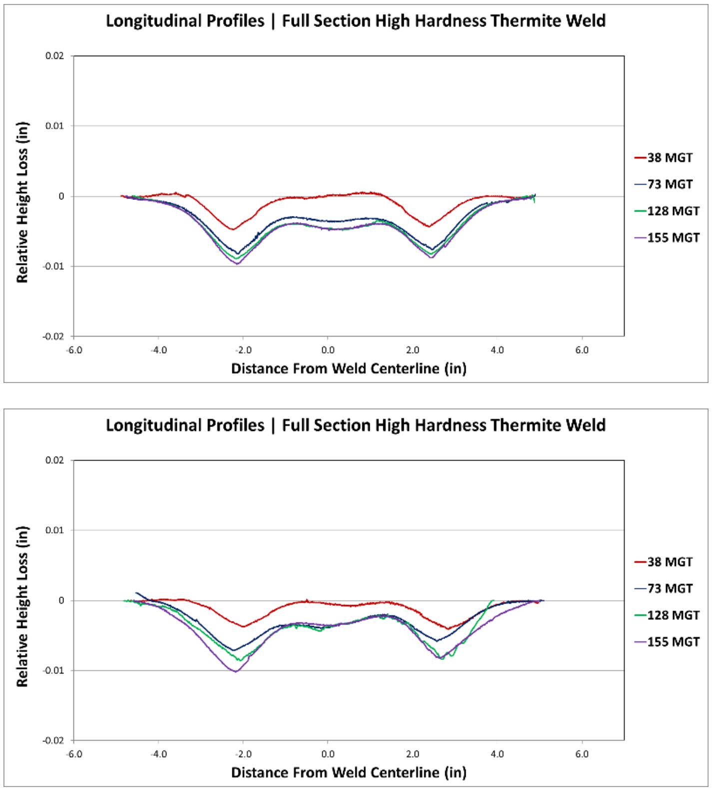

Figure 4. Top: Longitudinal profile of a full section high hardness thermite weld located on the high rail. Bottom: Longitudinal profile of a full section high hardness thermite weld located on the low rail

Routine maintenance was done in the test section including surfacing, repairing broken plates, ties or spikes if needed however, no grinding was performed. In-track testing of the full section, high hardness thermite welds show that the welds are wearing less than head alloyed thermite welds that were previously located in the same curve. The full section high hardness welds and the previous welds located in this curve show two spots in the profiles that have more wear and deformation which are the heat-affected zones. The increased wear in these locations is due to the softer microstructure that makes up the heat affected zone.

The difference with the full section high hardness thermite welds versus the previous welds is lower amount of wear in the weld material location which is located from about -1.0 inch to 1.0 inch in the profile graphs in Figure 3. At 128 MGT the full section high hardness thermite weld material on average has worn about 0.002 inch since installation compared to the head alloyed weld profiles in the previous study[1] which at similar MGT the weld material wore to about 0.007 inch. To date there has been no evidence of rolling contact fatigue (RCF) or shelling initiating on the running surface of the welds.

CONCLUSION

Full section high hardness welds pre-installed in 136RE premium head-hardened rails were evaluated to determine hardness, slow bend data and microstructural analysis using optical and scanning electron microscopes. Laboratory evaluations proved that the welds were safe for in-track testing.

After 156 MGT of in-track testing at FAST, the full section, high hardness thermite welds exhibit less wear than standard thermite welds and less than head alloyed thermite welds that were previously tested in the same curve.

References

1. Gutscher, Dan, and Joseph LoPresti. "Testing of Head Alloyed Thermite Welds at Facility for Accelerated Service Testing" *Technology Digest* TD-13-029. AAR/TTCI, Pueblo, CO, November 2013.

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