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Effects of Flashing and Alignment on Thermite Weld Performance

by Joseph Kristan

Summary

A 60-percent failure rate of thermite test welds with 3/16-inch vertical offsets was observed at the Facility for Accelerated Service Testing (FAST), Transportation Technology Center, Pueblo, Colorado, using 315,000-pound 4-axle cars.

Twenty-four vertically offset thermite welds were tested in a 5-degree curve with 4-inch superelevation at FAST. Twenty were installed in the high rail of the curve (10 unmodified welds that allowed excessive flashing to form below the rail base and 10 welds modified with a refractory paste to minimize the formation of flashing) and four were installed in the low rail (2 unmodified welds, and 2 modified welds). The track geometry and train operating conditions produce a 1.7-inch cant deficiency in the test curve, which imparts a higher load on the high rail of the curve with an axle load of 39 tons (315,000 pound 4 axle car). Most of the test welds were installed in the high rail to be tested under the more severe load environment.

Test results after 260 MGT:

- Six of the 10 (60%) high-rail test welds with flashing present fractured due to fatigue.
  - Five of the fatigue failures occurred directly above the flashing on the bottom of the rail base at a discontinuity at the head/web fillet; another one occurred at a discontinuity at the head/web fillet.
  - The average tonnage of the five failures was at 74.3 MGT.
- Six of 10 (60%) high- rail test welds with minimized flashing failed by fatigue.
  - One of the fatigue failures occurred at the bottom of the rail base; others occurred at the head/web and web/base fillets.
  - The average tonnage of the five non-base fractures was 122.8 MGT.
- The influence of the flashing supersedes the effect of geometry induced by the weld shape, though both are detrimental.
- The failure rate of maintenance thermite welds in the high rail of the same test curve during the same time as the offset thermite weld test was being conducted was 12.4 percent.
- The high rail maintenance weld failure rate for all curves at FAST was 19.7 percent under the same operating conditions as those of the offset weld test.
- There were no failures of the four test welds (two with flashing and two with minimized flashing at the rail base) in the low rail of the test curve.

Suggested Distribution:

- ❑ Maintenance-of-Way
- ❑ Track Maintenance
- ❑ Planning & Analysis

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INTRODUCTION AND CONCLUSIONS

Thermite welds are used mainly for the service repair of rail defects and fractures, and during the installation of track and track components. As with every component, there are limitations to their useful application. In order to determine the influence of excessive flashing and geometry effects resulting from a large (3/16-inch) vertical offset in the rail ends to be welded, the vertically offset thermite weld test was conducted. Under the test conditions employed, 60 percent of the test welds in the high rail had fractured after 260 MGT of testing.

The thermite welds used for this testing were designed to be applied with a maximum 1/8-inch base offset with step molds to be used for the welding of rail with larger offsets. The intentional use of the straight molds in the offset application was prescribed by the Technical Advisory Group (TAG) involved with the testing to allow evaluation of the influence of both the geometrical offset as well as the presence of flashing within a single test.

The flashing is the result of the molten thermite portion flowing into spaces that are not completely filled by the mold and/or the sealing sand or paste. Figure 1 shows the result of the formation of flashing.

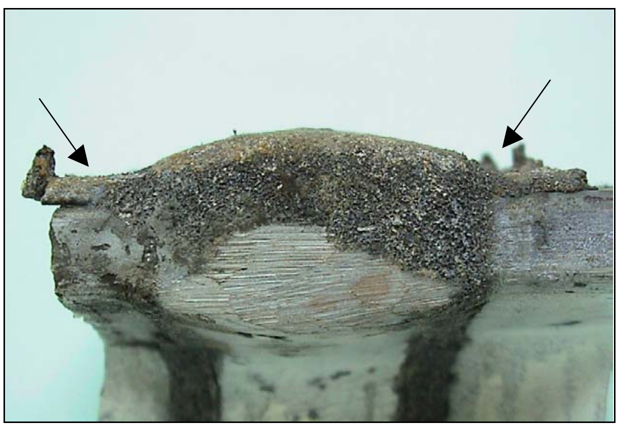

Figure 1: Flashing is present below the rail base on both sides of the weld because the molten thermite portion flowed into spaces that were not completely filled by the mold and/or the sealing sand or paste.

The overall failure rate of all 3/16-inch offset test welds was 60 percent for both the base flashing and reduced base flashing weld types. Five of the six test weld fractures with flashing failed by fatigue directly above the flashing on the bottom of the rail base (Figure 2); only one occurred at a discontinuity at the head/web fillet. Figure 3 shows a different view of the fracture shown in Figure 2, indicating fracture distance from the edge of the weld collar, which is inherently a stress raiser. The average failure tonnage accumulation of the five base failures of the test welds containing flashing was 74.3 MGT. One of the reduced flashing test weld-fatigue failures occurred at the bottom of the rail base; the other five occurred at the head/web and web/base fillets. The average failure tonnage of the five non-base test weld failures was at 122.8 MGT. Thus, the influence of the flashing supersedes that geometrically induced by the weld shape, though both are detrimental. The fatigue of a component occurs at the weakest point of the assembly, which for the test welds containing flashing was consistently the bottom of the rail base. The only failure to occur away from the base of the test welds with excessive flashing was at a discontinuity at the head/web fillet. Thus, this testing demonstrates that flashing is detrimental to the thermite rail weld.

Figure 2: Fatigue fracture of 3/16-inch vertically offset thermite test weld, which initiated at the base of the rail immediately above the flashing intentionally produced for the test (run-out).

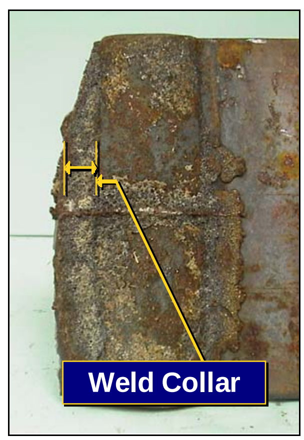

Figure 3: Bottom view of weld fracture shown in Figure 2 illustrating the location of the fracture relative to the weld collar.

Thermite Test Weld Installation

Twenty-four vertically offset thermite welds were tested in a 5-degree curve with 4-inch superelevation at FAST. Twenty were installed in the high rail of the curve (10 unmodified welds that allowed excessive flashing to form below the rail base and 10 welds modified with a refractory paste to minimize the formation of flashing) and four were installed in the low rail (2 unmodified welds, and 2 modified welds). The track geometry and train operating conditions produced a 1.7-inch cant deficiency in the test curve, which imparts a higher load on the high rail of the curve, and thus the majority of the test welds were installed in the high rail to be tested under the more severe load environment. The welds were installed using identical techniques and practices to reduce experimental error resulting from differences in installation. Additionally, the installation practices for this test were observed and audited by representatives from BNSF and Orgo-Thermit, Inc.

The continuous rail in the curve was sectioned to produce a 1-inch gap and then aligned to produce a 3/16-inch vertical base offset between the opposing rail ends of the finished weld. Thus, the railhead at one rail end extended 3/16 inch above the other, subsequent to weld manufacture. (The rail that extended above the other was ground to provide a smooth running surface.) The weld mold was modified to fit the offset rail by removing the required material from the head and base portions of the mold. (This type of field modification is often practiced in the field when poorly matching rails are welded.) A large gap between the mold and rail bottom at the rail base on the uplifted rail end resulted from this practice. Thus, for the unmodified flashing welds (no refractory added to reduce the formation of flashing), a large quantity of flashing intentionally formed in this area. Conversely, the test welds that were intentionally modified to reduce flashing by the use of refractory paste showed a substantial decrease in the formation of the flashing, as Figures 4a and 4b show. The type of refractory used and the application techniques were the result of research by the University of Illinois at Urbana Champaign to reduce flashing and improve thermite weld collar geometry.[1]

The setup of the test welds was intended to incorporate the two common factors of previous premature maintenance weld fractures that had occurred at FAST. The 3/16-inch offset of the bases correlates directly with the geometry of the premature fractures investigated. The resultant flashing from the offset of the rail bases (without reduced flashing) did produce a stress concentration site initiating fracture at the rail base a distance away from an inherent geometrically induced stress raiser at the end of the weld collar. These test results confirmed the conclusions that flashing was the major cause of the premature failures and that the weld geometry also contributed.

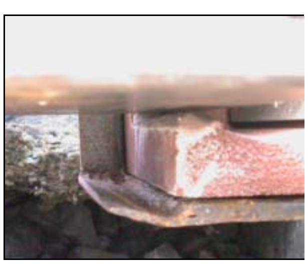

Figure 4a: Rail bottom and weld mold with refractory paste.

Figure 4b: Refractory paste reduced flashing formation at bottom of base.

Weld Geometry and Stress Concentration

The influence of weld geometry in the absence of flashing (run-out) was estimated using a finite element model with the approximate weld geometry of an Orgo-Thermit, Inc. 1-inch-gap weld. (A pre-existing rail model, with UIC60 section, was used to shorten the required time to complete the analysis.) The approximate weld geometry at the base of the rail for both no vertical offset and 0.25-inch vertical base offset was analyzed. The maximum localized stress for the aligned base model was 10.7 ksi symmetric on either side of the weld collar at the base of the rail. However, with a 0.25-inch vertical offset introduced and optimized base collar geometry, as with an offset base mold, the maximum stress increased to 13.0 ksi at the uplifted collar edge, as Figure 5 shows. This is an increase of more than 21 percent due strictly to the resultant weld geometry though optimized for the conditions of vertical offset. Orgo-Thermit, Inc. has modified the weld collar radius since this analysis was performed. Thus, the localized stress has likely been reduced though the magnitude in the difference between the aligned and vertically mismatched welds would likely be similar.

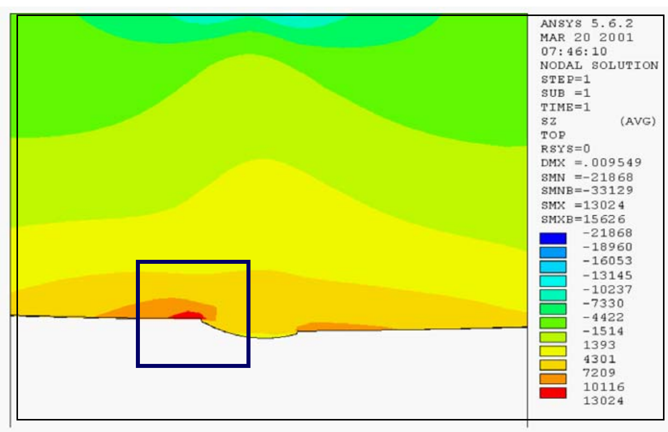

Figure 5: Finite element analysis of thermite weld base geometry influence on localized stress. Comparison between zero and ¼-inch base offsets determined a 21-percent stress increase at the uplifted base (influence of flashing [run-out] not included).

Test Results

Twenty-four vertically offset thermite welds were tested at FAST in a 5-degree curve with 4-inch superelevation.

The 3/16-inch vertical offset test welds received 260 MGT through September 2003. There have been 12 fractures to date (60-percent failure rate), with all occurring in the high rail. The breakdown of the weld failures is five fatigue fractures at the bottom of the base of the welds with excessive flashing present in that area. One fracture of this test weld occurred at a discontinuity in the weld collar located at the rail head/web radius. Conversely, only one reduced flashing test weld fractured because of fatigue at the bottom of the rail base. The other five failed because of fatigue either at the web/base fillet or discontinuities in the weld collar.

For the same period and under the same test conditions, the maintenance weld failure rate for the high-rail curve was only 12.4 percent. The high-rail thermite-weld failure rate for all curves at FAST during this period was 19.4 percent. The 60 percent failure rate of all test welds with 3/16-inch vertical offset indicates that there are limits to when thermite welds should be used. The use of molds not designed for such a large rail offset also negatively affected weld performance.

In addition to the 12 vertically offset test weld fractures, 3 welds were removed from test for required track maintenance. The three weld removals consisted of one reduced flashing weld and two non-modified test welds. None of the required removals occurred over the test zone before 90 MGT.

The average failure tonnage of the five base failure unmodified flashing welds was 74.3 MGT. Average failure tonnage of the five reduced flashing failures, occurring away from the rail base, was 122.8 MGT. High tonnage revenue service lines can accumulate 120+ MGT per year; thus, the test weld performance for the first 120 MGT is also shown. Nine of the 12 test weld failures had occurred by 120 MGT with 6 excess flashing and 3 reduced flashing test weld failures. Thus, the 3/16 vertical disparity between the opposing rail bases of the test welds along with the presence of excessive flashing produce a repeatable failure location and mode, with the average failure tonnage of 74.3 MGT. However, the reduced flashing test weld failure locations varied, with only one occurring at the base, and the others averaging a total of 122.8 MGT to failure.

DISCUSSION

The use of thermite weld molds designed for the application of mismatched rails (worn rail not rail of different sections) will improve weld performance from the 60-percent failure rate observed in the 3/16 vertical offset testing. However, under optimum conditions with large weld collar radii and limited flashing, the localized stress raisers inherent to thermite welding vertically mismatched rail will likely continue to decrease the fatigue life of this component, as shown by finite element analysis. Two methods of reducing the localized stress raisers produced by worn rail geometry mismatch are to split the offset between the head and the base and the use of wide gap welding.

Aligning worn rail of differing heights for welding at the base or halving the mismatch between the head and base will directly reduce the geometry mismatch and ultimately the localized stresses. However, this method will require additional grinding of the railhead to produce a level running surface.

The utilization of a wide-gap weld designed for vertically mismatched rail will allow the required geometry change to be absorbed over a distance 2.75 to 3 times that of the 1-inch-gap weld reducing the localized stress raisers. Wide-gap welds for worn and compromised use are currently being used outside North America with reported success.

The practice of minimizing the thermite weld vertical mismatch is being used with reported success by Norfolk Southern Corporation. Even though the versatility of thermite welds lends itself to use in a wide range of field applications, the use of thermite welds in vertically mismatched applications will likely result in reduced fatigue performance of the component compared to application where there is no rail mismatch.

Reference

1. Cyre, Jefferey Paul, (2002)."Concepts for Improving the Fatigue Resistance of Thermite Rail Welds," Thesis - Master of Science in Civil Engineering, University of Illinois at Urbana-Champaign.