

ELECTROMAGNETIC STIRRING OF THERMITE WELDS

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Summary

Compared to standard thermite welds, welds prepared with electromagnetic stirring (EMS) demonstrate:

- A more uniform and beneficial overall grain structure.
- Good weld refinement at the weld collar where many fatigue defects initiate.
- Less weld refinement at the weld center line, where service defects do not often originate.
- No effect on the ultimate tensile strength and a reduction in the ductility of longitudinal weld samples due to little refinement at the weld center line.

Full-size stirred and unstirred 1-inch-gap thermite welds have been made in 136 RE standard rail. Because results have not yet confirmed that better weld properties are obtained, further studies will optimize the stirring power and time. Full-scale stirred welds will be produced and tested in bending fatigue against conventional welds.

The Association of American Railroads is working with the Canada Centre for Mineral and Energy Technology (CANMET) to develop EMS practices to improve the service performance of thermite welds. Canadian National and Railwel (welding supplier) are also contributing to the project.

EMS is employed extensively in the steel industry to improve surface quality and the internal structure of castings. It uses a rotating magnetic field produced by coils to stir molten metal as it solidifies. The rotational flow helps to break up the cast structure, causing the steel to solidify with a more refined structure.



Suggested Distribution:

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

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INTRODUCTION AND CONCLUSIONS

The Association of American Railroads (AAR) and Canada Centre for Mineral and Energy Technology (CANMET) are working together to study the use of electromagnetic stirring (EMS) techniques to improve the service performance of thermite welds. Canadian National and Railwel (welding suppliers) are also contributing to the project.

The study has shown that EMS is capable of refining the normal cast structure seen in thermite welds. The normal structure has a coarse, needlelike form, termed columnar dendrite, which is believed to contribute to premature weld failure. The liquid metal flow induced by EMS breaks down this needle structure during solidification, to give a more refined solidification structure.

The study has not yet shown that this refinement gives better weld properties. Tensile tests on specimens from stirred and unstirred welds have not shown a benefit from EMS treatment. However, all the tensile specimens failed at or near the weld center line, where refinement was least pronounced. This is an area of the weld where service failures rarely start. Much better refinement was seen at the weld/rail fusion line. Further study will examine the effect of EMS on fatigue, using full-scale rail weld samples.

Thermite welds are considered a weak link in railroad track. A recent survey of six North American railroads showed that defective thermite welds accounted for 17.8 percent of detected defects from 1990 to 1995. Only transverse defects, at 24.9 percent, were more common. In part, this weld failure rate is explained by the weld cast structure, and the presence of inclusions and porosity. As well as refining, EMS is expected to improve weld performance by reducing inclusions and porosity.

ELECTROMAGNETIC STIRRING

EMS is used extensively in the steel industry to reduce centerline shrinkage, promote an equiaxed cast grain structure, and reduce

shrinkage porosity and the numbers of inclusions in castings. Most rails are produced from stirred continuously cast steel.

In EMS, a rotating magnetic field produced by coils imparts a circular motion to the liquid steel. The rotational flow fractures the growing steel dendrites, helps form the preferred equiaxed structure, and impels inclusions to the center of the solidifying steel.

Exhibit 1 shows the test set-up for the production of trial welds. The coil shown is made by JME Inc., has an internal diameter of 15 inches, a height of 12 inches, and a three-pole core. This allows 13- to 14-inch-long weld samples to be made. (A split coil will need to be designed for field application.) Coil power output for the tests was 53 kVA (468 V, 114 A), at 60 Hz frequency.

TEST PROGRAM

Early work studied the effect of coil current on the efficiency of stirring in cylindrical and rail-shape castings produced in sand molds. This confirmed the ability of EMS to refine the structure of steel solidifying to a relatively complex rail shape.

The main phase of the work used the test setup of Exhibit 1, with 1-inch welds made between two 6-inch sections of new 136 RE standard rail. Three welds were made using Railwel QP CJ welding kits, using a one-shot crucible and five minutes preheat. Each rail/mold assembly was preheated before

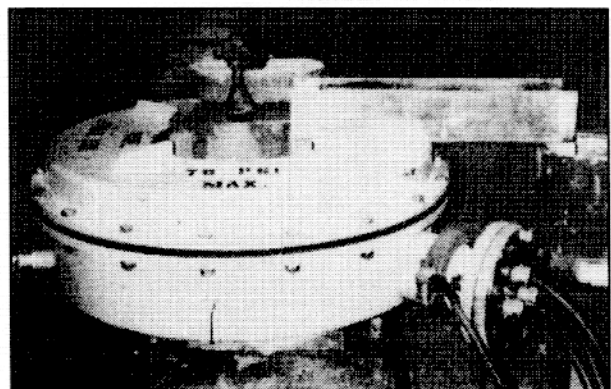


Exhibit 1. The Test Coil Enclosing Thermite Molds between Two 6-Inch Rail Samples



being transferred to the coil. Because of this, preheat temperature at pour was probably below the ideal. This may have affected rail-end fusion, but is not expected to have influenced the solidification structure. Reference weld A was made without EMS, welds B and C were made with EMS, at stirring times of 60 and 180 seconds respectively. (Times are measured from the start of pouring.)

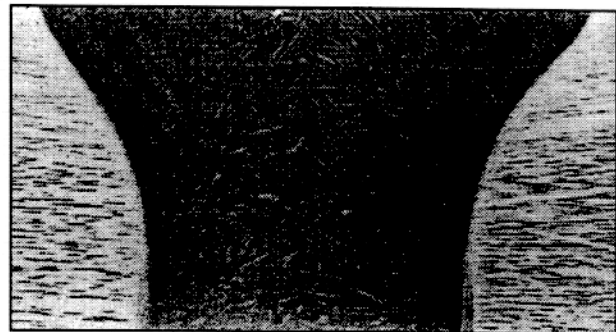
All three welds were sectioned and etched to reveal the solidification structure. Specimens were also prepared to assess the amounts of porosity and inclusions. The hardness profile was measured across each weld at a depth of 0.2 inch below the rail running surface. Finally, tensile test samples were taken centrally from the head and foot of each weld. Two samples were taken at each location.

SIGNIFICANT RESULTS

Exhibit 2 illustrates the refinement obtainable from EMS. The head of the reference weld made without EMS is shown in Exhibit 2A. A coarse dendritic structure is seen over the whole width of the weld. In contrast, in exhibits 2B and 2C, both EMS welds show a much more refined structure at and near the weld fusion lines. It is noticeable, however, that the EMS welds still show a coarse structure near the weld center line. This is the last area to solidify, and the least easy to stir through solidification.

Of the two stirred welds, the long-stir-time weld C shows the coarser center-line area and higher porosity and inclusion levels. The implication is that, for best results, stirring needs to be stopped before final solidification occurs at the center. The reason for this is not known, but it may be that prolonged stirring has concentrated inclusions in the center-line area.

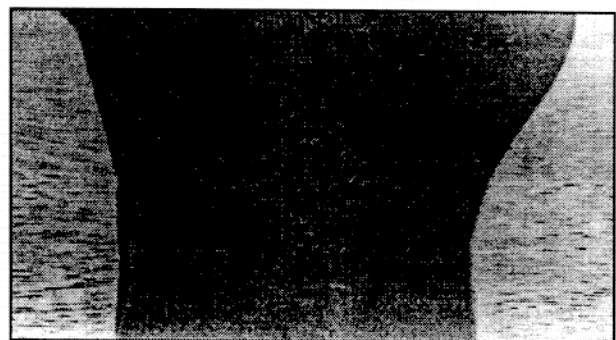
Exhibit 3 shows the average tensile properties found in the three welds. (Little difference was found between the head and foot samples.) It seems that EMS, although refining the weld, has had no beneficial effect on tensile properties.



A



B



C

**Exhibit 2. Effect of EMS on Weld Refinement
(A, No EMS; B, Short EMS; C, Long EMS)**

The ultimate strength falls slightly with stirring. The already low cast-thermite metal ductility (as indicated by "percent elongation") also falls, so that the long-stir-time weld C has a ductility half that of the unstirred weld. However, most of the tensile specimens broke near the weld center line, where stirring might have concentrated the inclusions.



It is rare for field welds to break at the center line. Rather, cracks tend to start at the stress concentration at the edge of the weld collar. Exhibit 2 shows a good refined weld metal structure at this area. Thus, although the tensile results are disappointing, they may not be a true reflection of the effect of EMS on weld fatigue.

Weld hardness depends primarily on the cooling rate after solidification, and so, as expected, stirring has no effect on weld hardness at the surface of the rail. This is shown in Exhibit 4, which compares the hardness of all three welds.

This hardness distribution is typical of thermite welds, and shows the decrease in hardness formed in the heat-affected zones.

FUTURE WORK

Electromagnetic stirring is able to refine the cast weld structure; but it has not yet been shown that this leads to better weld fatigue properties. This needs to be demonstrated. With this in mind, future work will progress in stages to:

Property	Weld A (no EMS)	Weld B (EMS)	Weld C (EMS)
Ultimate strength	114 ksi	108 ksi	102 ksi
Yield strength	89 ksi	89 ksi	89 ksi
Percent elongation	1.30	0.95	0.67
Fracture location: Ten of the specimens failed within 0.16 inch of the weld center line. The others failed at 0.27 and 0.4 inch.			

Exhibit 3. Effect of EMS on the Properties of Tensile Specimens Taken from the Weld Center

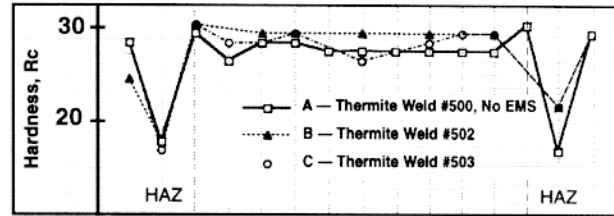


Exhibit 4. Change of Rockwell C Hardness across the Reference and Stirred Welds (HAZ: Heated-Affected Zone in Parent Rail)

- Examine the performance of full-size reference and stirred welds in four-point fatigue loading.
- Fine tune the stirring current and time to optimize weld structure and fatigue properties.
- Assess the likely costs of stirring, and weigh these against estimated benefits.
- Develop the stirring process to make it rapid and simple to use in the field, with extra equipment kept to a minimum.

This last phase of work is most important, and has two broad objectives. First, since railroads are under pressure to control track occupancy times, use of EMS ideally should not increase the overall time taken to make a thermite weld. Second, a main cause of thermite weld failure is the presence of defects introduced by improper installation. The EMS procedure must be simple to operate, such that it does not adversely affect the welder's ability to make a sound weld. A fully working EMS system will make good welds better, it will not make bad welds tolerable.

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