AAR Rail Welding Research – Recent Developments

Daniel Gutscher, Transportation Technology Center, Inc.

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ABSTRACT

As rail traffic continues to grow, the need for improved rail welding processes also grows. The Transportation Technology Center, Inc. under the Association of American Railroads’ Strategic Research Initiative for Improved Rail Welding is addressing this need through research directed toward improvement of traditional rail welding processes as well as through research and development of alternative rail welding processes. Two different vibration-based thermite weld treatments are being examined for potential benefits such as reduction of residual stresses and increased weld fatigue life. Electroslag welding is being developed as a potential alternative rail welding process with expected benefits to include a reduction in overall welding time and an improvement in weld quality over standard thermite welds. The Improved Rail Welding Strategic Research Initiative also tests new and improved rail weld products submitted by weld manufacturers for both laboratory and heavy axle load (HAL) performance. Recent weld developments have concentrated on improved weld geometries and railhead repair welding.

INTRODUCTION

Capacity persists as a major focus of railroad concern especially in light of the rising costs of fuel. As the demand and need to ship more and more by rail grows, the railroad industry continues to respond by finding ways to increase capacity. Increasing the tonnage on any given piece of track, whether through increased traffic or increased car
loads, results in accelerated wear and degradation of existing track components including rail welds. The Association of American Railroads (AAR) is addressing this issue in regard to rail welds through its Strategic Research Initiatives (SRI) Program for improved rail welding. The Transportation Technology Center, Inc. (TTCI), a subsidiary of the AAR, in conjunction with the SRI Program conducts research aimed at improving the performance of rail welds.

The primary focus of the improved welding SRI is to advance and test rail welding technologies with the goal of improving the performance of rail welds under HAL traffic. This is accomplished through several parallel paths of research. First, research is directed toward advancing existing welding technologies through changes to both weld process and design. Another path of research involves analyzing and testing new or improved weld technologies developed by the rail welding industry (e.g., thermite railhead repair welds). The SRI also seeks to explore and develop viable alternative processes to the existing rail weld processes. Finally, the SRI Program is investigating weld treatment methods to determine potential benefits to weld quality or longevity. Each of these paths is discussed in the following sections.

**Improving Thermite Weld Design**

Research conducted by the University of Illinois at Urbana Champaign (UIUC) resulted in a number of suggested improvements that could be made to existing thermite welds. The suggested improvements included changes to both the weld process as well as weld design. Of the proposed design changes, TTCI selected two specific changes for further investigation, namely modified weld geometry and increased weld gap. With the
assistance of Orgo-Thermit, Inc., a thermite weld, referred to as advanced geometry weld, was designed that incorporated the selected changes and welds were produced for testing.

The chosen weld modifications benefit the weld in several ways. Increasing the weld gap serves to increase the amount of thermal energy available from the molten weld metal to aid in achieving proper melt back of the rail ends. This in turn reduces the criticality of preheating in establishing good fusion of the weld bond. The weld gap used for these welds was 1.5 inches compared to the standard 1-inch gap for typical thermite welds. Figure 1 shows the longitudinal cross sections for both the standard gap and increased gap welds. Modifying the weld geometry in stress-critical locations serves to increase weld longevity by eliminating or reducing stress risers where fatigue cracks are most likely to initiate. The area targeted for geometry changes is the transition region from the weld collar to rail profile. Figure 2 illustrates the changes made to the weld geometry. The weld collar flank angle—the angle that the collar intersects the rail—was reduced to between 30 and 35 degrees. In standard thermite welds, the flank angle can range from 45 degrees up to 90 degrees. In addition to the change in flank angle, a toe radius of approximately 1/8 inch was added at the intersection to further reduce stress risers.
TTCI tested the advanced geometry welds in the laboratory to determine if the welds would meet AREMA specifications for thermite welds. All of the welds met AREMA requirements. Additionally, TTCI arranged for the UIUC to perform full-scale fatigue testing in 4-point bending. Under laboratory loading conditions the advanced geometry welds experienced a 34 percent increase in fatigue life over standard geometry thermite welds. Following laboratory testing, TTCI installed 10 advanced geometry welds at the Facility for Accelerated Service Testing (FAST) on the High Tonnage Loop as part of a
larger experiment aimed at testing increased gap thermite weld performance under heavy axle load traffic.

Unfortunately, the testing at FAST did not produce useful data for determining any benefit that geometry modification may have provided due to the predominance of shelling as the primary failure mode during the test, as opposed to the expected vertical fatigue crack propagation mode of failure. However, the test did improve the understanding of how welds fail under HAL operating conditions. The findings of this test are scheduled to be reported by TTCI in an upcoming Technology Digest.

**Thermite Weld Treatments**

Another way to improve the performance of thermite welds is through weld treatments. Weld treatments can be performed either during the welding operation or as a post-weld process. The purpose and application of weld treatments varies according to the desired weld performance enhancements. Some examples of weld characteristics that may be selected for improvement through treatment include railhead surface hardness, residual stress, wear performance, microstructure, and grain size. Weld treatment processes likewise are also varied and may include such methods as heat treatments, peening, and vibration.

Current research being conducted under the SRI Program is focusing on weld enhancements through two different vibration treatments. The first is a sub-harmonic frequency vibration that is applied during the welding process in an attempt to control gross porosity, as well as improve overall weld microstructure. The second is a high frequency post-weld vibration treatment developed by Applied Ultrasonics called Ultrasonic Impact Technology® (UIT). This treatment seeks to minimize the effects of
stress risers at critical weld geometries by reducing residual stresses and imparting localized compressive stresses to improve the fatigue life of the welds.

**Vibration Treatment of Thermite Welds**

Low frequency vibration treatment was applied using a mechanical shaker that was attached to the railhead about 3 feet from the thermite weld. Vibration was initiated just prior to preheating and was maintained throughout the welding process and for 25 minutes after the weld was tapped and poured.

The thermite welds made in this way were then sectioned and examined for any changes in microstructure and for effects on porosity, as tests conducted in early 2008 indicated that vibration had some effect on large porosity. While vibration treatment appears to reduce the amount of large porosity at certain critical locations, such as at the base to web fillet, a greater concentration of fine scattered porosity was observed near the weld centerline. No significant effects on microporosity or interdendritic porosity were observed.

**Ultrasonic Impact Treatment of Thermite Welds**

In 2007, Applied Ultrasonics sent an engineer to the Transportation Test Center in Pueblo, Colorado, to treat a series of thermite welds with UIT. The treatments were applied to the weld collar to rail transition along the web, web to base radius, and the base of the weld. Figure 3 shows the application of the UIT to the welds and the areas that were treated. Each treatment took approximately eight minutes to complete.

Treated welds were sent to Texas A & M University for full-scale fatigue testing. The results of this test indicated a potential increase in weld fatigue life between 50 to 170 percent. It should be noted that this increase was observed under laboratory
conditions while testing a single failure mode. Revenue service conditions can differ significantly from the laboratory loading environment, and, as a result, the predominance of other failure modes may limit the potential benefit of UIT treatments. Currently TTCI is making plans for testing UIT treated thermite welds at FAST and in revenue service.

![Figure 3: Application of Ultrasonic Impact Treatment to Thermite Welds](image)

**ALTERNATIVE RAIL WELDING PROCESS – ELECTROSLAG WELDING**

Electroslag welding is a wire welding process that uses electrical resistance heating of a molten slag pool to provide the heat necessary to melt the work pieces and consumables to produce a weld bond. Electroslag welding is primarily used in the welding of structural steels but has been adapted for welding of rail steels. Electroslag welding was first used to successfully weld rails at Oregon Graduate Institute in the 1980s as part of a program sponsored by the Union Pacific Railroad. As a result of the research, a patent was granted and several welds were produced for revenue service testing. The test welds
were removed after an indeterminate period of time with no recorded performance data, and the patent has since expired.

In 2000, Electroslag Systems Technology and Development (EST&D) again began developing electroslag for welding rail. In 2003, EST&D received an award from the Transportation Research Board’s (TRB) Innovations Deserving Exploratory Analysis (IDEA) program to continue development of the rail welding process. EST&D was able to advance the technology but did not reach the stated goal of “making a weld to meet the AREMA requirements for thermite welds.” Figure 4 shows the electroslag welding equipment used in production of welds, and Figure 5 illustrates a finished ESW weld.

![Figure 4: Electroslag Welding Equipment](image)
Electroslag welding has several potential strengths that can be beneficial in producing rail welds. Electroslag welding is an inherently clean welding process that produces high-quality welds that are relatively free of porosity and inclusions. Like thermite welding, the process does not consume rail that significantly reduces the time and labor required to make a weld. The overall setup is similar to a thermite weld using mold blocks placed around the weld joint. Weld times are also competitive with thermite welds. Unlike thermite welding, weld chemistry can be easily modified throughout the weld enabling the optimization of weld properties at targeted locations.

Because of the advances EST&D made under the TRB program, and the potential benefits of electroslag welding for joining of rail, TTCI identified electroslag rail welding as a viable potential alternative to traditional rail welding processes. In 2007, TTCI entered into a cooperative development agreement with EST&D in which EST&D would continue to develop electroslag welding under the SRI Program for improved rail welding. Several development milestones were established and a general timeline was developed to measure overall progress. Table 1 summarizes the various phases of the project.
Table 1: Outline of Electroslag Development Phases

<table>
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<tr>
<th>Phase</th>
<th>Description</th>
<th>Tentative Timeline</th>
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<tbody>
<tr>
<td>1</td>
<td>Weld analysis and preparation</td>
<td>2007</td>
</tr>
<tr>
<td>2</td>
<td>Produce ESRW welds to meet AREMA thermite weld requirements</td>
<td>2008</td>
</tr>
<tr>
<td>4</td>
<td>Continue process refinement and testing at FAST. Begin testing in revenue service</td>
<td>2009</td>
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Phase 1 of the project primarily focused on analyzing the advances made under the TRB IDEA program. Welds that were previously tested to failure in slow-bend testing were sectioned and examined under a microscope. The microstructure of the welds was fully pearlitic with the exception of martensite in several critical locations. Electroslag welding of structural steel typically uses copper cooling shoes to contain the weld. In the case of rail steels, which have higher carbon content than other steels, the cooling rates achieved with copper molds can be excessive and promote the formation of martensite. As a result, Phase 2 of the project is focusing on control of the welding thermal cycle through the use of different mold materials and through preheating, with the goal of producing welds that meet the AREMA requirements for thermite welds. Phases 3 and 4 of the project will build on the progress made in Phase 2 and will begin in-track testing of electroslag welds at FAST and in revenue service.

**Thermite Railhead Repair Welding**

The purpose of the railhead repair welds is to enable the repair of railhead defects without having to compromise rail integrity. This allows repair of the rail without changing the longitudinal stress of the rail. The idea of using thermite to repair head defects in rail is not new to the industry. In the 1980s, the Zokay process was explored by the Santa Fe Railway Company, but the process was never perfected and dropped out of service use.

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1 Two sample tables in the text, indicating the use of tables to organize data or information.

2 Reference or citation, indicating the need for further reading or exploration.
The process suffered primarily from problems with porosity and with distortion. Now, however, industry demand for a cost effective portable railhead repair process has prompted the two major thermite weld producers in North America to again adapt the thermite process for the repair of railhead defects.

TTCI began laboratory testing of the Orgo-Thermit, Inc. Head Repair Welds (HRW) in late 2007 and laboratory testing of the Railtech Boutet, Inc. Head Wash Repair (HWR) in early 2008. Laboratory testing included visual and ultrasonic inspection, hardness testing, slow-bend testing, macro inspection and microscopic inspection. Table 2 lists the welds tested and indicates the associated grind dimensions. Figure 6 shows a railhead ground in preparation for a full-head repair weld. All of the tested welds met the applicable requirements of AREMA for thermite welds. In-track testing at FAST of the Orgo-Thermit HRW welds began in early 2008, and Railtech Boutet HWR testing is scheduled to begin mid-2008.

<table>
<thead>
<tr>
<th>Manufacturer and Process</th>
<th>Width (in.)</th>
<th>Depth (in.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Railtech HWR</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Orgo HRW</td>
<td>2</td>
<td>1 1/8</td>
</tr>
<tr>
<td>Orgo Full HRW</td>
<td>2</td>
<td>Full Railhead</td>
</tr>
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</table>
CONCLUSION

Increasing the traffic volume over any given piece of track can result in increased wear and degradation of track components including rail welds. With the rapidly growing demand for improving the capacity of the North American rail network, improving rail weld performance is paramount. The AAR’s SRI Program is addressing this through the research and testing describe in this paper. If successful, implementation of these rail welding improvements will facilitate the safety and efficiency of the railways.

ACKNOWLEDGEMENTS:

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REFERENCES


Figure and Table Captions

Figure 1: Longitudinal Cross Section Macro-etches of 1 and 1.5 inch gap welds.

Figure 2: Detail Showing Geometry Modifications

Figure 3: Application of Ultrasonic Impact Treatment to Thermite Welds

Figure 4: Electroslag Welding Equipment

Figure 5: Conceptual Views of Electroslag Rail Weld

Figure 6: Railhead Ground in Preparation for Orgo Full-Head Repair Weld

Table 1: Outline of Electroslag Development Phases

Table 2: General Description of Railhead Repair Welds