TECHNOLOGY DIGEST

Timely Technology Transfer

EVALUATION OF THERMITE WELD TREATMENTS

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Summary

A laboratory investigation into the performance of treated thermite welds determined that subharmonic weld-treatment processes are feasible and produce mechanically sound welds suitable for service testing. The weld treatments consist of applying subharmonic vibrational energy into the rail at precise locations either during, or subsequent to, the application of the thermite weld.

The vibrational treatments are intended to produce a weld which is more resistant to premature cracking and fatigue. In addition, the treatments could possibly produce welds that are more wear resistant and less susceptible to typical thermite-weld defects. The improved weld performance will optimally lead to a reduction in weld maintenance and replacement costs. The results of the initial laboratory investigation confirmed that the test welds are suitable for in-service evaluation at the cooperative Association of American Railroads/Federal Railroad Administration (FRA) Facility for Accelerated Service Testing at the FRA's Transportation Technology Center located near Pueblo, Colorado.

Laboratory analyses of treated and untreated thermite welds show:

- No appreciable macrostructural or microstructural difference between the treated and untreated welds was observed.
- Each of the thermite welds, both treated and untreated, endured 1 million cycles of rolling-load testing.
- Saw-cutting of the welds did not show a discernible change in residual stress between the treated and untreated welds.
- Ultrasonic analysis did not identify any discontinuities in the test welds.

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Suggested Distribution:

- ❑ Research and Test
- ❑ Maintenance of Way
- ❑ Maintenance Planning
- ❑ Track Maintenance

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INTRODUCTION AND CONCLUSIONS

Subharmonic weld-treatment processes have been found in laboratory tests to produce mechanically sound welds suitable for service testing. As an improvement to the bolting of rail joints, thermite welding has become a widely used welding process which utilizes the highly exothermic aluminothermic reaction. This reaction between iron oxide (Fe_3O_4) and aluminum produces the heat required to melt filler metal which flows from a crucible into the opening between the rails and provides a suitable joint. Because of the popularity and widespread use of the thermite welding process, improvements in weld performance could possibly reduce track-maintenance and operational costs.

A metallurgical consequence of the thermite-weld process is the formation of residual stresses in the rail which can contribute to weld defects and failures. The thermal expansion of the rail and weld from heating and subsequent contraction from cooling, in conjunction with the contraction of the molten weld metal during solidification, produces thermally induced residual stresses in the rail. A contributing factor to the formation of residual stresses is the complex geometry which the weld assumes. Tensile residual stresses, which form during the typical thermite-weld application in the heat-affected zone of the weld, can lead to horizontal split web (HSW) and fatigue defects.

The weld-conditioning subharmonic treatment used in this evaluation was intended to both improve the structure of the thermite weld as well as reduce the magnitude of residual stresses present in the weld and adjacent rail. The stress-relieving treatment was designed to reduce the magnitude of residual stress in existing welds. The laboratory evaluation was performed to ensure that treated welds could be tested in service conditions at the Facility for Accelerated Service Testing without increasing and optimally decreasing the probability of failure. The tests conducted to ensure the performance of the treated thermite welds included ultrasonic hand mapping, rolling-load testing, hardness testing, saw cutting, and macro/microstructural analysis.

Results from the laboratory tests conducted on the treated and untreated thermite welds show that subharmonic stress-relieving treatment did not produce a detectable reduction in residual stress as determined by the saw-cut method. However, the saw-cut method cannot distinguish small changes in residual stress which the treatment could have induced. A finer, more uniform, grain structure and reduction in porosity expected from the subharmonic weld-conditioning treatment was not observed. Nonetheless, a structural change that was not discernible at the magnifications used for examination could still improve the performance of the weld-conditioned thermite welds.

SUBHARMONIC WELD TREATMENTS

The weld treatments implemented in the laboratory investigation were subharmonic stress-relieving and subharmonic weld-conditioning. The stress relieving process consists of applying subharmonic vibrational energy at frequencies between 45 and 66 Hz to the rail to neutralize unwanted residual stresses formed by the typical application of a thermite weld. Vibrational energy is used instead of the more common thermal heat treatment which provides heat energy to allow atomic diffusion to occur and the formation of a structure at a lower energy state (decreased residual stresses).

The weld-conditioning treatment utilizes the same process as the stress-relieving, except the vibration is taking place during weld application. The application of vibrational energy to the molten metal during weld solidification is intended to produce a finer, more uniform, grain structure along with a reduction in porosity. The theory behind the subharmonic weld-conditioning treatment is the vibrational energy breaking up large dendritic (Greek for "of a tree") branchlike crystals which form in the liquid weld during solidification. Breaking up the

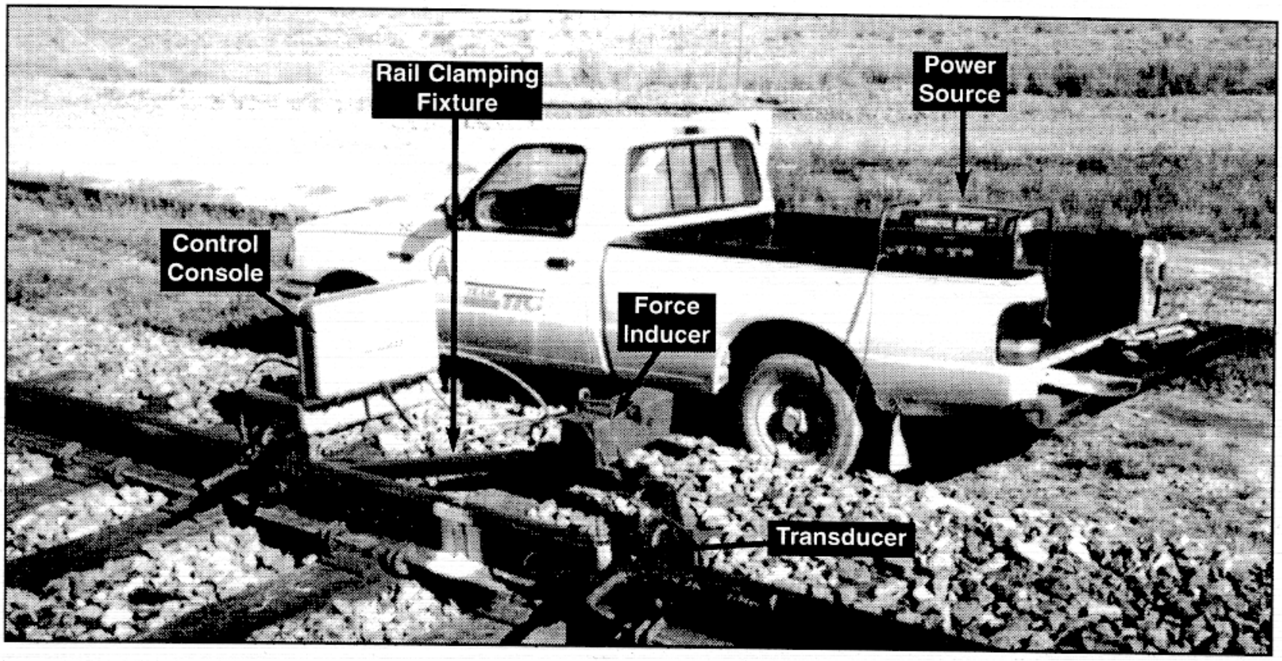

Exhibit 1. Subharmonic Weld-Treatment Setup

dendrites as they grow should provide additional nucleation sites (crystal seeds) for new grains to form, decreasing the size of the resulting individual crystals. The large dendritic treelike crystals are detrimental because they produce segregation of the weld-alloying elements and in themselves decrease the mechanical performance of the weld.

LABORATORY TEST PROGRAM

The thermite test welds and treatments evaluated in this study were produced using the manufacturer's recommended procedures.

Laboratory test welds include:

- Four subharmonic stress-relieved samples
- Four subharmonic weld-conditioned samples
- Four untreated welds

The thermite weld treatment consists of placing a fixture with an attached force inducer symmetrically around the weld and a transducer between the fixture and the weld to monitor the frequency of the applied vibrational energy. The subharmonic weld-treatment fixture setup is shown in Exhibit 1. Several frequencies and treatment times were used in order to determine the treatment which produces the optimal weld performance.

RESULTS

The laboratory results indicate that the thermite treatments produce sound welds which are suitable for service testing. After 1 million cycles of rolling-load fatigue testing, the test welds showed no harmful effects. Pulse-Echo Ultrasonic inspection (calibrated with ⅛-inch flat-bottom hole) of the test welds to determine the presence of cracks, voids, inclusions, and/or pores, did not discover any discontinuities in the material. Hardness testing of the welds shows that the hardness of the treated and untreated welds are similar, ranging between 260 BHN and 320 BHN for untreated welds, and 280 BHN and 320 BHN for treated welds.

The saw-cutting and structural analysis of the test welds did not show a discernible difference between the treated and untreated welds. A finer grain structure with less porosity was expected from the weld conditioning treatments. However, the macro- and

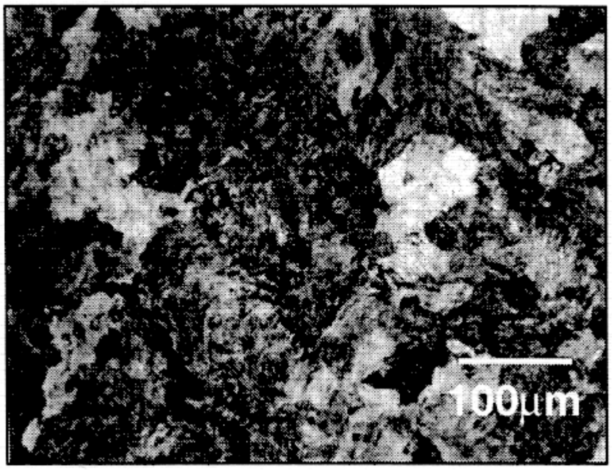

Exhibit 2. Microstructure of Untreated Thermite Weld

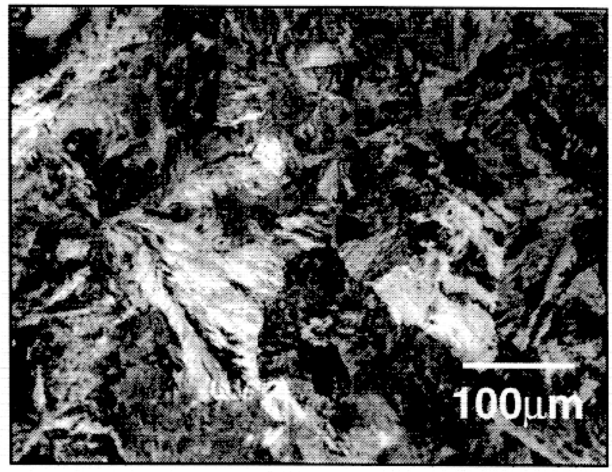

Exhibit 3. Microstructure of Subharmonic Weld-Conditioned Thermite Weld

microstructures do not show an observable difference. Exhibits 2 and 3 are representative photomicrographs from untreated and subharmonic weld-conditioned thermite welds, respectively. The absence of a finer structure or reduction in porosity in the treated welds is possibly an indication that the treatments did not greatly affect the properties of the thermite welds. Also, the subharmonic stress-relieving treatment intended to reduce the residual stresses within the weld and adjacent rail did not produce a detectable difference between the treated and untreated welds.

FUTURE WORK

Test welds consisting of both subharmonic stress-relieved and subharmonic weld-conditioned types were placed in the FAST track for service evaluation upon completion of the laboratory investigation. The welds were installed in Sections 30, 31, and 32, which consist of a spiral, a 5-degree curve, and another spiral with both wood and concrete ties. The type of rail used was 136-pound RE deep-head-hardened rail. Sixty-five test welds were placed in the track at both the low- and high-rail positions.

Test weld evaluation will consist of ultrasonic hand mapping, scheduled rail-flaw inspection every 3-5 million gross tons, and a visual inspection performed at weld installation and periodically thereafter. The weld and adjacent rail surface hardness will be monitored in BHN and the amount of metal flow will be monitored by performing longitudinal rail-profile measurements.

In future test welds, modifications to the amount of vibrational energy induced during the weld-conditioning treatment are planned in order to create a finer microstructure (refinement of dendritic structure). Additional laboratory welds will be produced and tested to determine the effect of these modifications to the weld-conditioning treatment.

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