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Initial Results of Robotic Slot Weld and Reduced Consumption EFB Weld Testing at FAST

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Summary

An evaluation is being performed at Facility for Accelerated Service Testing (FAST) at the Transportation Technology Center (TTC), to quantify the performance of both prototype gas metal arc weld (GMAW) railhead robotic slot welds and reduced consumption electric flash butt (EFB) welds. Both tests were originally installed at FAST in early March of 2004 with 12 slot welds and six reduced consumption welds.

- None of the reduced consumption EFB welds have produced a detectable ultrasonic indication or required maintenance. The originally installed six accumulated more than 216 million gross tons (MGT) traffic. Nineteen reduced consumption welds installed later have accumulated between 31 and 76 MGT without issue.
- Seven of the original 12 prototype GMAW robotic slot welds were identified with anomalies using ultrasonic inspection during rail installation. Hardness was found to vary considerably among the 12 welds.
- One prototype railhead repair slot weld was removed after 67 MGT due to a flaw that had propagated through 20 percent of the rail head area. A second weld was removed after 122 MGT as a result of flaw estimated at 10 percent of the head area.

These alternative repair weld methods have been developed by Holland Company and are designed to improve both efficiency and performance. The prototype slot weld, which uses a robotic gas metal arc welding technique, is capable of repairing shallow vertical defects in the head of the rail to a depth of 1.125 inches. The reduced consumption electric flash butt weld, as the name implies, reduces the amount of rail consumed in the conventional EFB process by nearly 50 percent. The reduction in rail consumption improves the utility and efficiency of EFB welding for field and closure welding. One potential use for the reduced consumption EFB method is rail repair by the consumption of vertical defects in the rail by simply flashing and forging out the defect in track. The reduced rail consumption decreases the influence on neutral rail temperature in comparison to the conventional EFB process which can consume as much as 1.5 inches of rail.

Transportation Technology Center, Inc. (TTCI) evaluated both slot and reduced consumption EFB weld specimens under laboratory tests prior to FAST service testing. The reduced consumption EFB laboratory weld performance was found to be consistent with that of conventional EFB welds. The GMAW slot welds met or exceeded each of the test parameters as outlined in TD-04-011.[1] The laboratory research efforts have been guided by the Engineering Research Committee and funded by the Association of American Railroads (AAR). The FAST evaluations have been guided by the Heavy Axle Load Research Committee. The AAR and Federal Railroad Administration (FRA) jointly fund the FAST Program.

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INTRODUCTION AND CONCLUSIONS

Several hundred thousand thermite welds are installed in North American railway systems each year. These welds provide a suitable joint through the cross section of the rail. However, they do not possess mechanical performance equal to the parent rail.[2] Electric flash-butt welds (EFB) fail at a lower rate than thermite welds,[3] but the conventional application of this technology can consume as much as 1.5 inches of rail, reducing its applicability. Improving the utility of the EFB weld would allow further utilization in field installations.

The Holland Company (Holland) has been developing a method of producing a robust EFB weld, with a consumption of approximately 50 percent less rail than conventional production, as well as developing a slot weld designed to repair rail-head defects without intrusion into the web or base. Each of these welds was tested in the laboratory and with acceptable results progressed to evaluation under the heavy axle load environment at FAST.

The FAST evaluations included the initial testing of 12 prototype slot welds and six reduced consumption welds all installed in test rail at the Holland facility in Crete, Illinois. These welds along with later slot test welds were installed in Section 3 of FAST, which is a 5-degree curve with 4 inches of superelevation. Subsequently, two additional prototype slot welds were installed in rail by Holland at their Pueblo, Colorado, facility and shipped to TTC for testing. Also, 19 additional reduced consumption welds were installed in track at FAST in an effort to reduce the number of thermite welds and increase the number of test welds. These welds were dispersed throughout the FAST loop, with most being in Section 3. None of the reduced consumption EFB welds have produced a detectable ultrasonic indication or required maintenance. The six originally installed accumulated more than 216 MGT traffic. The 19 reduced consumption welds installed subsequently have accumulated between 31 and 76 MGT without issue.

Seven of the original 12 prototype GMAW robotic slot welds were determined to have anomalies using ultrasonic inspection during rail installation. Hardness was found to vary considerably among the 12 welds. The hardness difference between the softest and hardness prototype slot welds measured was more than 100 HB. This variability in hardness along with the presence of ultrasonic indications suggest the manufacturing process was not yet consistent or fully developed at the time the prototype welds were made in February of 2004. Consequently, two welds produced internal fatigue cracks, which required removal from track.

By 67 MGT, one the prototype railhead repair slot welds was removed due to the indication of a flaw as identified by ultrasonic testing. The ultrasonic inspection report identified that the flaw had propagated through 20 percent of the rail head area. A second weld was removed after 122 MGT as a result of an ultrasonic indication estimated at 25 percent of the head area. Both welds were further evaluated with radiography and micro and macroscopic evaluation after sectioning of the samples, which revealed cracks that initiated at voids in the welds. The size of the cracks found in the first weld that was removed was consistent with the estimated size determined by ultrasonic inspection. But, the extent of cracking in the second weld was less than the original estimate, at approximately 10 percent of the head area. The complex shape of the cracks (Figure 1), and multiple crack locations produced multiple reflectors for the ultrasonic signal, leading to the overestimate.

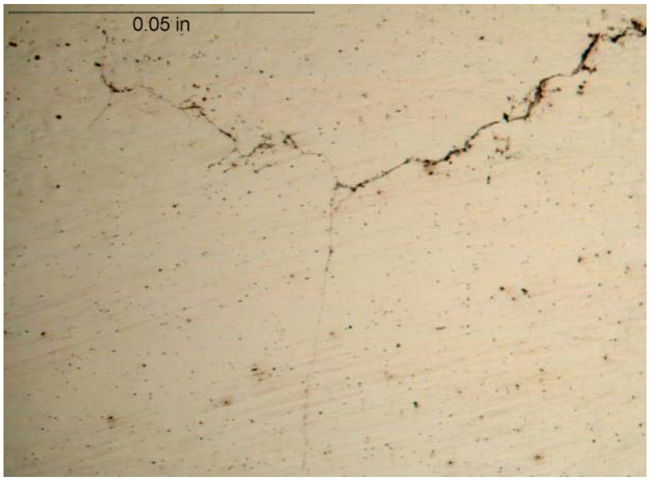

Figure 1. Fatigue Crack in the Second Slot Weld

The ultrasonic inspection procedure has been modified since the second weld was removed, to include a more representative calibration process that uses both a dual element 0-degree and a wedged 70-degree inspection approach.

Three of the remaining nine slot welds (one was removed for track maintenance not related to the slot welds) show ultrasonic indications of crack growth but all are less than 8 percent of the rail head area at this time. Thus, 42 percent of the originally installed prototype slot welds have either required removal due to the presence of a flaw greater than 10 percent of the rail head area, or currently contain a flaw that is growing.

Holland reports that they have developed a more robust production slot weld system with improved performance and capabilities, building on the results of these and other tests. The limited number of test welds produced for testing at FAST with the improved system (two test welds) contained neither ultrasonic anomalies nor have they required maintenance or removal. An attempt to install additional GMAW slot welds in track for test at FAST were unsuccessful as the technique developed in the laboratory was, at the time, not capable of repairing rail head defects on superelevated track. The track section available for test at FAST, which also contained the 12 prototype slot welds, was Section 3 with nominal 4-inch superelevation. The robotic slot weld technique at that time was not conducive to welding in superelevated track. Thus, the two slot welds produced for test with the production-welding unit were produced out-of-track by Holland on a level surface at their Pueblo facility.

APPLICATION AND UTILIZATION

The reduced consumption EFB weld is advantageous for field applications. Because of the consumption of rail during EFB welding, the rail must be unconstrained away from the weld to allow rail movement during welding for closure of the continuously welded rail (CWR). The consumption of rail also influences the neutral temperature of the rail in the vicinity of the closure weld. Reducing the amount of rail consumed directly reduces the need to remove clips constraining the rail, while reducing the change in rail neutral temperature. Thus, Holland has developed an EFB technique that consumes approximately 50 percent less rail than the conventional process. Consuming only approximately 0.75 inch of rail in the making of the EFB weld, makes the process more applicable to closure welding for the elimination of rail defects in the field.

The GMAW robotic slot weld is designed for 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 base (especially critical) 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 and site-to-site, if the rail type is the same. Thus, human error should be minimized.

Weld specifics for the current slot weld include a maximum 1.125-inch-depth of repair below the railhead with an initial 1-inch-width gap at the rail surface. An example rail is shown in Figure 2.

Figure 2. Rail Head Milled for GMAW Robotic Slot Weld

Final weld dimensions are significantly larger than the original gap due to melting of the rail at the rail/weld interface as shown in Figure 3.

Figure 3. Completed Slot Weld (etched to enhance visibility)

The depth of cut and subsequent weld repair are to be held constant independent of rail wear to ensure reproducibility in the process. Total repair time was between 35 to 45 minutes.

FAST Service Testing of GMAW Robotic Weld

TTCI fully evaluated the Holland GMAW robotic railhead slot weld in the laboratory 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, radiography, and ultrasonic testing.[1] The prototype slot welds met or exceeded each of the test criteria and thus progressed to service evaluation at FAST.

The acceptable performance from laboratory testing led to installation of 12 prototype test welds in Section 3 at FAST. The welds were installed in Rocky Mountain Steel Mills (RMSM) OCP 136 RE rail, and 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 as well or better in lower hardness and lower carbon rails with all other rail variables being equal.

The eight, 40-foot rails containing the slot welds (and six reduced consumption welds) were shipped from the Crete facility and installed at FAST. Thermite welds were used to produce continuously welded rail. Seven of the 12 welds were identified with anomalies that ranged from 0.03 to 0.19 inch using ultrasonic inspection during rail installation.

Prototype test welds with and without internal flaws were installed for comparison. Closely monitoring the test welds with ultrasonic inspection (weekly detector car and hand mapping) provided useful information in regard to crack initiation and propagation. Since installation, five of the 12 test welds sustained detectable fatigue crack growth. Two of these were removed. Crack growth has been identified in the three additional welds in track with crack propagation indicating less than 8 percent of the head area. A third weld was removed for maintenance purposes at FAST, but did not contain an ultrasonic indication. The hardness of the welds was measured subsequent to installation and found to vary substantially within the group, with the differences of more than 100 HB. However, the presence of fatigue cracks does not correlate with either a hardness level or the size of the initial indication identified.

The two test welds later produced at the Holland facility using the production slot weld unit, then installed at FAST, have accumulated 76 MGT without issue. Thus, the slot welds either removed because of defects or with indications of propagating defects constitute a defect rate for the entire 14 prototype slot welds of 36 percent.

Service Testing of Reduced Consumption EFB Welds at FAST

Prior to installation at FAST, TTCI and Holland tested reduced consumption electric flash butt welds in the laboratory to measure their performance compared to the AREMA Specification for the Quality Assurance of Electric-Flash Butt Welding of Rail. All welds were produced in RMSM HCP rail. The five welds tested by Holland and the three welds tested by TTCI exceeded the requirements for slow bend testing for high strength steel shown in Table 1. In addition, TTCI performed fatigue testing on seven samples with the base in tension. The reduced consumption welds performed as well as conventional EFB welds.

Table 1. AREMA Requirements for EFB Welds in High Strength Steel[4]

Grade	Modulus of Rupture (lbs/in^3)	Deflection (in)
High strength (341 BHN min)	125,000	0.75

Six reduced consumption test welds were produced by Holland in RMSM OCP rail for installation in test at FAST and were installed using thermite welds to produce a CWR. These welds were installed at the same time and location as the slot welds. The reduced consumption flash butt welds have accumulated 216 MGT without issue or incident. In order to augment the evaluation of the small sample size of reduced consumption test welds, an additional 19 welds were installed by Holland, shown in Figure 4.

Figure 4. Holland Installing Reduced Consumption Test Welds in Track at FAST

These welds eliminated 27 thermite welds and five rail defects and are being monitored for performance. The reduced consumption test welds have accumulated between 31 and 76 MGT of traffic, without issue. Thus, the failure rate is zero.

CONCLUSIONS

Holland GMAW robotic slot welds, as produced by prototype welding equipment, performed acceptably through a rigorous regime of laboratory tests but produced a 36 percent defect rate in test at FAST. Though voids were identified in several of the test welds prior to installation, it was decided to install the slot welds for testing at FAST to learn from the available welds. Additionally, the manufacturer reports appropriate changes have been or are being 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 at FAST.

The failure rate for the 25 reduced consumption test welds at FAST is zero with welds ranging in tonnage accumulation from 31 to 216 MGT. These welds will continue to be monitored at FAST, but it is suggested to progress to revenue service to continue the evaluation based on the current results.

FUTURE WORK

Future evaluation of the GMAW robotic slot weld may include ultrasonic testing of welds made with the production unit and installed in track at FAST. This would evaluate the production weld performance with reported changes made from the prototype unit to eliminate the identified anomalies. The evaluation of revenue-service GMAW slot weld installation(s) may also be performed (Holland began revenue service installation late in 2005). Future revenue service trials will be performed with the cooperation of the railroads and Holland. This work will be conducted to ensure acceptable performance of this component in the revenue service environment.

The reduced consumption EFB welds will continue to be monitored at FAST along with additional testing in revenue service. A limited number of these welds have previously been installed in revenue service. However, a larger number, 20 to 30 welds in a localized area will allow monitoring in revenue service by a team of railroad and TTCI engineers to further evaluate and quantify the utility and performance of this weld type.

Acknowledgements

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