FLASH BUTT WEDGE REPAIR OF WELD HEAD DEFECTS

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ABSTRACT

Rail up time is critical to the success of a railroad and its customers. Head defects in rail can cause a loss of rail up time and typically requires the replacement of the affected area with a rail plug. A new approach for the repair of head defects has been developed which appears to exceed industry standards for performance called flash butt wedge repair. This welding repair method differs from other repair methods by using flash butt welding to place a wedge of actual rail material into a slot which was cut out of the rail to eliminate the defective section in the head. Testing of these welded joints shows a minimal heat-affected zone (HAZ) and lack of any pores, cracks, or solidification structure. These features allow the repaired area to perform much the same as parent metal rail. The repair method has been tested to insure that it exceeds both AREMA weld specifications and AWS rail welding specifications. The rolling load test of a flash butt wedge weld showed no erratic wear patterns or any signs of crack initiation.

The repair can be completed in less than 45 minutes using a mobile welding truck. The rail is not fully severed only a small section of the head is removed thus eliminating any potential for change in the neutral rail temperature. The final repair area hardness can be matched to the parent rail with simple process changes. Currently, flash butt wedge repairs are being tested in service on heavy haul lines and at the TTCI FAST / HAL test loop for further analysis.

INTRODUCTION

Rail head defects attributed to the increased axle loading in the rail industry can now be effectively repaired using a flash butt welding derived process. Defects in the rail head are typically associated with increasing axle loads on heavy haul lines used to transport coal, ore, and grain. If the defect is not repaired within the prescribed period after detection, loss of service may be required on the rail line.

Currently, the common approach is to cut a plug of the rail out of the track and replace it with a repair plug. This method requires an array of steps to guarantee quality, many extra man hours of labor to remove rail fasteners, calculations to guarantee maintenance of the Neutral Rail Temperature (NRT), and
requires matching of rails to the existing wear condition to guarantee a smooth transition between the existing rail and plug. Installation of a rail plug could easily utilize 30 man-hours to fully install and manage rail quality.

Research was conducted to identify a more efficient method that produced equivalent performance to the rail plug installation method. The flash wedge welding method allows for localized removal of head defects and replacement of the area with a section of rail material using a solid-state welding technique. This approach minimizes risks and delivers a weld repair that matches the performance of flash butt welds in rail used today.

PROCESS DESCRIPTION

Flash Butt Wedge Welding

Flash butt welding is commonly used to join rail section ends in the field using portable flash butt welding systems and in fixed plants. It is used to make a joint between parallel faces of many different materials in many different industries worldwide. Flash butt welding produces a solid-state weld joint with no residual fusion zone or cast structure remaining in the weld or HAZ of the weld. The weld is initiated by drawing a high current arc between the two parts. The arc has an extremely high electrical resistance and facilitates rapid heating of the mating joint surfaces of the joint. The arcing is continued until adequate heat soaks back behind the faying surfaces. The heating due to the arcing creates a thermal profile where the joint faces are at a very high temperature and further back from the faces is at a lower temperature. In rail steel and most metals, the yield strength of the material decreases as the temperature increases. The thermal profile creates a variation in material strength such that the strength of the much hotter material close to the faying surfaces is very low compared to that of the base material which is at a lower temperature.

After the material has been heated adequately, the two sides of the joint are upset (forged) together forming a solid-state weld joint. This is accomplished by applying high forces at the end of the welding process to upset the heated material out of the joint as it inherently has lower yield strength. This upset occurs until the force applied to the joint no longer exceeds the yield strength of the heated metal in the
joint. This implies that the material is forged out of the joint until metal with a lower temperature and higher strength remains.

The flash butt welding process is typically applied to planar parallel mating surfaces as presented by the butt ends of rail. Applying the process to anything other than flat planar surfaces was unknown prior to this work and not suggested in process descriptions. Special tooling and process characteristics were used to create even heating and complete upset of the joint interfaces.

The slot in the rail was cut such that it would remove a transverse defect in the head of the rail using carbide saws to minimize excessive heat input. Originally, the rail head repair was thought to be only applicable to defects in the top portion of the rail head. Market surveys showed that defects often progress below the midpoint of the rail head such that a partial depth joint may not be able to address all defects encountered in the field. Figure 1 shows a cut out in the head of the rail prepared for flash butt wedge welding.

FIGURE 1. SLOT CUT IN RAIL HEAD TO REMOVE DEFECT

The wedge is produced from a forging made of rail steel. Prior heat treatment of the wedge is used to guarantee the resulting repair areas hardness. Because the chemistry of the rail and the repair wedge are nearly identical, thermal cycles from the flash welding process have a similar effect on the material properties of the wedge and the rail. Therefore, no special chemistry in the wedge is required to attain the desired final repair area hardness. Figure 2 shows a typical wedge used in flash butt wedge welding lying
in the slot cut in a rail sample. Note that geometric changes in the surface of the wedge have been added to simplify post weld clean-up of the weld joint.

FIGURE 2. WEDDGE BLANK SITING IN RAIL Slot CUT-OUT

The wedge is placed in a flash butt wedge welding machine shown in Figure 3. In this machine the flash welder control is used to make the joint in three steps. First, the joint is preheated to control the cooling rate of the weld joint. This is followed by a flashing cycle which builds the desired thermal profile and flashes contaminants from the joint. When the proper thermal profile is developed, high force is applied to the top area of the wedge resulting in a solid state weld joint. Clean-up of the resulting joint is completed using hot shearing and finish grinding to match the profile of the rail. A photograph of a weld without cleanup is shown in Figure 4.
FIGURE 3. FLASH BUTT WEDGE WELDING MACHINE

FIGURE 4. COMPLETED FLASH BUTT WEDGE WELD
Experimental Results of Weld Joint Testing

Metallographic Examination

In order to qualify the welds as acceptable, metallographic examinations of the welds were conducted. A section of a flash butt wedge weld is shown in Figure 5. Note that there are no areas of preferential acid attack suggesting a solid weld joint with very little variation of microstructure at the butt lines. Also of note, in the fully developed flash butt wedge welds was the absence of a notable decarburized zone typically displayed in welds in high-carbon steels. Typically, most welding processes diffuse carbon out of the solid steel into liquid steel when present due to a chemical potential between the solid and liquid steel. Liquid steel has a higher solubility of carbon than solid steel so the carbon migrates from the solid steel area next to the liquid metal into the liquid. This decarburized zone is typically at the fusion boundary or butt line in welds in rail steel. Rail steel is particularly sensitive to this as it has a high carbon level.

The removal of this decarburized zone is attributed to the development of an ideal forging process where the heated interfaces, most notably the decarburized zone developed during the flashing cycle, are fully forged out of the final weld joint. This is due to the high degree of upset developed in the flash wedge weld and the sliding of the surfaces against each other. An area at the top of a weld joint is shown in Figure 6 where the bondline is obvious without a decarburized line.

FIGURE 5. CROSS SECTION OF FLASH BUTT WEDGE WELD SHOWING HARDNESS INDENT LINES
Also obvious in the Figure 6 joint is the lack of dendrites showing the final joint is a solid-state weld. The resulting wedge and rail microstructure at the bondline appears to be a fine pearlitic microstructure.

Welding trials were conducted to attain the desired hardness profile in the weld joint. Weld hardness traverses were taken at the 5-mm depth line as prescribed by AWS and AREMA specifications. A plot of the hardness across the wedge repair is shown in Figure 7 for a 315HB rail and Figure 8 for 380HB head hardened rail. As shown in the metallographic specimen, there are two butt lines on the top of the rail head in a flash butt wedge weld and therefore two HAZs. The average hardness in the repair wedge is approximately 37 Rockwell C in this sample in the 315HB rail. Note that the final hardness of the wedge can be adjusted to fit the rail hardness by controlling the pre-weld heat treatment of the wedge. The HAZ peak hardness is approximately 39 Rockwell C adjacent to the butt line. In the subcritical anneal HAZ the hardness is approximately 28 Rockwell C. The base rail material in these trials was 330 Brinell or approximately 34 Rockwell C. The weld repair in the 380HB rail displays similar trends although the lowest hardmesses in the annealed zone of these welds remain higher. The peak hardmesses along the butt line are also higher due to a slightly faster cooling rate.
FIGURE 7. HORIZONTAL HARDNESS TRAVERSE AT 5-mm DEPTH LINE in 315 HB 136RE

FIGURE 8. HORIZONTAL HARDNESS TRAVERSE AT 5-mm DEPTH LINE in 380 HB 136RE

The remaining tests identified in a rail weld qualification include slow bend tests with the both head up and head down, and a rolling load test. The head up slow bend tests all passed the recommended procedure and the tests were stopped as the test specimens far exceeded the load and displacement prescribed without failure. A load displacement curve is shown in Figure 9 for a typical slow bend test from the test specimens. Figure 10 shows the group of three tested slow bend specimens all displaying twisting of the rail under load rather than fracture implying the weld is ductile and able to withstand elongation without fracture. These results exceed the typical displacement and load requirements as prescribed by AREMA and AWS specifications.
Inverted slow bend tests, or head-down slow bend tests, also performed as desired. A typical head down slow bend test load versus displacement curve is shown in Figure 11. The welds fractured through thickness in this test as shown in Figure 12. The fracture initiated in the sub-critical anneal zone, where the weld joint has the lowest strength, and progressed into the rail base metal. The flash butt wedge repair remained intact in these tests. The welds showed the desired deflection before fracture and most importantly fractured through thickness without ejecting the wedge repair from the rail. This is critical
performance in a signalled track territory as the through-thickness fracture will upset signaling and alert
train controllers that there is an issue with the track integrity.

Figure 11. Inverted Slow Bend Test Load Versus Displacement Curve

The final test prescribed for rail welding by AWS standards was the rolling load test. The rolling load
test conducted at TTCI was a 12-in. stroke cantilevered rolling load test. The test was halted at 2,000,000
cycles, as this is the qualification limit, with no sign of failure or irregular wear detected. A photograph showing the wear pattern over the wedge repair is shown in Figure 13. A light variation in the wear is apparent in the subcritical annealed zones but the difference is very subtle compared to the surrounding rail section. The results of the rolling load test suggest that the flash butt wedge rail repair will provide long service in actual field applications. Field testing at TTCI’s FAST/HAL track showed no unusual occurrences with 100 MGT across the repair along across a winter and spring season.

FIGURE 13. ROLLING LOAD TEST SHOWING WEAR PATTERN OVER REPAIRED WEDGE JOINT

The final testing completed on the flash butt wedge weld in rail was residual stress measurement of the flash butt wedge weld joint in several locations. The blind hole method was used to assess the level and direction of stress in several different locations on the flash butt wedge welds. The locations and respective longitudinal and transverse stresses are shown in Figure 14. These stresses were all taken on the butt line in the weld where applicable and below the wedge repair on the centerline of the weld joint.

Residual compressive stress exists on the top portion of the repair from the web to ball transition area and upward despite contraction of the wedge and weld joint during cooling after the welding process is completed. The stress transitions to tensile below the ball to web transition area and peaks near the neutral axis of the rail. Near the base of the rail, the residual stress turns compressive again. The tensile stress near the neutral axis of the rail is likely due to the force exerted on the wedge during forging where the temperatures are lower and stress relief is not possible. This location for tensile stress is ideal as the neutral axis of the rail is exposed to the least amount of tensile strain during use. The base of the rail is in compression to offset the tensile stress in the center portion of the web. Notably, the residual tensile
stress in the web area is of a low level, approximately 25% of the yield strength of the rail material. The longitudinal stress running the length of the rail is lower and generally more compressive than the transverse direction stress. This is likely due to the fact that the wedge can pull the rail with less force in the axial direction thus lowering the residual stress. In the transverse or vertical direction, the rail is stiffer enabling it to retain higher levels of tensile stress. Based on these assessments, there is peak of residual stress in the head or ball region of the repair which implies it should perform well in service.

FIGURE 14. LOCATION AND INTENSITY OF RESIDUAL STRESS MEASUREMENTS ON FLASH BUTT WEDGE WELD REPAIR

CONCLUSIONS
A new process for repairing transverse defects in the head of a rail was developed, tested, and qualified to the AREMA and AWS rail welding specifications. The process called flash butt wedge welding produces a solid-state weld joint replacing the entire head section in the area of concern. Because the weld produced is solid state, no solidification or alloying issues often associated with repair welding on rail steel are developed. A piece of rail steel forged into a wedge shape is flash welded into a slot in the head of the rail from which the defect has previously been excised.

Testing completed to meet AWS and AREMA requirements all showed good results with no deficiencies noted. Residual stress measurements were taken on a wedge repair weld with residual compressive stress found in the head, underball, and base of the rail. The web of the rail showed residual
tensile stress. In track testing of the flash butt wedge welds showed no issues with 100 MGT across the joints.
Flash Butt Wedge Repair of Head Defects in Rail

Name: David Workman
Title: Senior Engineer
Company Name: EWI
Head Defects

- Inspection indications in head area
- Typically start as shown in picture
- Cracks on head surface in final stage
- 2008/2009 FRA data showed 56 derailments
- Several defect types
  - TDC, TDD, TDT…
- Many defects located yearly
- Require repair to prevent service failures and train stoppage
Current Repair Technique

- Use special procedures to prevent change in NRT
- Pull rail spikes, clips, or bolts to release area around head defect
- Cut a length rail to remove affected section
- Install rail plug via Thermite or flash butt weld
  - Matching of rail wear
  - Transport plug to location
  - Disposal of defective rail section
- File track disturbance report
Objectives of Improved Method for Defect Repair

- Joint development effort between EWI and Holland Company
- Repair of head defects at various depths with same process
- No track disturbance
- Weld repair target 45 minutes on track
- Portability
- Repeatable and simple to use
How Does it Work

- Cut slot to remove defect from rail head
- Preheating phase
  - Control cooling rate of weldment
- Flashing phase
  - Create thermal profile
- Upset phase
  - Make solid-state weld
- Clean-up phase
  - Finish grind rail to match geometry
How is Repair Insert Produced

- Repair wedge is made of rail steel
  - Simplifies hardness management
  - Cooling rate for rail and wedge are identical
  - Resulting repair is wrought material with wear characteristics similar to existing rail
- Blanks of rail steel are forged to near net shape
- Finish machined to optimum geometry
- Heat treated to result in post repair desired hardness 315 HB or 380 HB
Steps in Repair
Testing of Welds

AREMA/AWS Recommended
- Rolling Load Test
- Slow Bend Testing
- Hardness Traverse
- Macro-Etch Specimen

Additional Testing
- Residual Stress
- Inverted Slow Bend Testing
Head Up Slow Bend Tests

- No fractures in head up testing
- All specimens deflected sideways
- Exceeded displacement and load requirements
Inverted Slow Bend Testing

- All specimens fractured through rail section
  - Insure safety in signaled territory
- No areas of brittle fracture
2.3 Test Results
The criteria for this test is no rail or weld failure for 2,000,000 cycles at the required load. From June 16 to July 29, 2010, the welded rail was subjected to the required load for 2,016,844 cycles. At the completion of the test, there were no visible signs of failure and only normal wear of the railhead. Figure 3 shows the welded rail after the test. The appendix shows additional pictures.

3.0 CONCLUSION
For approximately 24 days, from June 16 to July 29, 2010, a welded rail provided by Edison Welding Institute was subjected to a 12-inch cantilevered rolling load, with the applied load ranging from 54,000 to 60,490 pounds at a rate of 64 cycles per minute for 2,016,844 cycles. At the completion of the test, there were no visible signs of failure and only normal wear of the railhead.
Rolling Load Surface

- No shelling
- No excessive difference in wear
- Wedge performs as rail in test
Macro-Etch Specimen
Butt Line details

“Decarb” band typically associated with welds in rail steel is minimized

Attributed to
- Sliding motion during upset
- Increased upset
- Die design constraint forcing upset from desired area

Process enhancement continued through development to minimize “decarb” band

Elimination of Decarb band believed to enhance performance
Hardness Traverse 315 HB Rail (34 Rc)
Hardness Traverse in 136 Head Hard (380HB)
Residual Stress on Rail Head

- Measure residual stress on head surface
- Trepanning method
- Locations
  - Midpoint of wedge
  - On butt line
  - Between butt line and midpoint
Residual Stress on Head of Rail

<table>
<thead>
<tr>
<th>Location</th>
<th>Longitudinal Stress (ksi)</th>
<th>Transverse Stress (ksi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mid Span</td>
<td>-34.0</td>
<td>-8.2</td>
</tr>
<tr>
<td>Butt Line</td>
<td>-49.1</td>
<td>-13.3</td>
</tr>
<tr>
<td>¾ Point between MS and BL</td>
<td>-57.8</td>
<td>-8.0</td>
</tr>
</tbody>
</table>

Note that (–) stress indicates compression.
Residual Stress in Vertical Plane

- On rolling surface of repair area
- Trepanning method
- Measure in longitudinal and transverse direction
  - Longitudinal direction is down rail length
  - Transverse direction if vertical up/down
Vertical Residual Stress on Butt Line

compression
tension
Conclusions

- Repairs 132-141 RE rail in 315HB and 380HB hardness
- Meets hardness requirements
- Cycle time goals achieved
- Able to use the same process across a variety of rail size or chemistry
- Exceeds industry mechanical tests
- Simple repair method (no special procedures or operator input)
Next Steps

- Continued testing on TTCI test loop (Section 31)
- In-track testing at several rail lines
- End use portable welding machine completed
- Further research
  - Application to other rail sizes (115RE)
  - Application to other rail chemistries