



## DEVELOPING A RELIABLE METHOD FOR SIGNAL WIRE ATTACHMENT

### SUMMARY

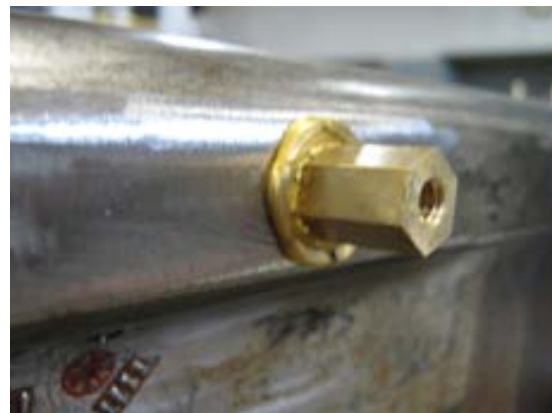
Railroad signaling systems detect trains on the track, identify track fractures, prevent derailments, and alert signal crossing stations when trains approach. These systems are vital to safe train operation; therefore, each component of this system has to be extremely reliable. Current methods of rail/wire attachment have shortcomings that are creating reliability problems for the railroads. Failures in signal cable attachments create uncertainty in the signaling system, resulting in reduced train speeds, additional inspection time to identify the cause of the failures, and reinstallation efforts that result in additional costs, train delays, lost productivity, and reduced operational safety.

Edison Welding Institute (EWI) conducted an investigation to examine the various signal wire attachment methods—their advantages, disadvantages, and known failure mechanisms. The findings indicate that signal wire attachments continue to be problematic for the rail industry and that existing processes to remedy the issue may yield unsatisfactory results if not carefully controlled. Samples of failures were analyzed and found to exhibit signs of Liquid Metal Embrittlement (LME) with martensite formations at the bond interface due to excessive heating. These conditions result in brittle joints and can lead to joint failure and rail head damage.

A solid-state welding process using inertia friction welding was investigated as an alternative to the welding and brazing processes currently in widespread use by the rail industry. A solid-state process enables precise control over the weld parameters and may improve weld quality and durability.

A plan was developed to use inertia friction welding to weld a stud of dissimilar metal to the rail that provides a mechanical connection to the signal wire. Several weld

stud alloys were chosen for preliminary weld trials. Development trials demonstrated that low speed and high thrust load parameters provided a solid-state weld that produced no martensite in the rail steel. A photograph of a completed weld is shown in Figure 1. Further experimental trials were conducted to define the process range for rotational speed and welding thrust load. Repeatability testing was also conducted and showed no evidence of martensite even after several repair cycles were carried out.



**Figure 1. Photograph of Stud Attached to Rail**

Based on the parametric study and process development, a conceptual design was completed for a portable inertia friction welder. The design is lightweight and can be powered by a small electric motor. Internal timing and process controls maintain the weld quality. The simplicity of the process will yield consistent joint quality with minimal operator training and in a variety of environmental conditions.

Additional work will be conducted to examine the reliability of the process through a series of bending fatigue tests, corrosion tests, and in-service testing on rail sections of various chemistries.



## BACKGROUND

An investigation was conducted to examine the various signal wire attachment methods currently used by railroads, their advantages, disadvantages, and known failure mechanisms. A literature review was completed that summarized work performed at the Transportation Technology Center, Incorporated (TTCI); a failure report was also provided by the National Transportation Safety Board (NTSB). Interviews with railroad personnel, and a failure analysis conducted at EWI, supported the findings of the literature review.

Some of the current methods of attaching signal wire studs to rail appear to exceed the transformation temperature of the rail material during the joining operation. This results in weld-heat-affected zones that can produce fractures when stress is applied and eventually lead to derailments [1]. In an effort to avoid damage to rail heads, studs have been moved from their ideal location (on the side of the rail head) to the neutral axis of the rail (middle of the web). Although this approach mitigates rail head damage, it places the signal wire system in an area susceptible to damage, especially from maintenance equipment. In addition, this change in placement does not address the underlying root cause of poor joint development between the rail and the signal wire system. [2]

Portable inertia friction welding using dissimilar materials was considered for attachment of the rail wires to the rail. This solid-state welding process controls the welding temperatures better than other methods, reducing the risk of over-heating the materials.

Previous research concluded that a welded or brazed connection at the Rail-Wire Interface (RWI) was preferred for durability and corrosion resistance, and Maintenance of Way (MOW) equipment snags still accounted for many wire or RWI failures due to wire location requirements in the web of the rail. Current CADWELD or brazing systems used in the field can produce martensite in the RWI joint, which can lead to rail section failure even if the RWI is located at the neutral axis in the web of the rail. Although the CADWELD and pin brazing processes can produce good welds under the right conditions, preheat

and preparation requirements must be adhered to, which add to the complexity of the process.

Based on these findings, a weld process was developed that creates a solid-state bond while controlling the peak temperature in the rail steel. This new process requires minimal surface preparation and can be performed using portable equipment. The recommended RWI joint is a friction type weld that can be completed using a portable inertia welding system. This creates a solid-state bond which, with careful selection of a copper-based alloy, will allow the weld to be produced without melting and without heating the rail steel to the transformation temperature, in turn reducing the likelihood of martensite formation. The inertia welding process is operator independent; the control of heat input and other key characteristics is handled by the equipment. A consumable lug can be welded to the rail, providing a connection to the signal wire through a specially designed bolt system.

## OBJECTIVES

The project objectives are to develop a process and procedure for rail wire attachment at the rail head location. Specific project goals are as follows:

- A signal wire attachment method that is operator independent to guarantee joint quality.
- A solid-state operation to prevent formation of martensite or liquid metal embrittlement in the rail during welding.
- A break-away feature to prevent rail damage in a wire snag scenario.
- A portable process that can be applied easily in the field.

## METHODS

A survey was conducted and several alloys were selected for welding trials based on metallurgical properties, strength, affordability, electrical conductivity, and corrosion resistance. Preference was given to alloys with lower forging temperatures in order to create a weld at the lowest possible temperature.

Inertia friction welding trials began after the alloys were selected. Trials were conducted at varying spindle RPM, welding force, upset speed, upset force, spindle inertia, and stud extension to determine operational parameters



for each of the materials selected. Welds were examined using standard metallographic techniques to determine which materials could create a high strength weld without forming martensite. Additionally, Scanning Electron Microscopy (SEM) analysis was conducted to confirm the absence of martensite in the as-welded microstructure.

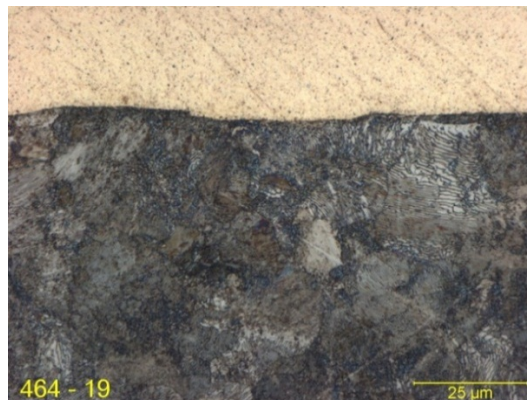
A single repair study was conducted to ensure the process could be used repeatedly at the same location in the rail. The preferred process for the tests was as follows: a stud was attached to the rail, broken off, the previously welded area smoothed with a grinder, and a stud re-welded in the same area. The process was repeated ten times at a single location on the rail. The rail was examined using standard metallographic techniques to assess any damage.

Using process requirements such as weld force, inertia mass and inertia RPM, EWI designed a conceptual welding system that provides the rigidity required to perform the process while maintaining the portability and ease of operability required by the railroads.

## RESULTS

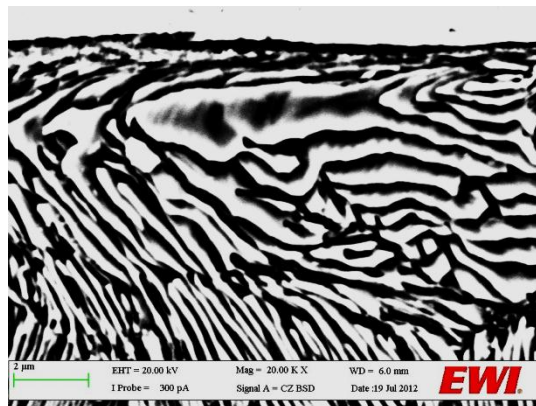
Based on metallurgical properties, strength, affordability, electrical conductivity, and corrosion resistance, the materials selected for study included 360 brass, Naval Brass, C172 copper, and C110 copper. As shown in Figure 1, a stud design was developed that provides sufficient bonding area for the friction process, as well as internal threads for easy removal of wiring during MOW activities. Additional alloys were considered acceptable, but not chosen for further study because they were not commercially available.

Initial welding trials exhibited bands of martensite at the interface between the rail and the stud. Parametric changes were made to reduce the peak temperature during welding without exceeding the martensite transformation temperature in the rail steel. Some materials still failed to produce acceptable welds with these parameter combinations. However, Naval Brass produced high strength welds and no martensite in the heat affected zone of the rail steel. Figure 2 shows a metallographic cross-section of the bond line between the Naval Brass and the parent rail steel which exhibited no martensite.



**Figure 2. Photomicrograph of Inertia Friction Weld Interface between Naval Brass and Rail Steel**

Figure 3 shows SEM analysis of the bond line with pearlite bands adjacent to the welded stud under high magnification. These pearlite bands adjacent to the Naval Brass prove that the thermal cycle in the process did not exceed the martensite transformation temperature in the rail steel.

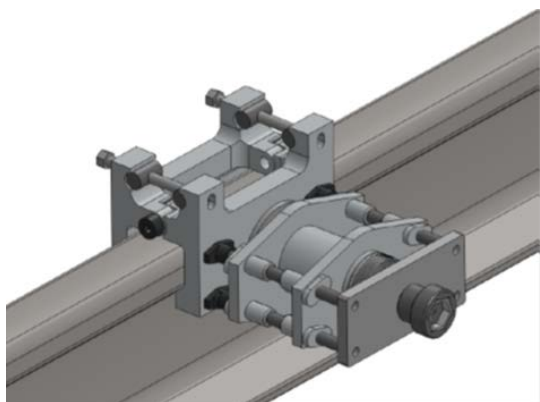


**Figure 3. SEM Photograph of IFW Joint Between Naval Brass and Rail Steel**

A single ten-weld repeatability study was conducted and showed that welds could be produced at the same location without the formation of martensite and without observable change in microstructure or joint strength. An equipment prototype design was completed. Figure 4 shows a conceptual design of the portable unit mounted on the rail head. The design is lightweight and capable of being powered by a small electric motor. Internal timing and process controls maintain the weld quality. The simplicity of the process will yield



consistent joint quality with minimal operator training and in a variety of environmental conditions.



**Figure 4. Concept Drawing Portable Inertia Friction Welding System**

## CONCLUSIONS

An inertia friction welding process was developed to attach rail signal wire studs to rail steel without the formation of martensite. As demonstrated in the trials, an internally threaded stud uses a fusible mechanical link or breakaway in the assembly of signal wires to prevent damage to the rail in the event that the wire is snagged.

Of all alloys reviewed, C464 Naval Brass studs showed the best characteristics for attachment to rail steel, from an inertia welding perspective. Naval Brass was selected based on its welding characteristics and ability to form welds with low force, permitting the design of a lightweight portable inertia friction welding system.

## FUTURE ACTION

The final phase of this project is an analysis and robustness testing phase. Welded specimens will be prepared for fatigue and corrosion testing to assess the welded signal wire attachment life. Weld specimens will be made on various types of commonly used rail steels and tested to ensure the process and materials perform well under a variety of conditions.

## ACKNOWLEDGEMENTS

The authors acknowledge David Davis, Senior Scientist, and Daniel Gutscher, Senior Engineer, at TTCl; Dale Mellor, Rail Test and Track Quality Manager, Union Pacific Railroad; and, Joseph Smak, Director of Track Standards and Specifications, Amtrak, for their technical assistance throughout this project.

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## KEYWORDS

Inertia Friction Welding, Signal Wire, Signal Wire Bonding, Rail Wire Interface

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