

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

Laboratory Evaluation of Robotic Slot Weld for Railhead Repair

by Joseph Kristan

Summary

An alternative repair weld has been developed by Holland Company that can be used for field repairs of the railhead. This process uses robotic gas metal arc welding (GMAW) and repairs head defects to a reported maximum depth of 1.375 inches.

Transportation Technology Center, Inc. evaluated weld specimens under an array of laboratory tests at the end of 2003 and earlier this year. The laboratory research effort was conducted under the guidance of the Engineering Research Committee to determine the applicability of the welds for revenue service. The Association of American Railroads (AAR) funded this work.

The GMAW or "slot welds" met or exceeded each of the test parameters compared to the performance of the thermite and electric flash butt welds. Installation of 12 slot welds for further evaluation began in early March 2004 under the direction of the Heavy Axle Load Research Committee at the Facility for Accelerated Service Testing. The welds have accumulated almost 50 million gross tons (MGT) to date without remedial repair or replacement. The AAR and the Federal Railroad Administration (FRA) jointly funded this work.

The process begins after a defect has been identified in the railhead with accurate mapping by ultrasonic testing. The defect is then removed from the railhead by milling. The milling process, once prepared, requires approximately 2 minutes to complete with a full traverse of the railhead, according to Holland Company. The milled region is inspected once again using magnetic particle examination to ensure that all of the transverse defect has been completely removed from the railhead. The robotic gas metal arc welder and fixturing are then installed on the rail in preparation for welding. Once the welder is prepared, the slot is preheated using induction heating. The robotic welding process begins immediately after preheating and requires approximately 5 minutes to complete. The entire process is reported to take 35 to 45 minutes from the time the welding truck arrives until it leaves the site. The weld installation time will be confirmed once the production welding equipment is completed at Holland Company. Timing is consistent with that for installing a single thermite weld.

An obvious benefit of the slot weld is that the web and base of the rail are unmodified. The weld extends only through the head of the rail in which the defect is present. This performance was confirmed by slow bend testing with four specimens exceeding the capacity of the test equipment with the rail base in tension.



INTRODUCTION AND CONCLUSIONS

Several hundred thousand thermite and flash-butt welds are installed in North American railway systems each year. These welds provide a suitable joint through the cross section of the rail. However, neither type possesses mechanical performance equal to the parent rail (TD02-026, "Bending Fatigue Properties of Rail Welds"). Thus, to optimize the performance of continuously welded rail, these welds should be kept to a minimum. An alternative repair weld has been developed by Holland Company and can be used for field repairs of the railhead. This process uses robotic gas metal arc welding (GMAW) and can be used for the repair of head defects to a reported maximum depth of 1.375 inches.

The weld is designed for the repair of shallow vertical defects in the head of the rail as identified by a detector car. There are two major advantages to this welding process: (1) the weld does not compromise the web or the base of the rail and (2) the welding is robotic and should yield consistent performance and reproducibility. The use of this weld repair method provides a rail in which the web and especially the base are not influenced by the presence of a weld in the tensile stressed regions of the rail. With proper preheat and setup, these welds should be reproducible from rail to rail, if the rail type is the same. Thus, human error is minimized.

Weld specifics include a maximum 1.375-inch-depth repair below the railhead with an initial 1.00-inch-width gap at the rail surface. Subsequent to welding, the final dimensions are significantly different from the original gap due to melting of the rail at the rail/weld interface, as Figure 1 shows. The depth of cut and subsequent weld repair is reported to be held constant independent of rail wear to ensure reproducibility in the process. The total time of repair from arrival to departure of the weld crew is reported to be approximately 35 to 45 minutes, which is consistent with the installation of a thermite weld. The initial GMAW robotic slot weld field production unit is scheduled to be completed this September. The unit will be further evaluated in the field to document the process and performance with initial welding trials to begin in September at the Holland facility in Crete, Illinois.

Prototype slot welds were evaluated in the laboratory under the direction of the Engineering Research Committee. The slot welds are currently being evaluated at FAST under the guidance of the HAL Research Committee. The laboratory and preliminary FAST results are:

- Two slot welds passed rolling load testing (2-million cycles)
- Slow bend test performance equivalent to rail (base in tension)
- Slow bend test consistent with thermite weld (head in tension)

- Impact test performance of slot weld fusion line exceeded that of the thermite weld, electric flash butt (EFB) weld, and parent rail.
- GMAW slot weld tensile strength and elongation consistent with EFB weld
- Hardness variation within both laboratory and FAST test weld groups – reported to manufacturer
- Voids observed in three laboratory test welds and seven of twelve FAST test welds – reported to manufacturer

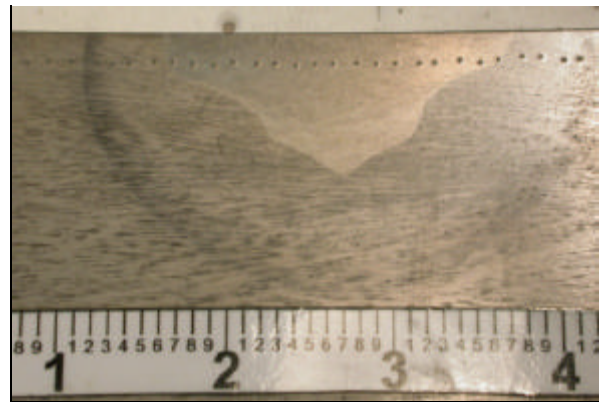


Figure 1. Cross section of finished GMAW robotic rail slot weld. The depth of penetration below the rail surface for this test weld was 0.875 inch.

Laboratory Testing

The Holland GMAW robotic railhead slot weld was fully evaluated in the laboratory by TTCI prior to installation at FAST. The test regime included rolling load, slow bend, Charpy impact, tensile, longitudinal and transverse hardness testing, micro- and macro-examination, and radiography and ultrasonic testing. The slot test welds were installed in Rocky Mountain Steel Mills (RMSM) DHH 136RE rail; whereas, the EFB welds were installed in RMSM HCP type 136RE. The thermite welds used for comparison are a commonly used commercial type installed in RMSM DHH 136RE rail. Different rail types were used due to material availability at the various locations for which test welds were manufactured. All of the slot and EFB welds were manufactured at the Holland facility in Crete, Illinois. The thermite welds were manufactured here at TTC.

Rolling Load Testing

Two test welds each sustained the required 2-million cycles of cantilever beam rolling load testing under a 59,400- pound wheel load for the 136RE rail tested. The wheel load applied during testing is much more severe than that in revenue service. Thus, the weld sustained these conditions.

Slow Bend Testing

The GMAW slot welded rail did not fracture in slow bend testing with the base in tension. In addition, it performed similarly to the thermite weld with the head in tension. The average deflection and modulus of rupture for the testing of four slot and four thermite welds with the head in tension were 0.63 inch and 0.68 inch, respectively, and 144 ksi and 146 ksi, respectively.

Weld Impact Testing

The slot weld fusion lines were impact tested at room temperature as a method of quantifying the quality of the weldment. Charpy impact tests of the slot weld were compared with those of the base rail, EFB and thermite welds. Eight tests of each type were performed to obtain the data. The weld fusion line was centered in the test specimen for evaluation. The impact strength at the slot-weld fusion line surpassed both that of the thermite and EFB welds tested but also the head hardened parent rail material. The average impact strength of the slot-weld fusion line was 5.75 ft-lbs with a standard deviation of 1.10. The thermite and EFB weld fusion lines were 3.16 ft lbs and 2.49 ft lbs, respectively, with a standard deviation of 0.33 and 0.26, respectively. The head hardened rail material had impact strength of 3.93 ft lbs with a standard deviation of 0.79.

Tensile Testing

Tensile testing was also performed which showed the GMAW slot weld tensile properties to be consistent with that of the EFB weld. The tensile specimens were prepared with the fusion line in the center of the gage length for evaluation. Two specimen of each type were tested to obtain the data shown in Figure 2. The tensile strength of the slot weld is consistent with that of the EFB at 149.4 ksi and 150.1 ksi, respectively. These both exceeded that of the thermite weld at 116.1 ksi. The elongation and reduction of area were again consistent for the slot and EFB welds at 8.5 percent and 8.5 percent (elongation) and 32.7 percent and 27.5 percent (reduction of area), respectively. The elongation and reduction of area of the thermite weld were 2.2 percent and 1.2 percent, respectively.

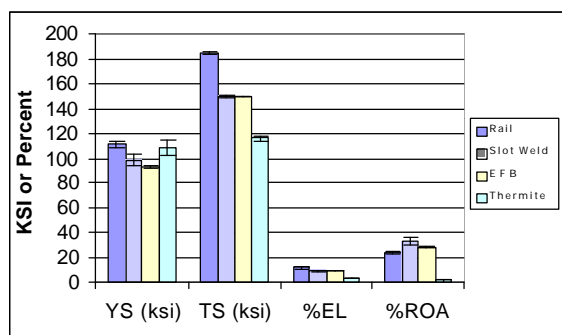


Figure 2. Tensile test results of the GMAW slot weld along with EFB and thermite welds as well as head hardened rail.

Weld Hardness

The longitudinal and transverse hardness of the GMAW slot welds were measured using two test welds. The longitudinal hardness was determined by sectioning the specimen vertically along the length of the rail and surface grinding the cut face flat to allow accurate hardness measurements. The transverse hardness was performed by sectioning the rail transversely through the center of the weld. This provided hardness data at depth consistent with AREMA specification for the internal hardness determination of high strength rail (Chapter 4, Section 2.1.3.3 of the AREMA Manual). The longitudinal hardness was measured 0.1875 inch below the head of the rail 6 inches on either side of the weld center at 0.125-inch increments. The transverse hardness measurements were made at 0.125-inch increments to the bottom of the railhead.

Variation in hardness at or adjacent to the weld allows for plastic deformation and batter at the areas of the running surface leading to impact loading. This increased loading from impact can produce further deterioration of these regions producing a cycle of rail damage. Thus, assuring the weld and adjacent rail heat affected zones (HAZ) are of consistent hardness with the parent rail is of obvious importance.

The minimum longitudinal hardness measured in the slot weld HAZ was 28 HRC, which converts to 293 HB. The minimum HAZ hardness of the thermite weld was 23 HRC, which converts to 261 HB with a parent rail hardness of 40.5 HRC or 389 HB. The minimum rail hardness because of the EFB weld was 31 HRC or 314 HB in rail with a hardness of 42.5, which converts to 406 HB. The width of the slot and thermite HAZs are consistent as Figure 3 shows. Thus, the longitudinal hardness resulting from the slot weld is consistent with that of a thermite weld with a slightly lower drop in hardness because of the weld.

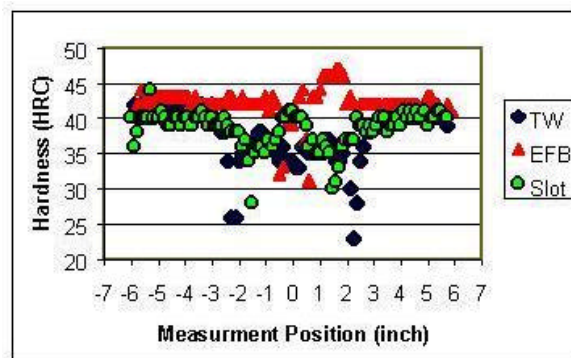


Figure 3. Weld longitudinal hardness as measured for each of the GMAW slot, thermite and EFB welds. The zero position is the center location of each of the respective welds.

The transverse hardness measured at the center of the weld to determine weld hardness as a function of depth showed the thermite weld hardness to be consistent with depth. The hardness at 0.125 below the surface of the thermite weld was 30 HRC or 306 HB with a hardness of 33 HRC to 34 HRC (328 HB to 336 HB) at the bottom of the head. The slot weld hardness was more variable with depth but more closely matched that of the parent rail with hardness at 0.125 inch of between 40 and 45 HRC (384 and 429 HB). The slot weld hardness at the bottom of the railhead was 32 HRC (321 HB). The hardness of the parent rail was 389 HB at a depth of 0.1875 inch below the rail surface. Thus, the slot weld appears to better match the hardness of the parent rail and thus should inhibit batter at the weld based on this testing.

Macro and Micro Weld Examination

The macrostructure and microstructure of the slot welds were closely examined with the sectioning and preparation of three separate welds. The macrostructure was consistent with a properly made weld in high carbon steel as was the microstructure. The microstructure of the slot weld is bainitic with some intermixed pearlite colonies. This differs from the parent rail which has a fully pearlitic structure. One of the specimens revealed voids and/or inclusions near the surface of the rail adjacent to the fusion line as Figure 4 shows. They were not observed at any other locations or within any other specimens examined. The observed microstructures and anomaly were reported to the manufacturer.

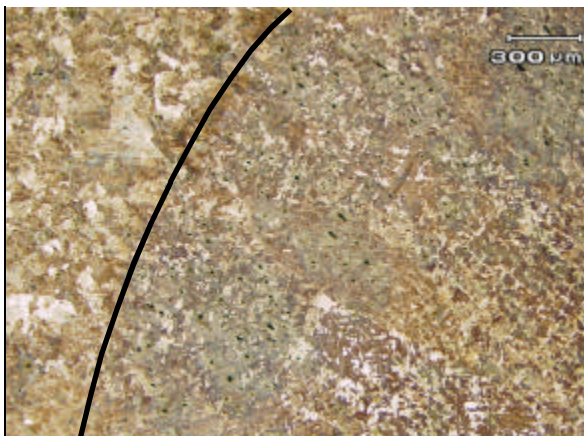


Figure 4. Microstructure of GMAW slot weld with black line demarcating the approximate fusion line. Voids and/or inclusions are present in the slot weld just to the right of the fusion line (black marks).

Radiography and Ultrasonic Testing

Three laboratory slot welds and seven of twelve FAST test slot welds contained voids as identified by both radiography and ultrasonic testing with sizes ranging from 0.032 inch to 0.1875 inch. The identified anomalies were reported to the

manufacturer. Holland is currently addressing the anomalies by changes in the welding process and equipment from that of the prototype used to produce the test welds.

FAST SERVICE TESTING

The acceptable performance of the slot welds from laboratory testing led to installation of 12 test welds in Section 3 at FAST, which is a 5 degree curve with nominal 4-inch superelevation. The welds were installed in RMSM OCP 136 RE rail at the Holland facility in Crete, Illinois. This rail was chosen because it is a high-carbon modern head hardened rail. The assumption being that if the welds performed well in the higher hardness, higher carbon rail, they should perform equally or superior in lower hardness and lower carbon rails with all other rail variables being equal.

The prototype test welds were installed in the OCP rail at the Holland facility and the rail shipped to TTC for testing. The eight 40-foot rails containing the slot welds were installed using thermite welds to maintain continuously welded rail. Seven of the 12 welds were identified with anomalies using ultrasonic inspection during rail installation. The sizes of the anomalies range from 0.0313 inch to 0.1875 inch. None, however, has grown nor have any welds required maintenance through 47 MGT of traffic.

FUTURE WORK

Future evaluation of the GMAW robotic slot weld will include ultrasonic testing of welds made with the production unit. This will evaluate the production weld performance with reported changes made from the prototype unit to eliminate the identified anomalies. The weld installation procedures, required time, and equipment will be audited when available. The evaluation of revenue-service GMAW slot weld installation(s) will be performed with the cooperation of the railroads and the continued cooperation of Holland Company. This work will be conducted to ensure acceptable performance of this component in the revenue service environment.

CONCLUSIONS

The Holland GMAW robotic slot welds, as produced by prototype welding equipment, performed acceptably through a rigorous regime of laboratory tests and are also performing acceptably in trials at FAST. Though voids were identified in several of the test welds, their presence has not contributed to any performance issues. Additionally, the manufacturer reports appropriate changes have been or will be made to the process to eliminate the anomalies produced by the prototype unit. This will be investigated with the manufacture of additional slot welds for testing as well as the monitoring of revenue service test installations. Several revenue-service test weld installations are planned for 2004.

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