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Key Findings

- The UIT process has been modified with an improved impact needle design and changes to the peening unit with the goal of reducing treatment time and achieving full accuracy of impacting tight corners on weld surfaces.
- Shear timing is critical for weld integrity since the removal of heat from the weld and subsequent cooling happens much more quickly in head repair welds than in regular full-section thermite welds. Shearing sooner can cause liquid metal to form hot tear defects and shearing late can lead to incomplete shearing due to solidification.
- A high flow preheater is being evaluated for its ability to improve surface hardness and toughness of thermite welds via air quenching. The heater is designed to use propane for pre-heating the molds prior to welding and can be used in quenching mode with a preset duration to use surrounding air blown on the weld surface to achieve rapid cooling.

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MxV Rail, a subsidiary of the Association of American Railroads, performed the research described in this publication.

Recent Developments in Thermite Welding Methods

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Over the past three decades, MxV Rail has been conducting various tests on thermite welding processes under the Association of American Railroads (AAR) Strategic Research Initative (SRI) program. As a part of the welding research, MxV Rail simultaneously evaluates technologies related to pre- and post-weld processes aimed at improving weld longevity. In the last few years, MxV Rail worked with a supplier to modify the ultrasonic impact treatment (UIT) process and trialed the supplier's newly designed impact needles and peening unit. Additionally, along with collaborating on evaluating weld surface quench capabilities of another company's high flow pre-heater (HFP), MxV Rail has been evaluating head repair high hardness welds of two weld kit manufacturers and the issues related to weld shearing. This *Technology Digest* summarizes findings from the evaluations being done on three thermite welding related processes and next steps coming up on this research.

ULTRASONIC IMPACT TREATMENT (UIT)

Background

The UIT process uses a needle operating at ultrasonic frequencies to make small, rapid, localized impacts that plastically deform the material along the edges of the weld collar and introduce compressive residual stresses.[1] Fatigue defects grow under tensile stresses depending on the orientation of the cracks in relation to the direction of applied stresses. The peening needle of UIT reduces fatigue defect growth in the head/web and, more importantly, in the web/base fillets by introducing compressive stresses in these locations. Empowering Technologies developed a UIT-application tool for welds that has been tested with success at the Facility for Accelerated Service Testing (FAST®*). MxV Rail evaluated UIT welds at FAST from 2018 through 2022[2] and noticed a five percent decrease in the weld failure rate, primarily in the head/web and web/base fillets.

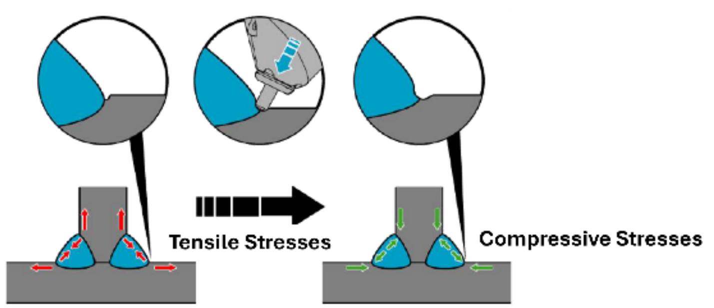

Figure 1. Diagram of UIT process to transform tensile to compressive stresses
(Image courtesy of Empowering Technologies)

When treating a thermite weld, the goal is to treat the location where the weld material meets the rail material at the steepest angle. The treatment begins at the head/web fillet on one side of the weld, works down to the base, and continues on the other side along the same path from head/web fillet to web/base fillet.

Recent developments in UIT

Based on the feedback received from MxV Rail's previous trial at FAST, significant changes were made to both the peening needle design and the UIT process. While the peening head has not changed, the end piece has been designed to be lighter and easier for the operator to maneuver.

The endpiece accommodates two different needles—circular and chisel-shaped—as shown in Figure 2. Compared to the 3-mm-diameter needles used previously, the circular design has a 6-mm diameter. The smaller needles required the operator to spend more time applying the treatment, especially at the web-base fillet region. During the recent trials of these modified needles on three thermite welds, the duration of UIT application was reduced from approximately 20 minutes to 15 minutes, although further trials are planned and data will be collected on duration of application. Additionally, some changes to the unit have been made to prevent needles from getting loose inside the endpiece.

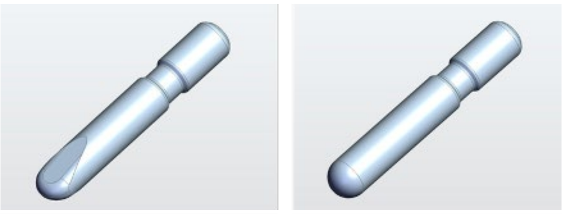

Figure 2. Chisel-shaped needle (left) and spherical tip needle (right), both having 6-mm diameters at the circular ends
(Image courtesy of Empowering Technologies)

Figure 3 shows the weld application with both the 3- and 6-mm needles at FAST during the UIT trials. Figure 4 shows a schematic diagram demonstrating that selection of the needle is critical for an effective treatment. While the circular needle is effective on areas where the rail geometry changes, the chisel-shaped needle is more suitable for applying UIT to the vertical wall of the web. The newly designed needles need to be applied to additional welds to better understand advantages and disadvantages faced by the operator. Additionally, if the needle is changed from circular to chisel-shaped in the middle of the process, MxV Rail plans to document the time required to change the needle. Recent trials showed that the chisel-shaped needle can be used for treating the entire weld surface.

Figure 3. 3-mm needle (left) during 2018 FAST trial and 6-mm needle (right) during 2024 FAST trial

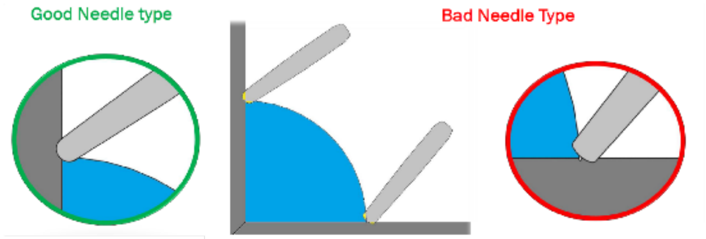

Figure 4. Diagram showing the different needles needed based on geometry of the area receiving UIT
(Image courtesy of Empowering Technologies)

At this point, UIT is not practicable in treating the bottom of the weld base. The process to treat the bottom of the weld base requires ballast removal and necessitates applying the needle with limited visibility, despite the option of holding a mirror or keeping a cell phone camera focused on the bottom of the weld base. Developing fatigue defects in thermite welds at the bottom of the base can still grow quickly under tensile stresses, and the MxV Rail welding research team is planning further investigations into how UIT can be applied to those critical areas. UIT application revenue service trials where duration of the process with new needles and operational efficiency will be documented along with monitoring of weld longevity are planned in upcoming months.

HEAD REPAIR WELDS

Background

Head repair welds (HRWs) were evaluated as a part of the SRI program in 2009–2010. At that time, higher hardness HRWs were not available.[3,4] Since rail hardness has increased in the last 15 years, thermite weld kit manufacturers have also increased the hardness of their HRW kits. It is important to understand that there are major differences between a regular thermite weld and thermite HRW. An HRW is designed to replace a defect in the head of the rail without cutting the full rail cross section and disturbing the track or modifying the rail neutral temperature (RNT). A regular thermite weld with a plug rail can replace a defect in any part of the rail, requiring the rail to be cut and adjusted for RNT and thereby making the thermite weld process more time consuming and more impactful to the track structure. In order for both processes to work, however, adjustments to temperature and time control need to be made because the HRW has less thermal mass and a larger heat sink that draws heat away from the cooling weld more quickly compared to a regular thermite weld.

Per the recommendations from the Welding Technical Advisory Group (TAG), MxV Rail reached out to HRW manufacturers regarding changes to HRW guidelines in the past 15 years. Two HRW manufacturers have updated guidelines regarding how much metal in the head needs to be removed before their respective HRW thermite portions are poured. While one manufacturer recommends a full removal of the rail head, a second manufacturer recommends leaving no more than a 1/4 inch on the ball of the rail head.

Recent Issues with HRWs

This trial evaluated the performance of two HRW weld kit types—Type A and Type B—from two different manufacturers. Four welds of each type were planned for installation in track. The evaluation focused on the performance of the HRW and weld integrity. Type A welds, characterized by a shorter pre-heat time and earlier shearing, exhibited hot tear defects in all samples as shown in Figure 5. A hot tear forms when the hot metal does not fuse properly and oozes out the side after the shearing process, becoming a permanent defect once cooled. Four Type B welds were performed using an extended pre-heat time and delayed shear time, showed no hot tears on the outside, and are currently being monitored in track at FAST.

Figure 5. Hot tear defects on the side of the head after a complete shear

Shearing Velocity

Shearing velocity plays a pivotal role in the integrity and success of HRWs. The shearing equipment used for both Type A and Type B welds is manually operated, meaning the shearing speed is entirely dependent on the operator's control and timing. Manual operations introduce variability into the process, as operator skill and reaction time can influence the outcome. When executed optimally, manual shearing can result in faster separation and complete shearing, especially if the timing aligns well with the cooling curve of the weld.

In contrast, a vendor-supplied shear system that operates at a slower, controlled velocity was tried on Type A welds. This equipment is designed to maintain a consistent shearing speed by setting parameters in advance, with the goal of reducing variability and allowing for more predictable outcomes. Both systems—manual and automated—are capable of achieving full shearing, but only when the timing is carefully calibrated to the weld's thermal profile. Vendor-supported trials demonstrated that using a fixed velocity shear and adjusting shear timing by 30 seconds earlier than recommended times improved initial weld outcomes, whereas the manually operated shear equipment seen in Figure 6 moving at a faster velocity led to inconsistent results. These findings highlight the critical role of controlled cooling and consistent shear velocity in minimizing weld defects.

Figure 6. MxV Rail shear used during head repair trials

Such outcomes highlight the importance of synchronizing shear velocity with the cooling behavior of the weld. In particular, initiating shear too late can result in increased resistance and incomplete separation while shearing too soon can cause molten metal to form weld defects, such as hot tears. Although more work needs to be done to understand the differences between shearing early and shearing late, adjustments to the pre-heat process can make the shearing process smoother and less sensitive to time changes. For example, increasing the necessary pre-heat time by adjusting the torch height can cause more heat to impact the existing rail, thereby preventing the rail from acting as a heat sink and allowing the HRW to retain more heat.

HIGH FLOW PREHEATER (HFP)

In 2023, Pandrol published a new concept of increasing thermite weld surface hardness by applying an air quenching technique after the shearing process using a device called the high flow preheater (HFP).[5] MxV Rail and Pandrol began evaluating the effectiveness of this quenching on weld surface hardness and decided on a two-phase trial. Figure 7 shows the quenching process during one of the trials conducted at MxV Rail. The HFP uses pressurized propane to preheat the mold. The unit uses two 18-volt batteries, and it can be used as a pre-heating unit with a fixed height. When used in air quenching mode, the outlet nozzle is placed directly over the weld to cool the weld using surrounding air for quenching.

Phase I consisted of quenching for both 5- and 10-minute periods along with natural cooling on a different combination of weld kits of intermediate and high hardness along with rails of intermediate and high strength. A total of 12 welds were made as a part of Phase I. Eight of the 12 combinations were chosen for Phase II. Three welds were made for each of the eight combinations, 24 welds total. In both phases, the quenching technique was used only on full thermite welds not on HRWs. The findings from Phases I and II of this research will be documented in a future publication.

Figure 7. HFP using air quenching to cool a thermite weld

Preheating times can be set on the HFP; when the chosen preheating time is reached, the HFP turns off. During Phase II, both the temperatures and the temperature differential of the top of the weld directly under the preheater were recorded by a thermal camera. Temperatures were measured for 20 minutes for both the naturally cooled welds and those that were air quenched with the HFP. The camera was not placed close to the weld to allow the welders access to the area during de-molding. Figure 8 shows a thermal camera image for one of the welds after the mold was removed.

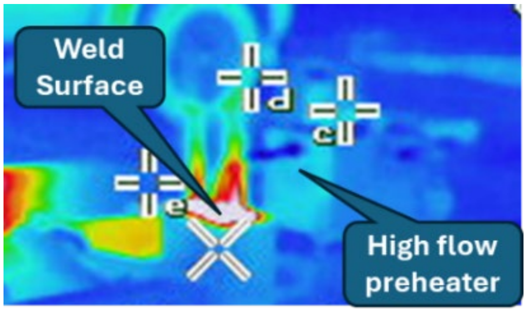

Figure 8. Thermite weld with mold removed. Weld surface and high flow preheater are marked in the image.

Cooling rates for the naturally cooled, 5-minute, and 10-minute quenches were calculated, but there was not a strong correlation between the cooling rate temperature change and the quench duration. The lack of correlation could have been due to camera resolution, the camera distance from the weld, or the small measurement area at the top of the weld. Welds from Phase II will be slow bend tested to find any possible differences, for both modulus of rupture and deflection caused by the air quenching on the surface of the weld fusion zone.

CONCLUSIONS

MxV Rail is evaluating the ability of pre- and post-weld processes to improve the longevity of new and existing welds. Engineers are evaluating the latest developments in the UIT process, including using redesigned impact needles. Revenue service trials will be performed using redesigned needles and while documenting the reduction in process time and effectiveness of application. High hardness HRWs from two manufacturers were evaluated and issues with shearing were identified. Premature shearing caused molten metal to form hot tears while late shearing lead to an incomplete shear. A new device aimed at post-treatment of the weld surface is currently under evaluation. The device can be used for air quenching to increase weld hardness and toughness both on the surface and up to a certain subsurface depth based on the duration of the quench.

ACKNOWLEDGEMENTS

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