TECHNOLOGY DIGEST

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Improving Thermite Weld Heat Affected Zones

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Summary

Transportation Technology Center, Inc. (TTCI) explored two ways to reduce heat affected zone (HAZ) degradation through treatments applied during the welding process. Chill blocks were used to remove heat at the running surface to reduce the overall size of the HAZ. HAZ overlay treatments (i.e., arc welds deposited over the HAZ immediately after shearing the thermite weld head riser) were applied to the railhead over the area where the low hardness HAZ forms.

In the laboratory environment, the two thermite weld treatments showed the following results:

- Chill blocks reduced the low hardness HAZ width at the running surface by 22–44 percent.
- HAZ overlay treatment reduced the low hardness HAZ width at the running surface by 44 percent.

TTCI selected the HAZ overlay treatment for additional in-track testing based on the laboratory results and weighing the various advantages and disadvantages of each process. Initial test results at the Facility for Accelerated Service Testing (FAST) showed a significant visible reduction in HAZ batter for the treated welds. At 110 million gross tons (MGT) of heavy axle load traffic, the treated welds had no visible HAZ batter, whereas the untreated welds already had visible batter of the HAZ at 40 MGT.

Both the use of HAZ overlay treatment and the use of chill blocks have distinct advantages and disadvantages. The chill blocks require minimal operator skill or training, whereas welders must be skilled in wire or stick welding for the overlay process. The chill blocks do not require special equipment to implement; however, the overlay treatment needs additional welding equipment on the weld vehicle, depending on current practice by individual railroads. The overlay process can easily account for rail condition such as head or gage corner wear. The chill blocks require good surface contact between the rail and chill to effectively treat the HAZ. This means that multiple chill blocks must be carried to accommodate head worn or gage worn rails.

Based on the initial investigation of the chill process and the weld overlay process, TTCI selected the HAZ overlay treatment process for in-track testing, because of its greater potential in HAZ improvement and greater application potential for diverse weather conditions. The weld overlay process can be used at lower ambient temperatures, because it adds heat, as opposed to removing heat as in the targeted chill process.

Initial testing of the HAZ overlay weld treatment at FAST shows a strong reduction in visible HAZ batter at the weld running surface. TTCI is conducting further testing of overlay welds at FAST and in revenue service.

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INTRODUCTION

A thermite weld HAZ is a region in rail adjacent to the weld that undergoes metallurgical changes during the thermal cycle imposed by the weld process (preheat and molten weld metal). A HAZ consists of two primary regions, the near HAZ and the far HAZ. Figure 1 illustrates these regions. The near HAZ regains a portion of its original hardness as its microstructure transforms to pearlite. The microstructure in the far HAZ degrades to spheres of cementite in a soft iron matrix, and as a result becomes much softer than the adjacent rail and near HAZ. This is problematic, because the far HAZ will batter and accelerate weld fatigue by increasing impact loading on the weld during train operations. While it is impossible to prevent the formation of a HAZ when making a thermite weld, it is possible to modify its size, shape, and severity by modifying the thermal cycle that produces the HAZ. HAZ degradation is discussed in greater detail in another *Technology Digest* (TD).[1]

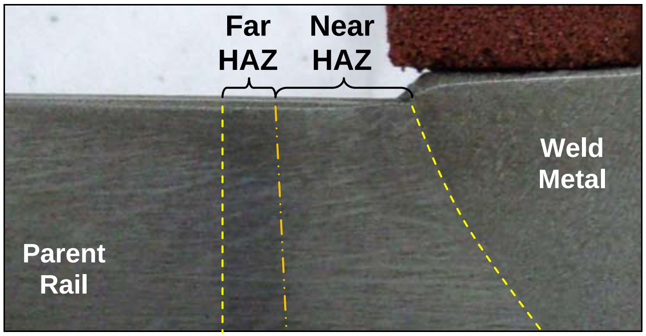

Figure 1. Longitudinal Cross Section of a Thermite HAZ at the Running Surface

Research on thermite weld HAZs over the past couple of decades has focused largely on methods, such as post weld heat treating, to remediate HAZ properties. Often they require a visit to a weld site at a later date and taking the track out of service to perform the required work. TTCI has instead focused on reducing the width of the far HAZ during the weld process. The general benefit from this approach is that treatments are applied concurrent with weld production; and therefore, do not require significant extra time or separate visits to perform.

TTCI has explored two mitigation methods for improving the thermite weld running surface at the HAZ. First, targeted passive chill blocks were incorporated into the weld process to remove heat from the rail running surface. Second, a weld overlay surface treatment was made directly over the spot where the far (soft) HAZ typically forms. Both processes share the following advantages:

- Do not require a separate visit to the weld site
- Do not require additional track time
- Are implemented as part of welding procedure
- Provide improved HAZ characteristics
- Do not add significant time to the weld procedure

PASSIVE TARGETED CHILLS

TTCI investigated the use of copper chill blocks to draw heat away from the running surface of the rail during weld production. Two separate scenarios were tested: (1) A single chill was placed immediately adjacent to the top of the thermite sand molds before luting was performed, and (2) Two chills were placed on the rail adjacent to the weld immediately after the weld was sheared. Figure 2 shows the placement of the single copper chill next to the weld mold, and Figure 3 shows the placement of the two chills after shearing the head riser.

Figure 2. Single Chill Block Placed Flush to Weld Mold and Packed with Luting Sand. Chill is Applied throughout Weld Preheat and Pour

Figure 3. Two Chill Blocks placed adjacent to Sheared Head Material. Chills are applied Immediately after Shearing

The process is called “passive” because the chill blocks draw heat away from the rail by their capacity to conduct and hold heat and do not actively control the temperature at the running surface. The process is highly dependent on obtaining good surface contact between the chill and the rail. The chills are “targeted” in that they are positioned so that they only draw heat away from the running surface where the HAZ forms.

The primary advantages of the chills are that they require minimal operator skill or training and do not require any special equipment beyond the chills to implement. The main disadvantage is that good contact between the chill and the rail is essential for proper heat transfer, meaning multiple chill designs must be carried by the welders to ensure good chill-to-rail contact for various rail profiles like head worn or gage worn rails. Weather variations adversely affect the process, and it may not be useful at low ambient temperatures. Additionally, implementation of the single chill during the weld pour draws heat away from the head riser and can change the head riser shear time or result in shrinkage at the weld running surface.

TTCI produced welds using each chill scenario and evaluated the changes that occurred in the HAZ. Figure 4 shows the longitudinal cross sections of the thermite welds. Table 1 shows the measurements of the HAZ and the benefit obtained. The weld made using the single chill had minor shrinkage at the running surface, which remained after grinding.

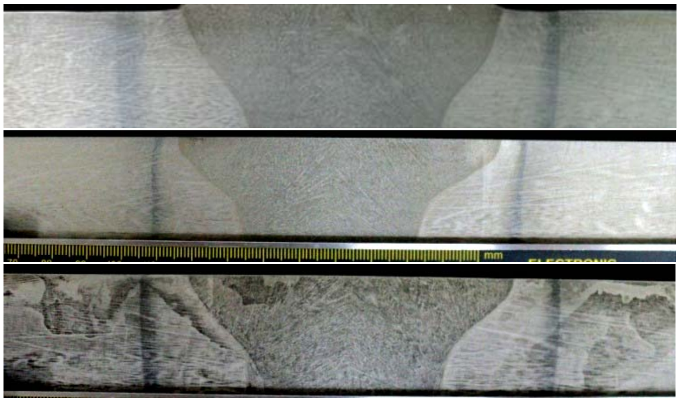

Figure 4. Thermite Weld Longitudinal Cross Section View of Railhead Top – Untreated Thermite Weld; Middle – Thermite Weld with Single Chill during Weld Pour; Bottom – Thermite Weld with Two Chills placed after Shearing

Table 1. HAZ Width Changes Resulting from Targeted Passive Chills placed at Different Points in the Welding Process

Targeted Passive Chills			
	Overall HAZ Width (inch)	Visible Far HAZ Width (inch)	Percent Reduction in Far HAZ Width
Without passive chill	0.67	0.18	-
With single passive chill during weld preheat and pour	0.27	0.14	22
With double passive chill after shear of head riser	0.55	0.10	44

HAZ OVERLAY TREATMENT

TTCI investigated application of a manual arc weld overlay at the surface of the rail over the thermite weld HAZ. The overlay weld was made using a flux core wire specifically designed for rail buildup. The overlay weld was applied over the HAZ immediately after the thermite weld was sheared. The wire weld metal was deposited in bands approximately 0.75–1 inch in width adjacent to the sheared thermite weld material. The welds were then ground flush to the rail as part of the thermite weld finish grinding process. Figure 5 shows a mockup that demonstrates the placement and orientation of the overlay weld in relation to the hot thermite weld metal.

Figure 5. Mockup Showing Application of Surface Hardening Material over HAZ next to Weld (Orange paint represents sheared head riser, and white chalk marking indicates location of applied hardening material)

TTCI made overlay welds in different locations to test effectiveness of modifying the underlying HAZ. Figure 6 shows the macros for an untreated weld and a weld made beginning at 0.25 inch from the thermite weld. The heat from the weld overlay narrowed the far HAZ (dark etching regions) and pushed it away from the thermite weld at the running surface. Overlay welds made further from the thermite weld had narrower far HAZ widths at the running surface, but did not effectively alter the underlying HAZ. Based on these results, TTCI selected 0.25 inch for all subsequent in-track testing. Table 2 shows the measurements of the HAZ and the reduction in far HAZ width.

The primary advantage of the HAZ overlay treatment is that it can be easily adjusted to account for head worn or gage worn rail profiles. Unlike traditional rail end buildup welds, the overlay process does not require additional preheat or interpass heating, because the hot thermite weld provides all necessary heat.

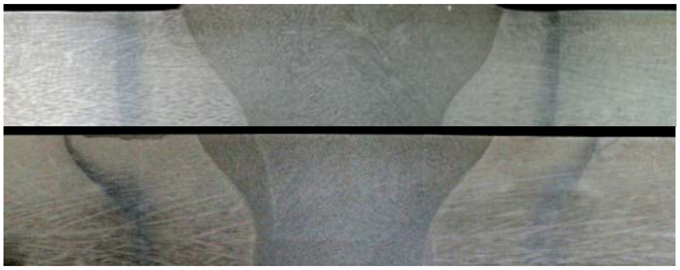

Figure 6. Thermite Weld Longitudinal Cross-Section View of Railhead. Top – Untreated Thermite Weld; Bottom – Overlay Treated Thermite Weld

Table 2. HAZ Width Changes Resulting from Surface Overlay Treatments

HAZ Overlay Welds			
	Overall HAZ Width (inch)	Visible Far HAZ Width (inch)	Percent Reduction in Far HAZ Width
Without surface hardening	0.67	0.18	-
With hardening located 0.25 inch from weld	1.28	0.10	44

FAST TESTING

In November 2011, TTCI installed five pairs of thermite welds at FAST to test the HAZ overlay welds. Each pair consisted of one treated and one untreated weld on opposite ends of a rail plug. Three of the test weld pairs were removed for maintenance or fractures unrelated to the overlays. However, the treated welds that remained in track showed a distinct running surface improvement over the untreated welds. After 110 MGT, no visible batter was present on the treated welds, whereas the untreated welds began showing visible signs of HAZ batter around 40 MGT. Figure 7 shows the difference in visible batter at the running surface of the welds at 70 MGT. Figure 8 compares the profiles of thermite welds with and without HAZ overlay treatment.

In July 2012, TTCI initiated a new HAZ overlay treatment test at FAST. The test includes treated and untreated welds from two different thermite weld manufacturers. In September 2012, TTCI and Canadian National Railway (CN) installed a group of test welds in track near Superior, Wisconsin. In November 2012, TTCI and CN established additional tests in track near Toronto, Canada and Winnipeg, Canada. Results of these tests will be reported at a later date.

Figure 7. Railhead Running Surface.
Top – Untreated Thermite Weld at 70 MGT
Bottom – Treated Thermite Weld at 70 MGT

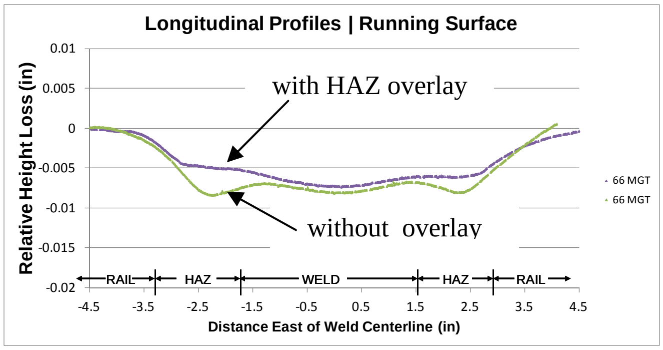

Figure 8. Running Surface Profiles Taken at 66 MGT for HAZ Overlay Treated and Untreated Thermite Welds

CONCLUSION

The targeted chill and HAZ overlay treatment processes share the following advantages:

- Do not require a separate visit to the weld site
- Do not require additional track time
- Are implemented as part of welding procedure
- Provide improved HAZ performance in heavy axle load service
- Improve weld life

Based on the initial investigation of the chill process and the HAZ overlay process, TTCI selected the HAZ overlay process, because of its greater potential in HAZ improvement and greater application potential for diverse weather conditions. The HAZ overlay process can be used at lower ambient temperatures, because it adds heat, as opposed to removing heat as in the targeted chill process.

Initial testing of the HAZ overlay treatment at FAST shows a strong reduction in visible batter at the weld HAZ running surface. TTCI is conducting further testing of HAZ overlay treated welds at FAST and in revenue service.

FUTURE WORK

The HAZ overlay process described in this TD is heavily dependent on operator skill and training. TTCI plans to investigate alternative methods of modifying the HAZ at the rail running surface. Potential methods include automated welding, flame heating, and induction heating.

REFERENCE

1. Gutscher, Daniel. July 2013. “Degradation of Thermite Weld Running Surface in Heavy Axle Load Environment.” *Technology Digest* TD-13-017, Association of American Railroads, Transportation Technology Center, Inc., Pueblo, Colo.