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Thermite Weld Progress

by Joseph Kristan

Summary

Research and testing by Transportation Technology Center, Inc. (TTCI) and the University of Illinois at Urbana-Champaign (UIUC) over the past few years has brought about several recommended modifications to the current thermite weld to reduce the failure rate.

Significant areas of thermite weld performance were investigated.[1,2,3] Of these, the following areas were found to have the most influence on weld performance:

- Minimizing vertical offset.
- Controlling the preheating conditions to ensure adequate heat input.
- Modifying the weld collar geometry to reduce stress concentration.
- Modifying the mold fit to ensure a minimum gap between the mold and rail.
- Increasing the weld gap from the standard 1 inch to reduce the criticality of preheat and variability in the thermite reaction.
- Optimizing mold materials or liners to reduce gas entrapment and mold material fusing with the weld surface.
- Removing the oxide layer on the rail surface below the mold to improve fusion between the collar and the rail surface.

As can be seen from this list, nearly every aspect of making a thermite weld plays a part in the weld's ultimate performance.

Thus, the variables with the greatest influence on weld performance are being addressed as proposed modifications to the current thermite weld designs:

- Modifying the weld collar geometry to reduce localized stress concentration, thus improving the fatigue life of thermite welds.
- Increasing the refractory mold collar width to accommodate an increased weld gap width of 1.25 inch instead of the current 1 inch to reduce the criticality of the preheat by providing additional superheated thermite portion. This change should reduce the likelihood of producing a defective weld.
- Minimizing the vertical offset at the base of the weld to minimize localized stress concentration, thus improving the fatigue life of the weld.
- Using superior mold refractory material and washes to provide a smooth surface finish and to inhibit melting of the mold material while allowing gases to permeate. Reduction in gas pockets along with an improvement in surface finish should provide improved fatigue performance (reduced stress raisers).

The Engineering Research Committee and the Heavy Axle Load Research Committee of the Association of American Railroads directed TTCI's research. TTCI and the Transportation Research Board (TRB) directed UIUC's related research. TTCI, as part of the AAR's Strategic Research Initiative (SRI) Program, and TRB as part of the High-Speed Rail IDEA program, contributed funding to allow the performance of UIUC's research effort.

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INTRODUCTION

TTCI, with direction from the Engineering Research Committee (ERC) and Heavy Axle Load Research Committee (HALRC), has been conducting rail-welding research for numerous years. This effort has included research performed at the University of Illinois at Urbana-Champaign (UIUC).

Research into thermite welds over the past few years by both TTCI and UIUC has culminated in the completion of several laboratory tests and field-testing at the Facility for Accelerated Testing (FAST).[2,4]

The knowledge gained in the manufacture and performance of thermite welds is being used in recommended modifications to the current consumables and installation practices. There are approximately 60,000 defective thermite welds repaired by replacement annually in North America at an estimated cost of $54 million. The goal is to improve the performance and strength of thermite welds by making a more robust and forgiving weld with minimal penalties in cost and installation time.

The modern thermite weld shown in Figure 1 contains a collar or segment that protrudes from the rail surface. This portion of the weld and the stress concentration caused by the resulting geometry was the subject of much study.[2,4,5] Recommendations to improve thermite weld fatigue performance with regard to the collar geometry are simple; i.e., reduce the sharp concave corners to reduce the stress concentration.

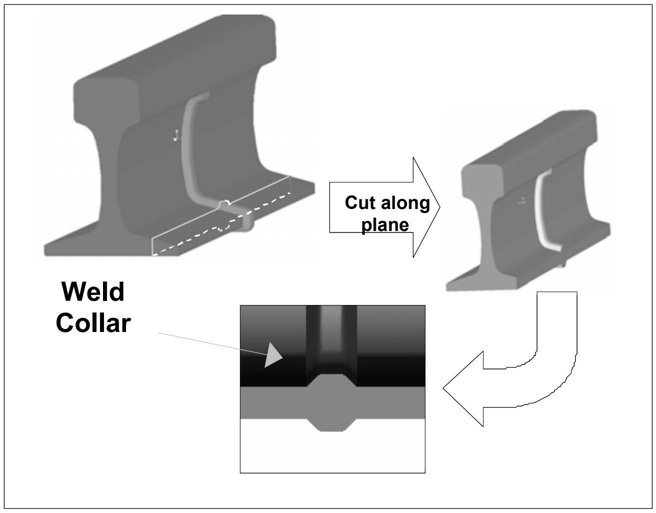

Figure 1. Diagram showing rail sections and views of the thermite weld collar which extends from the bottom of the railhead down through the web to beneath the bottom of the base.[2]

Other important recommendations include widening of the weld gap to minimize the criticality of both preheat and any variability in the thermal output of the thermite portion. This modification will require a new refractory mold design with an increased weld collar width along with bigger mold shoes.

Minimizing the vertical offset at the base of the weld will greatly reduce the localized stress concentration. The use of higher grade refractory mold material and washes will still allow gas to permeate along with inhibiting melting of the mold and will produce a superior surface finish. These along with other recommendations to improve thermite weld performance based on previous research are also included. Welds with these described modifications will be tested at FAST to quantify their effectiveness.

Thermite Weld Geometry

Thermite weld collar geometry (the portion of the weld that protrudes outward from the web and base of the rail) can produce a stress raiser at the interface between the collar and rail. Weld fatigue failures typically initiate at the edge of the collar either below the base or at the web/base fillet. Previous geometry from production welds produced stress concentrations of up to four times nominal due to a high-flank angle and small weld-toe radius. Figure 2 shows the general geometry of a cross section of the weld collar.

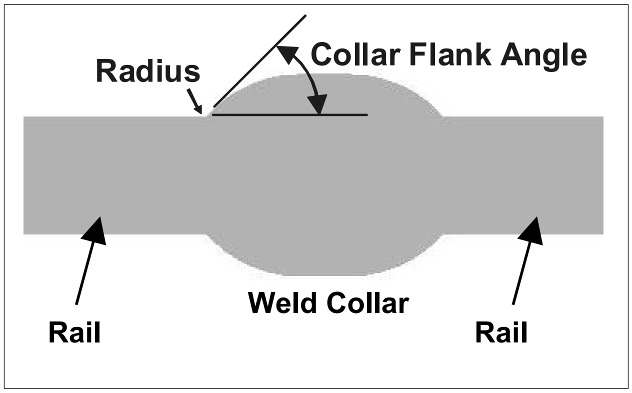

Figure 2. Cross section of thermite weld collar showing the flank angle and toe radius[2]

The flank angle produces the same maximum stress concentration from about 60 to 90 degrees. The stress concentration only begins to fall below 60 degrees, based on finite element modeling (FEM). Also, the larger the weld toe radius, the lower the localized stress concentration. Bending fatigue tests performed at UIUC confirmed the improvement with a 30-degree flank angle and a 3-millimeter toe radius, as Figure 3 shows. Further reducing the collar flank angle beyond 30 degrees would continue to reduce the stress concentration. However, if this region, which is designed to fuse with the rail surface, is too thin, a fin and/or cold lap will form that produces an extreme stress raiser (Figure 4). Thus, a weld collar design with approximately a 30-degree flank angle and 3-millimeter toe radius is recommended for optimum fatigue performance. This modification will neither increase consumable cost nor require additional installation time, important factors in the utilization of thermite welds.

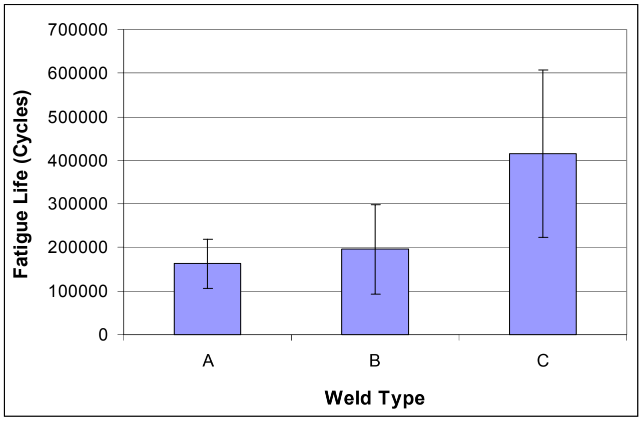

Figure 3. Laboratory fatigue tests of welds (A) 90-degree flank angle and <1 mm toe radius, (B) 45-degree flank angle and <1 mm toe radius, and (C) 30-degree flank angle and 3-mm toe radius all tested at the same loading with a delta P of 141.2 kips[2]

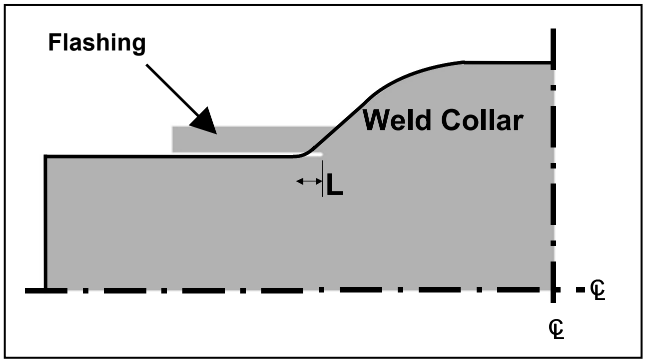

Figure 4. Cross section of thermite weld collar showing flashing and lack of fusion (L) of the collar (white region at edge of collar) at center of figure[2]

Vertical Offset and Flashing

The influence of vertical offset between the adjoining rail ends and resulting flashing were investigated through analysis and experimentation by TTCI. FEM showed that the stress concentration at the 1/4 inch uplifted collar edge of an offset weld increased 21 percent compared to zero offset (collar flank angle and toe radius constant). A 3/16 vertical offset thermite weld test was performed at FAST in the high rail of a nominal 5-degree curve with 4-inch superelevation producing a 1.7-inch cant deficiency. Half of the welds contained flashing at the base resulting from the large gap between the two-piece mold and the rail surface. The flashing at the bottom of the base was reduced in the second half of the test welds as Figures 5a and 5b show.

After 260 MGT, there was a 60 percent failure rate in both test weld types (six of ten failures per type). The high-rail maintenance weld failure rate for all curves at FAST was 19.7 percent under the same operating conditions and tonnage accumulation. Thus, a simple vertical offset of 3/16 inch created more than a three-fold increase in failure rate.

The average life of the welds with flashing was 74.3 MGT; average life without was 122.8 MGT. Five of the six failures of the flashing welds occurred directly above the edge of the flashing at the bottom of the base. Conversely, five of the six reduced base flashing welds occurred in the rail fillet areas. FEM performed at UIUC showed that the weld is sensitive to flashing thickness and relatively insensitive to length. A thin flashing layer is relatively benign but a thickness of 3 millimeters can produce a stress raiser equal to a 90-degree flank angle with a 0.5 millimeter toe radius. Thus, if the performance advantages of the improved collar geometry are to be realized, the flashing must be minimized, or it will negate the intended improvement in the localized weld geometry.

Consequently, tighter fitting two piece molds and 3 piece molds are recommended to allow a tight fit at the bottom of the rail base as well as the web/base fillet. With attention in the fitting of the mold, to ensure the gaps between the rail and mold are minimized to reduce resulting flashing. The weld performance is also dependent on vertical offset and thus, the offset should be kept to a minimum. One Class I railroad’s practice is to align the base or split the offset between the head and the base, requiring additional grinding of the head of the finished weld. This practice is certainly more labor and time intensive but should result in a better performing weld.

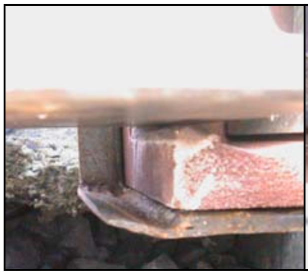

Figure 5a: Rail bottom and weld mold with refractory paste[1]

Figure 5b: Results of paste are reduced flashing formation at bottom of base[1]

Thermal Input

Thermite welds are sensitive to thermal input because both the preheat and thermite reaction provide the energy required to produce the needed melt back of the rail ends for proper fusion. Insufficient thermal input does not produce adequate washing and melt back of the rail ends and lack of fusion and other defects can form. The average thermite pouring temperature of four identical commercially available welds from one manufacturer had a standard deviation of 16 degrees Celsius. Thus, this manufacturer’s exothermic thermite reaction appears to be under control. However, the preheating technique employed by all of the manufacturers may not be as well controlled.

The current preheating method relies on the welder to adjust and maintain proper thermal input based on the appearance of the flame and sound of the torch. Each welder’s opinion and experience comes into play in regard to the correct preheating torch settings. A method of minimizing the influence of preheating is to provide additional heat input from the thermite portion as Figure 6 shows. The cross section of the rail is constant and thus increasing the weld gap (distance between rail ends) to introduce additional superheated thermite portion will minimize the criticality of the preheat. Tests performed by TTCI showed wide gap welds (2.75 inch) to possess a residual stress profile similar to the conventional 1-inch gap weld. Tests at UIUC with 1.22-inch weld gaps showed no discernable difference in residual stress in comparison to the conventional welds. Thus, it is recommended that the standard mold collar width be increased to accommodate a wider weld gap width 1.25 inch rather than the current gap of 1 inch.

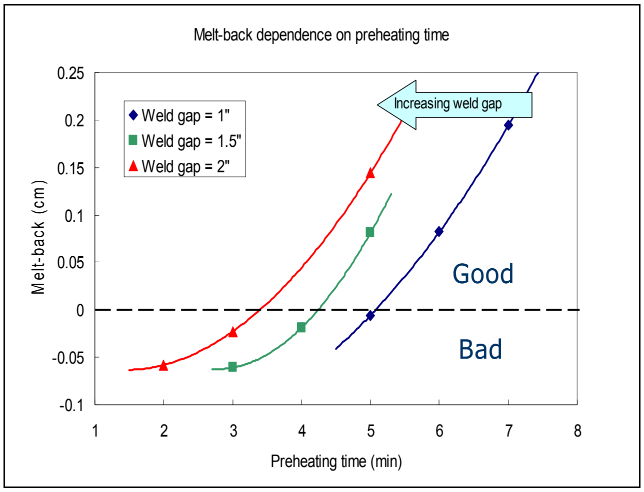

Figure 6. Effects of thermite weld preheating time on resulting rail melt back as a function of weld gap determined by FEM thermal modeling.[6] The zero melt back position is equal to the depth of the weld collar.

Refractory Molds and Washes

Current commercial mold materials are used without washes (painted on thin layer of refractory). The mold material is porous which allows the gases produced from the molten thermite portion to escape, which helps to reduce gas pockets and porosity. However, this material can melt and does not produce as smooth a surface finish as a mold with a zircon wash might. The zircon wash is an excellent refractory and produces a superior surface finish, but does not allow the gases to permeate as freely as observed in "blowholes" in previously tested welds at TTC. A zircon facing sand mold backed by silica oxide sand should allow the gases to escape.

Thermite Weld Installation

Some of the inherent installation issues with thermite welds are the reliance on the human element (welders) to properly align, install and pack the molds, preheat the rail, prepare and ignite the thermite portion, disassemble, and finish grind the weld. Experience and training should help to ensure that proper installation techniques are used. However, with time constraints and other adverse conditions, the opportunity to follow the proper installation techniques may be diminished. Thus, modifications to the weld consumables and installation techniques to improve the robustness of the weld, while minimizing installation time, will likely improve weld performance.

As an example, the previously discussed widening of the weld gap to provide additional thermal input should mitigate a shortened preheat, preheating with plugged torch orifices, and/or improper gas pressures.

In addition to ensuring that the proper installation techniques are used, cleaning of the rail ends will also aid in proper fusion of thermite welds. Ensuring that the cut rail ends are clean along with removing the oxide layer on the surface of the rail to which the weld collar must fuse will reduce the chances of improper fusion of the weld at these locations.

CONCLUSIONS

Numerous recommended modifications to the current thermite weld are proposed. Welds containing the described modifications will be manufactured and tested at FAST to quantify the effect of the changes:

- Modifying the weld collar geometry to reduce localized stress concentration
- Increasing the weld gap to reduce the criticality of the preheat
- Minimizing the vertical offset at the base of the weld to minimize localized stress concentration
- Using superior refractory material and washes for mold manufacturing to provide a smooth surface finish and to inhibit melting of the mold refractory material while still allowing the entrapped gases to permeate from the weld

The optimal testing method is to quantify the effect of a single variable before proceeding to quantify the next design change. However, under the circumstances, the optimal test protocol is not viable, as this would likely require 15 to 20 years to quantify each of the proposed modifications singularly. Track space is not currently available to allow more than a single weld test with a minimal number of test specimens to be statistically significant. Thus, based on current thermite weld knowledge, the optimal weld containing each of the described changes will be tested.

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