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Degradation of Thermite Weld Running Surface in Heavy Axle Load Environment

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Summary

Transportation Technology Center, Inc. (TTCI) has studied the performance of thermite welds in rails under heavy axle load operating conditions at the Facility for Accelerated Service Testing (FAST) to better understand how thermite weld running surfaces degrade and to gain an understanding of maintenance practices that can help reduce the observed degradation. This *Technology Digest* (TD) highlights the findings of that research. Running surface degradation exacerbates all fatigue related forms of weld failure, such as web fatigue fractures and base fatigue fractures.

Thermite weld running surface degradation and associated weld failures generally follow this sequence:

1. Soft weld heat affected zones (HAZ) rapidly deform under loading
2. HAZ deformation and flow (batter) creates loading events (impacts)
3. Loading events contribute to fatigue cycles
4. Welds fail as a result of fatigue

Welds can experience fatigue related failures even in the absence of high impact wheels. This is evidenced by train operations at FAST where the use of out-of-round wheels, wheels with flat spots, and high impact wheels is minimized. This points to the batter and degradation of the weld running surface as a strong contributor to fatigue loading of the thermite welds.

TTCI conducted a study to understand how rail welds degrade and develop shelling. This study resulted in implementing a post-weld grinding policy to reduce the effects of HAZ batter on weld fatigue life. The process was effective in reducing the formation of shelling on thermite welds. This post-weld grinding, while effective at FAST, may not be as easily implemented in revenue service, because it would require a visit to a weld site at a later date and taking the track out of service to perform the required work. Consequently, TTCI began researching ways to reduce the formation of the HAZ during the weld production.

Based on the findings of these degradation studies, TTCI explored methods to mitigate the size of the low hardness HAZ during the weld process that do not add significant time to the process. Results will be presented in a subsequent TD.



INTRODUCTION

Under heavy axle load (HAL) service conditions, the running surfaces of thermite welds can rapidly degrade, resulting in weld failures or unplanned maintenance. Figure 1 shows a thermite weld that has batter of the HAZs on each side of the weld and gage corner shelling on the weld itself. Batter is metal deformation and flow at the rail running surface in the HAZ and welds, which results from high contact forces at the wheel/rail interface. TTCI has conducted laboratory testing and in-track observations at FAST to better understand how and why thermite welds degrade.



Figure 1. Thermite Weld Showing Batter of HAZ (indicated by arrows) and Shelling at Gage Corner of Weld

HEAT AFFECTED ZONE

HAZ is a region in the parent metal that undergoes metallurgical changes during the thermal cycle imposed by an adjacent weld. For thermite welds, the heat from the thermal cycle comes from the preheat and from the molten weld metal. While it is impossible to prevent the formation of a HAZ, it is possible to modify its size, shape and severity by modifying the thermal cycle that produces the HAZ.

A thermite weld HAZ can be generally divided into two distinct regions. First is the near HAZ, which is located immediately adjacent to the thermite weld metal. Second is the far HAZ, which is located just outside the near HAZ. Figure 2 shows a cross section of a thermite weld HAZ at the running surface and identifies the near HAZ and the far HAZ.

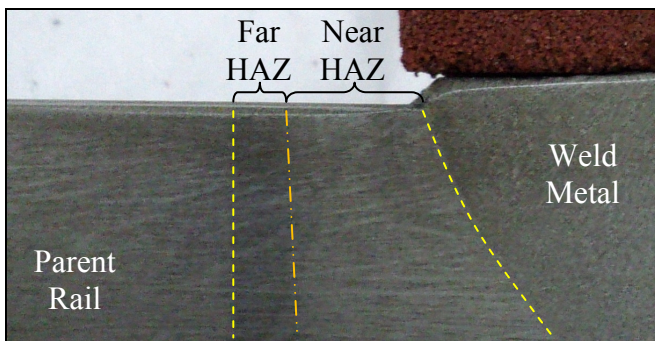


Figure 2. Longitudinal Cross Section of a Thermite HAZ at the Running Surface

The rail steel in the near HAZ experiences a thermal cycle in which the time and temperature were sufficient to transform the steel to austenite. Upon cooling, the austenite in this region transforms back to pearlite, resulting in a hardened microstructure. Martensite can potentially form in this region if rapid cooling occurs.

The rail steel in the far HAZ experiences a thermal cycle with a lower peak temperature than the near HAZ. The temperature at this location is sufficient to activate diffusion of carbon, but is insufficient to transform the microstructure to austenite. Diffusion of carbon causes the lamellar pearlite microstructure (which gives rail its hardness and good wear properties) to break down into iron carbide (cementite) spheres surrounded by a softer iron (ferrite) matrix. Figure 3 contrasts the hard wear-resistant microstructure of pearlite with the softer more easily deformed microstructure of the far HAZ.

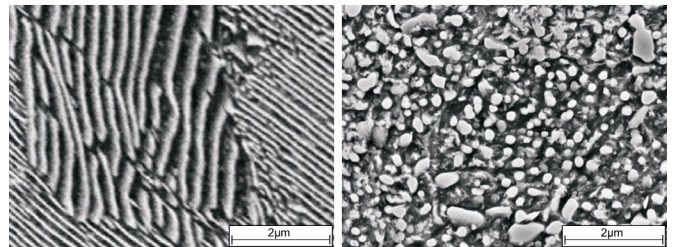


Figure 3. Scanning Electron Micrographs of Pearlitic Microstructure Typical of Rails and Thermite Welds (left) and Cementite Spheres in the Far HAZ (right)

The transformation of the rail microstructure to spheres of cementite effectively erases the benefits of the thermo-mechanical processing (TMP) that produces the high strength characteristics of the rail. The result is a reduction of the hardness (i.e., yield strength) that allows the material in the far HAZ to batter rapidly under HAL traffic in comparison to the nearby rail and weld. HAZ and weld microstructures are presented and discussed in greater depth in TD-10-015.¹

COMPLICATIONS IN HIGH STRENGTH RAIL

Rail manufacturers have continued to improve rail performance through changes to rail chemistry and with TMP. TMP improvements have refined austenite grain size and reduced lamellar spacing of pearlite, which contribute to increased hardness and strength of the rail.

The weld thermal cycle produces the same detrimental change in HAZ microstructure in high strength rail as it does in standard strength rail. The hardness of the far HAZ (i.e., cementite spheres region) is effectively the same whether the parent rail is standard strength or high strength. The result is a greater difference in hardness between high strength rail and the HAZ than between standard strength rail and the HAZ.

Figure 4 illustrates this by comparing the hardness profile for a thermite weld made in high strength rail with a thermite weld made in standard strength rail. In the illustration, the high strength rail has a hardness of 410 Brinell and the standard strength rail has a hardness of 310 Brinell. In both cases, the hardness in the soft region of the HAZ drops to 260 Brinell. In the high strength rail this is a difference of 150 Brinell, whereas in the standard strength rail the difference is only 50 Brinell.

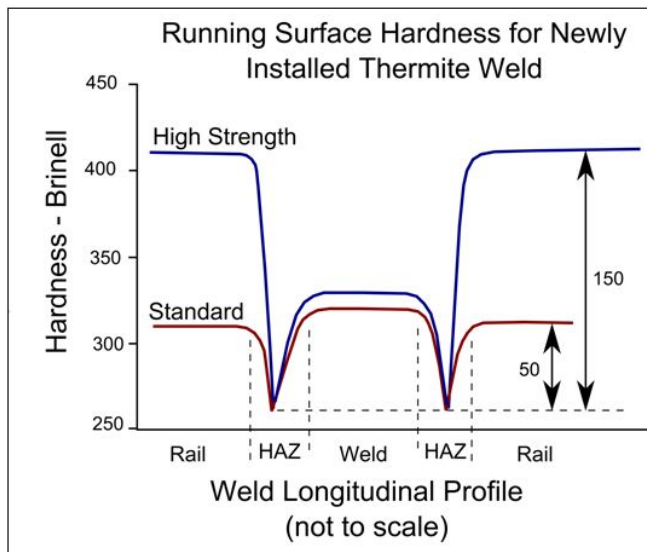


Figure 4. Conceptual Hardness Diagram Showing HAZ Hardness Dip is more severe in High Strength Rails compared to Standard Strength Rails (Note weld hardness represents intermediate hardness portion commonly used in North America)

The rate and amount of batter at the running surface is a function of the load applied and the hardness of the running surface. For a given wheel load, harder running surfaces batter at a slower rate than softer surfaces. In the case of HAZs in high strength rails, the difference in hardness results in a greater difference in batter, and therefore, greater dipping in the HAZ compared to standard strength rail.

DEGRADATION OF WELD RUNNING SURFACE

Thermite weld running surface degradation and associated weld failures generally follow this sequence:

1. Soft weld HAZ rapidly deforms under loading
2. HAZ batter creates loading events (impacts)
3. Loading events contribute to fatigue cycles
4. Welds fail as a result of fatigue

Hardness measurements of thermite welds at FAST reveal a rapid increase in HAZ hardness during the first 25 to 50 million gross tons (MGT) of weld life, and then the rate slows. This period, when the HAZ surface is still relatively soft

compared to the adjacent rail, is when batter of the running surface occurs the fastest. Longitudinal profiles across the running surface of a weld show that the initial batter in a HAZ forms very quickly. Figure 5 shows the hardness progression with MGT for a typical thermite weld HAZ at FAST. Figure 6 shows several longitudinal profiles that illustrate how quickly batter begins to set in for a typical thermite weld at FAST. As the HAZ work hardens, the rate of batter decreases.

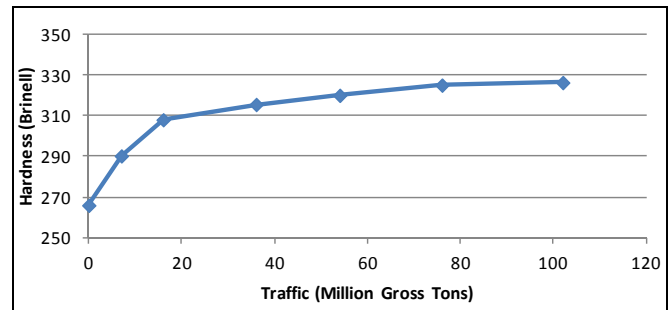


Figure 5. Hardness Progression for the HAZ of a Typical Thermite Weld at FAST

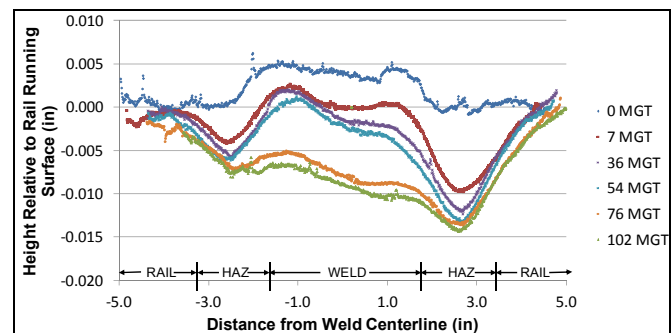


Figure 6. Longitudinal Profile for a Thermite Weld Running Surface that Illustrates the Rapid Onset of Batter in the HAZ followed by Batter of the Weld

Impacts that contribute to fatigue cycles on thermite welds can come from several sources. These include high impact wheels and surface degradation.² At FAST, unless a test specifically calls for it, there are few out-of-round wheels, wheels with flat spots, or high impact wheels in the train. Regardless, thermite welds at FAST commonly experience fatigue failures. This fact points to the running surface degradation as the predominant contributor to weld fatigue at FAST.

An example of this from FAST was a thermite weld located in tangent track with 0.1 inch deep batter at the HAZ and weld. An instrumented freight car passing over this weld recorded 4.0 g vertical peak accelerations measured at the side frame during 40 mile per hour operations. An instrumented wheelset that passed over the weld during the same time recorded an instantaneous vertical load of 86,000 pounds at 40 miles per hour. The weld failed shortly afterward from fatigue that initiated in the base of the weld.

RUNNING SURFACE REMEDIATION (FAST GRINDING STUDY)

Vertical fractures originating from the base or base radius of a weld is the dominant failure mode of thermite rail welds at FAST. From 2005 to 2009, weld failures at FAST began a steady shift toward shelling as one of the dominant reasons for weld removal.

In early 2009, TTCI conducted a brief grinding study in an attempt to gain control of rapidly increasing weld failure rate due to gage corner shelling at FAST. Manual grinding at different tonnage intervals was conducted on a series of maintenance welds, and the welds were observed for improvements in performance.

Based on the results of the study, TTCI implemented a basic post-weld grinding practice at FAST. After approximately 1 to 2 weeks of operation (from 5 to 14 MGT of traffic) on a new maintenance weld, the welders returned to the weld and conducted a light manual grind of the weld and adjacent rail.

Light maintenance grinding reduced the overall dip of the weld and HAZ compared to the adjacent rail. The grinding of rails did not remove the full depth of work hardened material in the dipped HAZ, but resulted in a smaller hardness differential at the running surface between the HAZ and surrounding material. This delayed the onset of running surface degradation.

Before the new grinding practice was implemented, thermite weld removals at FAST because of shelling of the weld gage corner had grown to nearly 35 percent of all unplanned weld removals. After the grinding practice was implemented in late 2009, weld removals due to shelling dropped to less than 15 percent in 2010. The grinding study did not investigate any changes in weld life that may have occurred as a result of grinding.

Although this practice may be somewhat unrealistic for application in revenue service where weld crews can be responsible for hundreds of miles of rail, it points to possible maintenance practice changes that can significantly influence weld performance. For example; if a welding maintenance blitz in a given railroad subdivision can be scheduled from 5 to 20 MGT prior to arrival of a rail grinder, the running surface performance of the welds can be considerably improved, and correspondingly, the life expectancy of the welds can be increased. Although the TTCI study did not specifically address mobile unit electric flash-butt welds, similar improvements in running surface performance are likely, because these welds also develop similar HAZ microstructure changes as seen with thermite welds.

MITIGATING HAZ FORMATION

Research on weld HAZs over the past couple of decades has focused largely on methods to remediate HAZ. Examples include post-weld heat treatment and followup grinding. These methods often require a visit to a weld site at a later date and taking the track out of service to perform the required work.

As a result, these methods can be time consuming and costly to implement. TTCI has explored methods to mitigate the size and location of the far HAZ during the weld process. The first of these methods is the use of a targeted chill, which is designed to reduce the severity of the thermal cycle and thereby narrow the overall HAZ width. The second is an overlay weld made directly over the far HAZ to reduce the effects of batter at the running surface. Both methods will be discussed in further detail in a subsequent TD.

SUMMARY AND CONCLUSIONS

- During the production of a thermite weld, a HAZ forms adjacent to the weld in the parent rail. The HAZ consists of two distinct regions referred to as the near HAZ and far HAZ. The near HAZ is located adjacent to the weld metal. The near HAZ reaches a sufficient temperature to transform to austenite prior to cooling allowing it to recover some of its strength as it transforms back to pearlite. The far HAZ, located just outside the near HAZ experiences a thermal cycle that causes the lamellar pearlite to degrade into spheres of cementite in a soft ferrite matrix.
- Running surface degradation due to batter is directly related to the hardness of the running surface at the HAZ and weld.
- Impacts caused by HAZ and weld batter contribute to all fatigue-related modes of degradation and failure, including vertical cracking in the weld base and horizontal cracking in the web.
- A similar phenomenon may be contributing to degradation of electric flash-butt welds in premium rails.
- Coordinated weld installation and subsequent rail grinding can significantly improve weld performance in high strength rails. If a welding maintenance blitz in a given railroad subdivision can be scheduled from 5 to 20 MGT prior to arrival of a rail grinder, the running surface performance of the welds can be considerably improved, and correspondingly, the life expectancy of the welds may be increased.

WAY FORWARD

Further research would assist in quantifying the improvement in weld performance and increased weld life expectancy.

REFERENCES

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