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Railhead Repair Weld Residual Stress Investigation

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Summary

Transportation Technology Center, Inc. (TTCI) conducted a residual stress study of thermite railhead repair welds to investigate and gain an understanding of the stress-state of the welds and how they in turn affect the stress-state of the parent rail. Additionally, the study examined the potential use of thermite railhead repair welds to repair head defects in electric flash-butt plant welds. Following are the findings of the study:

- Analysis of the residual stresses in railhead repair welds made on electric flash-butt plant welds did not identify any abnormally high tensile stresses that would specifically preclude repairing a defect in the head of a plant weld. During installation of the welds, extra care must be taken to avoid formation of cold lapping under the railhead due to the geometry of the plant weld. This may include grinding of the plant weld under the railhead and in the web, and it may require modification of the weld molds to ensure a proper fit under the railhead.
- The region of highest tensile stress in thermite railhead repair welds was located in the radius under the railhead. These stresses were anywhere from 1.2 to 2 times the residual stresses under the railhead for standard thermite welds. In testing previously conducted at the Facility for Accelerated Service Testing (FAST), welds that fractured had fatigue cracks that initiated at regions of cold lapping[1] under the railhead that were located in this area of high residual tensile stress.
- The residual stress profiles in the rail below thermite railhead repair welds maintained the profile of the parent rail except that the stress profiles under the railhead repair welds were shifted from between 8 to 12 ksi further into compression.
- The magnitude of tensile residual stresses for the railhead repair welds made on electric flash-butt plant welds were no greater than those found in either a thermite railhead repair weld or standard electric flash-butt weld. The residual stresses in the weld combination alternated between tension and compression throughout the web and base of the rail.

Thermite railhead repair welds enable the repair of railhead defects without the need to cut the rail, thereby keeping the rail longitudinal stresses intact. The ability to repair defects in the head of electric flash-butt plant welds would extend the capabilities of the thermite repair welds. In 2010, TTCI plans to test thermite railhead repairs of electric flash-butt welds in track at FAST.

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INTRODUCTION

In 2008, both Orgo-Thermit, Inc. and Railtech Boutet, Inc. introduced thermite railhead repair welds in response to industry requests for an alternative repair method for railhead defects. Traditional repair of a railhead defect requires the use of a rail plug and two thermite welds or a single wide-gap weld. Both methods require the cutting of the rail thereby altering the rail neutral temperature. Railhead repair welds allow the repair of railhead defects without altering the rail neutral temperature of the rail.

TTCI has tested thermite railhead repair welds in the laboratory and in track at FAST. During discussions with the Heavy Axle Load and Engineering Research Committees and with the Rail Welding Technical Advisory Group, two questions were raised. First, what is the stress-state of a thermite railhead repair weld and its parent rail? Second, can thermite railhead repair welds be used to repair head defects in electric flash-butt welds? In response, TTCI conducted residual stress measurements on a series of welds to determine the effects thermite railhead repair welds have on the stress-state of rail and electric flash-butt plant welds.

TEST PROCEDURE

The following rail, weld, and weld combinations were manufactured and tested to determine longitudinal residual stresses:

- (One rail) rail that had received roller straightening typical for new rail
- (Two welds) one standard thermite weld from each of two different manufacturers
- (One weld) electric flash-butt plant weld that had received service tonnage
- (Two welds) one thermite railhead repair weld from each of two different manufacturers
- (Two welds) one thermite railhead repair weld from each of two different manufacturers that were made on existing electric flash-butt plant welds

For each rail/weld, strain gages were placed on the: (1) top center of the railhead, (2) side of the railhead, (3) center of radius under the railhead, (4) rail neutral axis, (5) center of radius between the rail web and foot, (6) tip of base flange, and (7) bottom center of the rail foot. Strain gages were oriented flush to a plane that was oriented perpendicular to the rail longitudinal direction. Figure 1 illustrates the placement of strain gages for a railhead repair weld. Rail cuts were made transverse to the rail at 0.25 inch from the strain gages. For the standard thermite welds, the cuts were made at the collar-to-rail transition to facilitate strain gage placement; however, for all other rail, weld, and weld combinations, the cuts were made along the weld centerline.

Strain measurements were taken before and after cutting the welds. Then the differences in strain were converted to stress values and plotted against the vertical position of the gages to produce profiles of the longitudinal stresses.

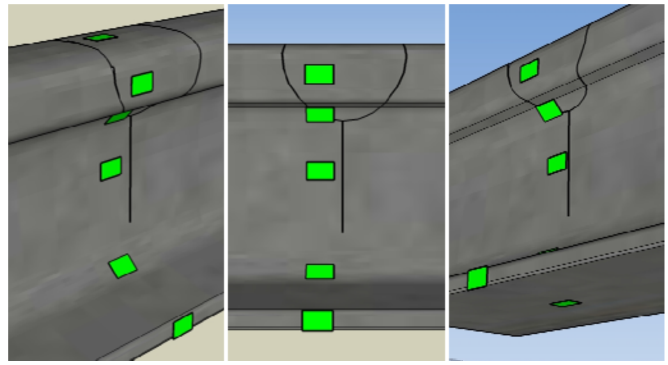

Figure 1. Illustrative Views showing Placement of Strain Gages for a Railhead Repair Weld

RESULTS AND DISCUSSION

For all the plots presented herein, the connecting lines are provided for ease of visual interpretation and do not indicate actual intermediate values. Residual stress patterns in welds and rails are complex and cannot be fully represented by a few surface strain gage measurements.[2] However, for the purposes of this investigation, determination of residual stress values at specific critical locations around the rail/weld provide a useful and adequate means to compare and evaluate the welds. Figure 2 shows the residual stress for a new roller-straightened rail. Figure 3 shows the longitudinal residual stresses present in standard thermite welds for two different manufacturers. Figure 4 shows the longitudinal residual stresses present in an electric flash-butt plant weld that was removed from service.

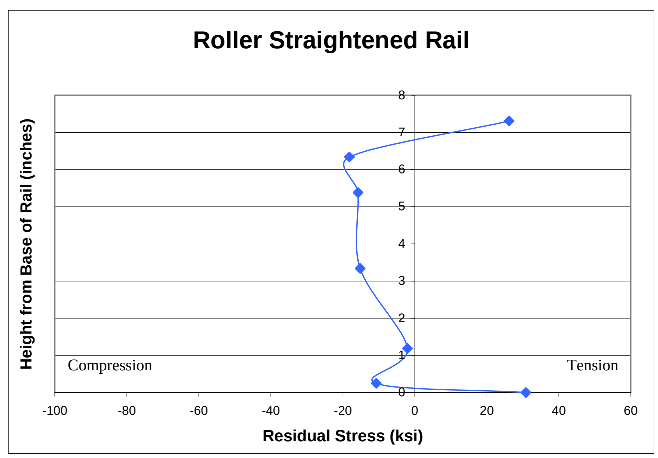

Figure 2. Longitudinal Residual Stress Profile for New Rail

The longitudinal residual stress profile for the new rail was primarily in compression with the exception of the top of the head and the base of the rail, which were both in tension. Contrary to the residual stress profile of the rail, both the thermite welds and the electric flash-butt plant weld had residual stress profiles in which the web was in tension and both the head and base of the welds were in compression. The stress profiles for the welds from the two different manufacturers were similar to each other, varying on average by about 4 ksi with the exception of the base flange tip that varied by 19 ksi. In general, the profile shapes obtained were similar to those in published literature for rail,[2] for thermite welds[3] and for electric flash-butt welds.[4]

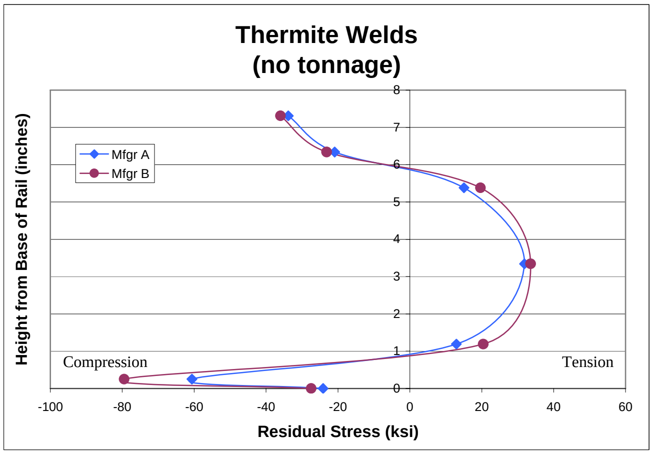

Figure 3. Longitudinal Residual Stress Profiles for New Thermite Welds

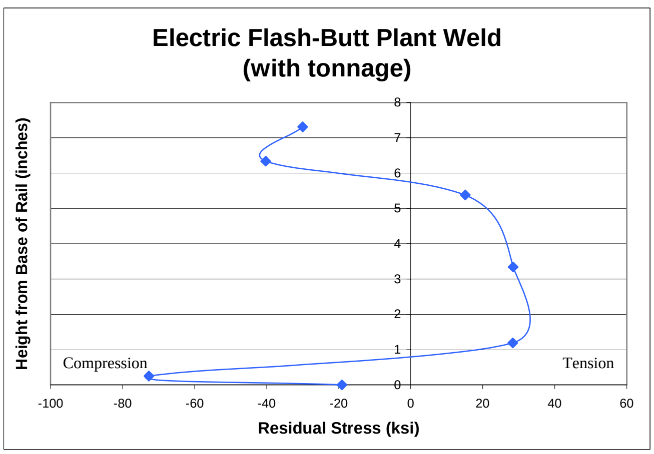

Figure 4. Longitudinal Residual Stress Profile for an Electric Flash-butt Plant Weld with Service Experience

Figure 5 shows the residual stress profiles for thermite railhead repair welds made on rail for two different manufacturers. The residual stress patterns in the base of the rail below the thermite railhead repair welds were similar to that of roller straightened rail with the exception that they were shifted further into or toward compression by approximately 8 to 12 ksi. The measurements in the head region were similar to standard thermite welds, with the exception that the tensile stresses immediately under the railhead ranged from 1.2 to 2 times the residual stresses values under the railhead in standard thermite welds. This is important because railhead repair weld fatigue failures at FAST have initiated under the railhead at regions of cold lapping[1] that acted as stress concentrators. Consequently, care should be taken during weld installation to prevent cold lapping under the railhead, especially in the region of increased tensile stress.

When thermite railhead repair welds were placed on electric flash-butt plant welds, the combination generated residual stress profiles that oscillated between tension and compression throughout the web and base of the rail. Figure 6 shows the residual stress profiles for the repair weld and plant weld combinations. Residual stresses under the railhead for the weld combinations were lower than for the railhead repair welds alone by 0.3 to 3 ksi. These residual stress profiles do not appear to indicate any potential stress problems associated with using railhead repair welds to repair head defects in plant welds. It should be noted, however, that during manufacture of the test welds, TTCI engineers observed that plant weld collars had to be ground and/or weld molds had to be filed to ensure proper fit of the mold to the rail to prevent the formation of cold lapping that can act as a stress concentrator. In initial efforts, TTCI welders found this to be problematic and difficult to achieve; however, this may be addressed through future mold modifications by the weld manufacturers to accommodate the electric flash-butt weld geometry.

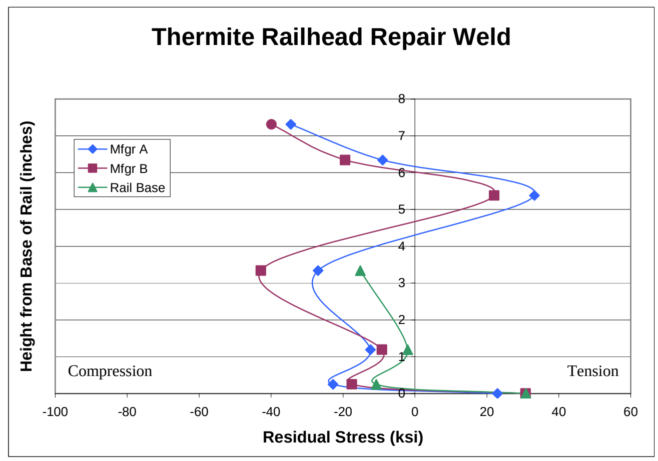

Figure 5. Longitudinal Residual Stress Profiles for Thermite Railhead Repair Welds. The lower four points of a rail base profile are included for comparison (see Figure 2).

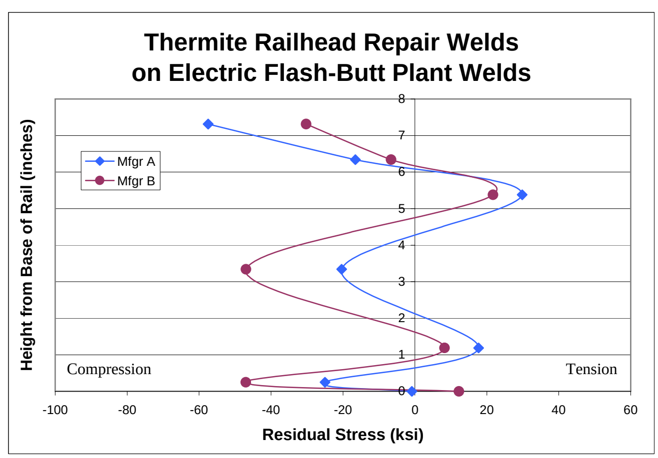

Figure 6. Longitudinal Residual Stress Profiles for Thermite Railhead Repair Welds for Two Different Manufacturers made on Electric Flash-butt Plant Welds

In addition to the residual stress measurements that were made on the railhead repair weld and electric flash-butt weld combination, TTCI conducted a metallurgical analysis. The welds were sectioned and etched for observation of the microstructures. No formation of martensite was observed in the weld combination. Figure 7 shows two cross section pieces that were examined.

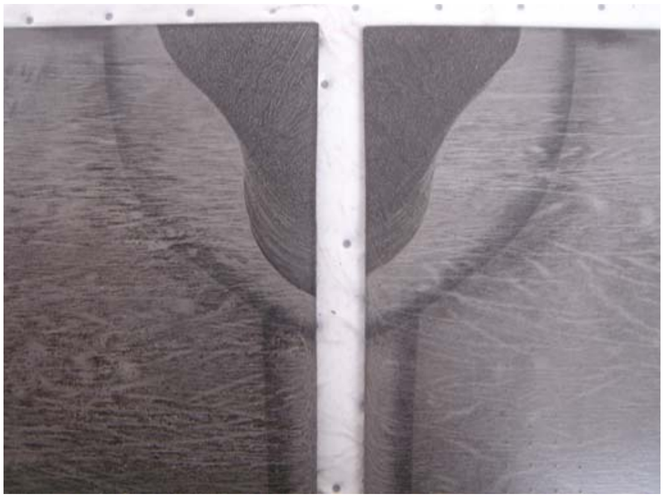

Figure 7. Macro Etch of a Longitudinal Cross Section of a Thermite Railhead Repair Weld made on an Electric Flash-butt Weld

CONCLUSIONS

The region of highest tensile stress in thermite railhead repair welds was located in the radius under the railhead. These stresses were 1.2 to 2 times the residual stresses under the railhead for standard thermite welds. Although these stresses were higher, it should be noted that they were similar in magnitude to the stresses found in the web of standard thermite welds. The fact that these increased stresses were located under the railhead means that greater care must be taken to avoid flashing or cold lapping occurring under the railhead. In testing previously conducted at FAST, welds that fractured had fatigue cracks that initiated at regions of cold lapping under the railhead that were located in this area of high residual tensile stress.[1]

The residual stress profiles in the rail below thermite railhead repair welds were similar to the profile of the parent rail except that the stress profiles under the railhead repair welds were shifted from 8 to 12 ksi further into compression.

The magnitude of tensile residual stresses for the railhead repair welds made on electric flash-butt plant welds were no greater than those found in either a thermite railhead repair weld or a standard electric flash-butt weld. The residual stresses in the weld combination alternated between tension and compression throughout the web and base of the rail.

Analysis of the residual stresses in railhead repair welds made on electric flash-butt plant welds did not identify any abnormally high tensile stresses that would specifically preclude repairing a defect in the head of a plant weld. During installation of the welds, extra care must be taken to avoid formation of cold lapping under the railhead. This may include grinding of the plant weld and modifying the weld mold to ensure proper fit.

FUTURE WORK

TTCI is making plans to conduct in-track testing of railhead repair welds made on existing electric flash-butt plant welds at FAST. Although the laboratory tests do not indicate any potential problems with the weld combination, in-track testing will allow for an in-service evaluation before revenue service application.

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