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RESEARCH RESULTS

FRA OFFICE OF RESEARCH, DEVELOPMENT & TECHNOLOGY

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SOLID-STATE WELDING OF SIGNAL WIRE ATTACHMENT

SUMMARY

An essential component of railroad signaling systems is the attachment of signal wires to the rail. Railroad signaling systems detect track failures, prevent derailments, and alert signal crossing stations to approaching traffic. If these safety-critical attachments fail, rail traffic slows and crews must investigate and repair these systems. More reliable signal wire attachments can reduce uncertainty, improve safety, and reduce operational costs.

The Federal Railroad Administration (FRA) and EWI have worked together to investigate the causes of failures at these attachments and develop an alternative signal wire-to-rail attachment process. Early research findings are published on FRA's eLibrary: http://www.fra.dot.gov/eLib/details/L04424

In the developed solid-state joining technique, called friction welding, a brass stud is welded to rail at temperatures too low to form martensite, a brittle and undesireable steel microstructure that can form with other high-heat attachment processes. EWI designed and fabricated a prototype portable friction welder (Figure 1) for use on 136RE rail. This battery-powered system allows for studs to be attached to the web and head of rails.

In this research, EWI modified an earlier design of the brass stud to reduce the weld area and then developed new friction welding process conditions for the new design. The smaller weld area enabled the design of a small and lighter second-generation prototype welder. The design of the studs also allowed for wires to be removed and reattached during maintenance activities, without the need to produce an additional weld.

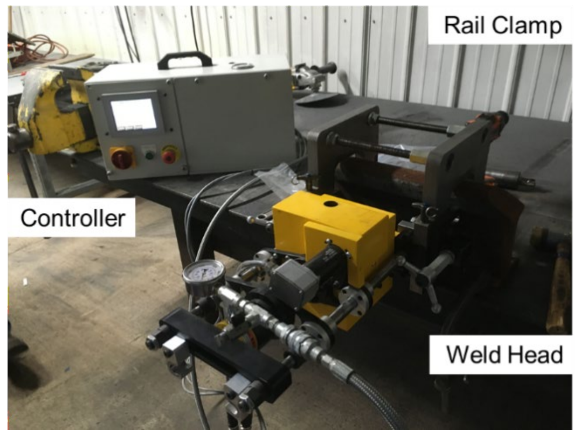

Figure 1. Prototype friction welder

Friction-welded stud attachments tests were made on the FAST track at the Transportation Technology Center (TTC) in Pueblo, Colorado. In-track testing during the spring 2020 heavy-haul session saw no attachment failure after 66 million gross tons (MGT). The test attachments were torque tested at 25 ft-lbf every 10 MGT with no failures. Electrical resistance was measured between evenly spaced pairs of the stud attachments throughout the session. All measurements met AREMA signal wire attachment standards. EWI is currently seeking railroads for revenue service testing of the attachments and commercialization partners to take the solid-state signal stud attachment technology to market.

BACKGROUND

Failures in railroad signal wire attachments reduce safety and reliability for the rail system. Failures create uncertainty in the signal wire system – resulting in reduced train speeds, additional inspections to identify failure causes, and reinstallation of attachment studs. Improper wire attachment can also result in rail breaks and derailments, such as the 2003 Tamaroa derailment (see NTSB reference). Earlier EWI research found that exothermic and brazing signal wire attachment processes can damage rail. These processes require the rail surface be heated above the austenization temperature, making it possible for brittle untempered martensite to form in the rail under the attachment (Figure 2). Also, copper from the exothermic weld or braze material can penetrate the grain boundaries of the steel in the heat-affected zone and form liquid metal embrittlement in the rail microstructure (Figure 2). This combined damage leaves the rail more susceptible to fatigue crack initiation and growth – and eventual breakage.

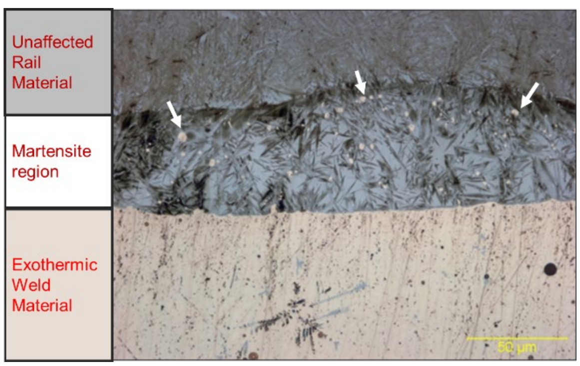

Figure 2. Martensite region near the surface of rail formed under an exothermic weld; copper contamination areas highlighted by white arrows

EWI developed a solid-state joining process, specifically friction welding, to place studs onto rail. Inertia friction welding (FRW-I) has been used in manufacturing for decades to join dissimilar materials. For this project, over 20 stud materials were tested to ensure a strong, low, electrical resistance attachment could be made with FRW-I. Rail preheating is not required for successful welding. The only rail preparation needed is to create a clean area that is perpendicular to the stud centerline. EWI designed and fabricated a portable, prototype FRW-I system for in-track use. The portable welding system consists of three components: the friction welding head, a rail clamp for positioning the weld head to the rail, and a control box that includes the battery and hydraulic power. A separate tool is used to prepare the rail for welding.

OBJECTIVES

The objectives of this project were to evaluate rail preparation methods, to remove weight from the portable FRW-I system by reducing the stud attachment area and to test solid-state signal wire attachments in simulated track service.

METHODS

EWI developed a rail preparation method that creates a consistent, repeatable weld surface, regardless of the rail's existing condition. This method also removes oxides from the surface of the rail where the weld will be made. Tooling was designed and fabricated to use the prototype system rail clamp as a support. This ensures the prepared area and weld spindle centerline are aligned. The preparation tooling is a custom mounting bar and an off-the-shelf, indexable square-shoulder end mill with easily changed cutting inserts. The milling tool is driven with a cordless 0.5-inch drill.

Portability is key for rail industry adoption. FRW-I uses a free-spinning flywheel at a set RPM to provide energy for the welding process. In an effort to reduce the weight of future systems, the wire attachment stud was redesigned to optimize the weld area to balance the weld strength required and weight of the system. The redesigned stud reduces the weld area by 30 percent, which in turn reduces the needed weld force and flywheel size, thus reducing the welding system's size, making it more portable.

EWI developed welding conditions to produce repeatable attachments using the new stud design. The rail preparation method and new stud welding procedure were tested at TTC by attaching studs to rail subjected to heavy-haul rail service. The studs were placed in a curved section of the test track for the spring 2020 FAST session (Figure 3). The current fixturing positions the studs at the neutral axis of the rail. With different fixturing, the system can weld studs to the rail head.

Figure 3. Friction welded studs attached to FAST track at TTC

RESULTS

Development of the rail preparation process found that operating the end mill tool at low spindle RPMs under high-pressure produced a good combination of surface finish with a short processing time. Surface roughness was measured at better than 64 Ra. To minimize material removal, milling of the rail was performed only until a complete circle of fresh steel (oxides removed) was visible (Figure 4). Milling insert life was approximately 10 weld area preparations per insert.

Figure 4. Rail web prepared for signal stud attachment (machined circle in center of image)

The smaller weld cross-section required less energy and force to create a satisfactory weld, without sacrificing strength. A torque wrench was used to test the welds. All development test studs withstood 50 ft-lbf of torque without a weld failure.

In January 2020, EWI attached studs to the FAST track at TTC. At installation, all studs were torque-tested at 25 ft-lbf to validate in-service weld quality. The studs were then torque-tested at the same level every 10 MGT during the FAST session. No studs failed during the in-track test. Electrical resistance was also tested between pairs of studs at installation and every 10 MGT during the FAST session. All measurements were at electrical resistance levels below the AREMA requirements for signal wire attachments. After 66 MGT, the rail sections with the studs attached were removed and sent to EWI. A cross-section of one stud revealed a sound interface and no damage to the rail material below the stud (Figure 6).

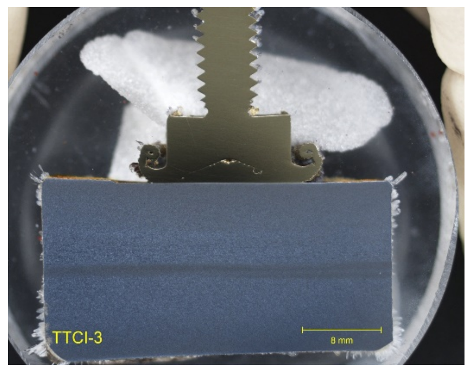

Figure 5. Friction stud attachment cross-section

CONCLUSIONS

A solid-state welding process like friction welding helps to avoid harmful rail material property changes from other attachment processes – like exothermic and brazing processes. The first portable, prototype friction stud welding system proved viable for this novel attachment process through simulated field testing of over 66 MGT at TTC. Attachments made with this solid-state welding process prevented damage to rail and provided equal or better attachment strength and electrical resistance compared to existing methods.

FUTURE ACTION

EWI is seeking railroad support for revenue service testing. The prototype portable friction welder can easily be deployed in-track for stud installation at the rail's neutral axis point (or rail head with fixture adjustments). EWI is also working with the rail industry to find commercialization partners that will manufacture the next-generation solid-state welding system for field deployment.

REFERENCES

Workman, D., and Stuart, C. (November 2014). Developing a Reliable Signal Wire Attachment Method [DOT/FRA/ORD-14/33]. Washington, DC: U.S. Department of Transportation, Federal Railroad Administration.

National Transportation Safety Board. (2005). Derailment of Canadian National Freight Train M33371 and Subsequent Release of Hazardous Materials in Tamaroa, Illinois, February 9, 2003. Railroad Accident Report NTSB/RAR-05/01. Washington, DC.

Video documenting the welding process:

EWI Signal Wire Welding Webinar

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CONTACT

Cameron Stuart
Program Manager
Federal Railroad Administration
Office of Research, Development, and Technology
1200 New Jersey Avenue, SE
Washington, DC 20590
(202) 493-6384
cameron.stuart@dot.gov

Seth Shira
Applications Engineer
EWI
1250 Arthur E Adams Dr.
Columbus, OH 43221
(614) 688-5147
sshira@ewi.org

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