Modified Thermite Rail Welding Procedure

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A modified thermite rail welding procedure was developed in which thermite steel that normally comprises the filler metal of a full fusion thermite rail weld was expelled from between the rail ends while in a liquid or partially solidified state. This expulsion was caused by applying an axial force to the rails to move their ends together. It was believed that the expulsion would alter the solidification microstructure and decrease the number and size of metallurgical discontinuities in the fusion zone by decreasing the volume of filler metal, thus improving the joint's fatigue properties. Modified and standard thermite welds were fabricated and compared using the results of chemical analyses, metallography, hardness tests, and tension tests. The application of force during solidification disrupted the directional patterns of solidification and caused a refinement of pearlite colony size compared with the standard thermite rail weld fusion zone. The modified thermite rail weld had a hardness similar to the standard thermite rail weld and tensile properties superior to standard thermite rail welds. The modified joint's tensile properties were similar to those of electric-flash-butt rail welds.

Thermite welding is used primarily in the field for installing and repairing continuous welded rail (CWR). Recent increases in tonnage, train speed, and wheel loads have spawned increases in maintenance costs due to the fatigue failure of thermite welds.

The thermite reaction was applied to the field welding of rail as early as 1906 (*1*). Hauser gives a brief description of the thermite reaction and thermite welding (*2*). Historically there have been two accepted methods of thermite rail welding: pressure-fusion welding and full-fusion welding. Both methods require establishing a gap between the ends of two rails enclosed by molds that conform to the sides of the rails. The volume within the molds is left open at the top so that thermite reaction products can pour freely into the joint from a crucible suspended from above. In the case of the full-fusion weld, the gap is established by spacing the rail ends apart so that no part of the cross-section of the rails is in contact; the thermite steel becomes the filler metal of a fusion weld (*3*).

However, in the pressure-fusion weld, the heads of each rail are pressed together. The base and web of each rail are undercut with a torch so that a 12.7-mm (0.5-in.) gap exists in that region when the heads are brought together with rail clamps. The thermite steel fills the gap between the webs and bases of the rails and slag surrounds the heads, heating them to welding temperature. Then, after 2 min, the pressure on the heads is increased using the rail clamps. The webs and bases are fusion welded; the heads are pressure welded (*4*). Today the most common field thermite rail welds are full-fusion welds (*2*). Figure 1 is a schematic drawing of a typical modern thermite welding process (*5*).

A modified thermite rail welding procedure was developed in which thermite steel that normally comprises the filler metal of a full fusion thermite rail weld was expelled from between the rail ends while in the liquid or partially solidified state. This expulsion was accomplished by applying an axial force to the rails to move their ends together. It was believed that the expulsion would decrease the number and size of metallurgical discontinuities in the fusion zone by decreasing the volume of filler metal, and would thus improve the joint's fatigue properties. Figure 2 shows a schematic drawing of the modified thermite rail weld concept.

PROCEDURES

Parent Rail Material

Modified and standard thermite welds were fabricated and compared using the results of chemical analyses, metallography, hardness tests, and tension tests. The Transportation Test Center of the Association of American Railroads (AAR) provided the 136 RE rail that was used. The rail chemical composition was determined by the Chicago Spectro Service Laboratories, Inc. and is given in Table 1. This composition was within the limits for standard rail steel (*6*).

Experimental Thermite Weld Fabrication Apparatus

An experimental thermite weld fabrication apparatus was assembled so that either a controlled force or a controlled displacement could be imposed on the rails to reduce the initial weld gap after the thermite steel began to pour into the joint. The apparatus consisted of a structural-steel, wide-flange shape with two reaction blocks fixed to its upper flange. A 490-kN (55-ton) servo-hydraulic actuator was placed against one of the reaction blocks, and the two lengths of rail to be joined were placed between the actuator and the other block. The apparatus was capable of supplying a 178-kN (20-ton) force to the end of the rail. Both the maximum force applied or the actuator stroke could be controlled or programmed to vary as a function of time. Figure 3 shows a schematic drawing of the apparatus. Figure 4 is a photograph of the apparatus.

Experimental Thermite Weld Fabrication

Thermite welds were fabricated using different combinations of actuator control and timing. Technicians from the Research and Test Department of the Chicago Technical Center of the AAR provided the necessary equipment and performed the welding.

Weldment Examination

Specimen Definition, Chemical Analysis, and Metallography

To assess the effects of the modified procedure, two weldments were sectioned and examined: one was a standard thermite weld

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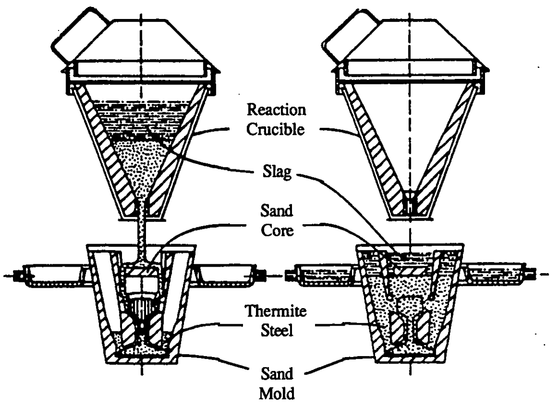

FIGURE 1 Modern full fusion thermite rail welding process (5).

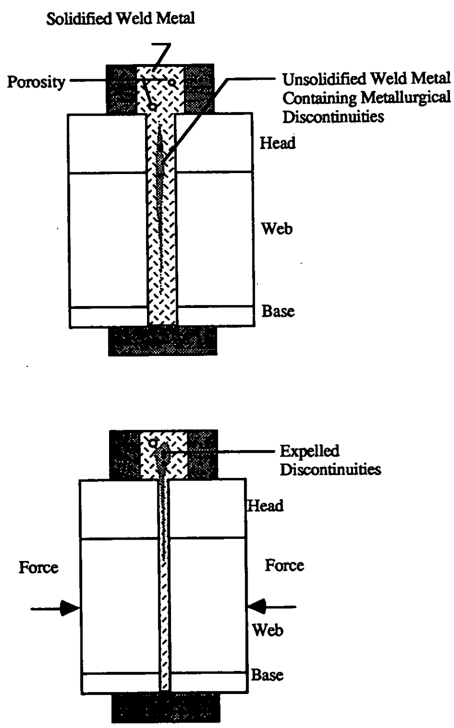

FIGURE 2 Modified thermite rail welding procedure showing the application of force while the filler metal is liquid and partially solidified.

TABLE 1 Weld Metal Chemistry

	Weight % of Selected Elements		
	STW	MTW	Base Metal
C	0.67	0.62	0.77
Mn	0.91	0.89	0.74
P	0.02	0.012	0.011
S	0.019	0.016	0.021
Si	1.1	0.81	0.15
Ni	0.02	0.01	<0.01
Cr	0.14	0.10	0.04
Mo	0.01	0.01	<0.01
Cu	0.09	0.07	0.01
Al	0.095	0.098	<0.005

(hereafter termed STW) and the other was a modified thermite weld (hereafter termed MTW). Samples of the STW and MTW were sent out for chemical analysis to Chicago Spectro Service Laboratories, Inc. The chemical analysis results for both STW and MTW specimens and the rail base metal are presented in Table 1.

Other samples of the STW and MTW were examined using conventional metallographic methods. Rectangular macro samples were extracted from the center of the rail cross-section. When polished and then etched with 2 percent Nital, these samples exposed a profile of the entire fusion zone (Figures 5 and 6). A sample from the head region of each weldment was extracted for microstructural examination. These samples were polished and then etched with Kalling's reagent (Figures 7 and 8).

Measurement of Porosity and Inclusion Content

The volume percent of porosity and inclusions in the weld metal of the STW and MTW specimens was determined from 400× photomicrographs, such as seen in Figure 9. These samples were polished but not etched.

Hardness Measurements

Hardness measurements were obtained to characterize the STW and MTW weld metal as well as the rail base metal. Two types of hardness tests were performed: Rockwell-C, and Vickers micro hardness.

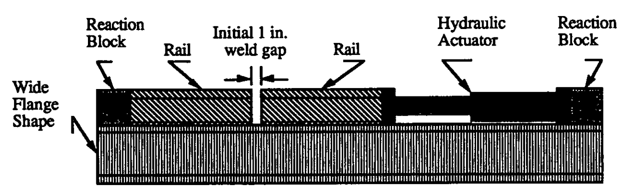

FIGURE 3 Schematic drawing of experimental weld fabrication apparatus.

FIGURE 4 Photograph of apparatus.

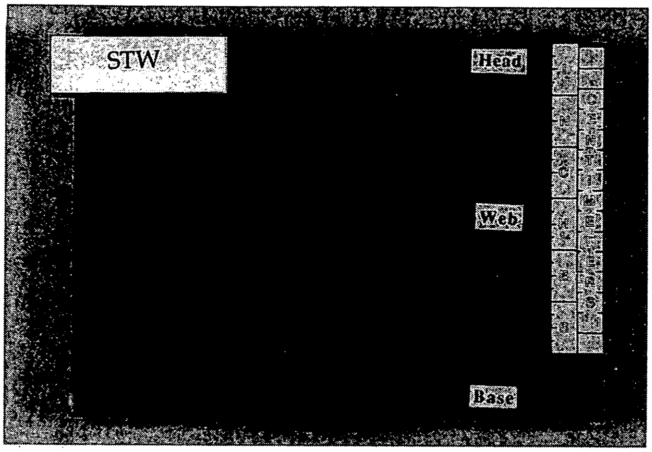

FIGURE 5 STW longitudinal section etched with 2 percent Nital.

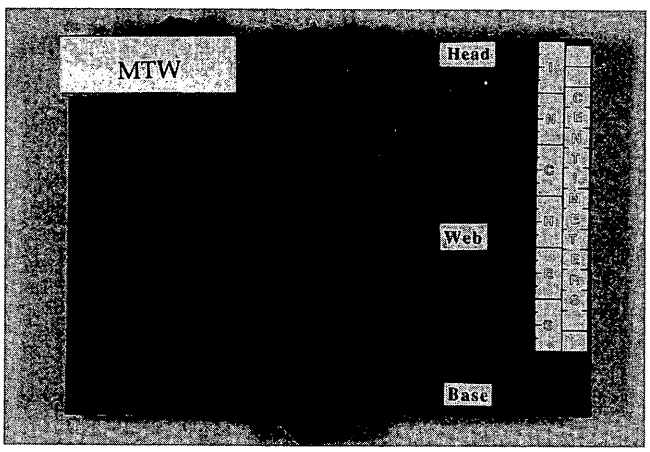

FIGURE 6 MTW longitudinal section etched with 2 percent Nital.

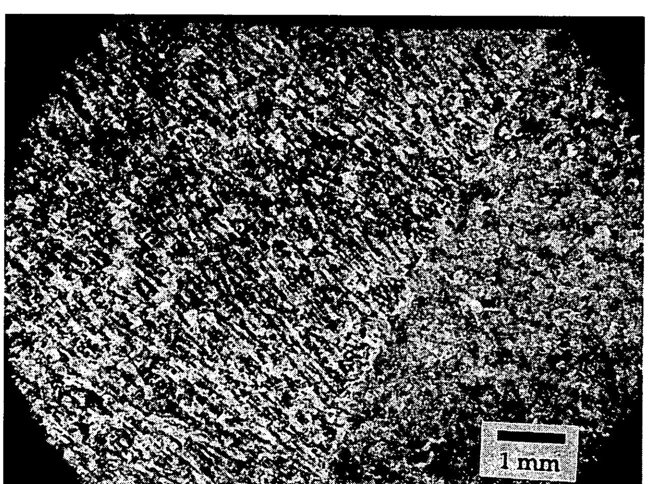

FIGURE 7 Microstructure of the STW etched with Kalling's reagent to expose the directional patterns of solidification.

Tensile Tests

Five tension tests were carried out on each of the STW, MTW, and rail base metal materials. Using a servo-hydraulic test apparatus, load and elongation in a gauge length of 12.7 mm (0.5 in.) were measured and digitally recorded using a computer.

RESULTS

Fabrication

Both the STW and MTW were performed using an initial gap of 25.4 mm (1 in.). The STW preheating operation lasted for 390 sec, and the tap time was 25 sec. The MTW preheating operation lasted for 462 sec and the tap time was 24 sec. To displace the rail ends in the case of the MTW, a controlled force of 182.4 kN (41,000 lbf)

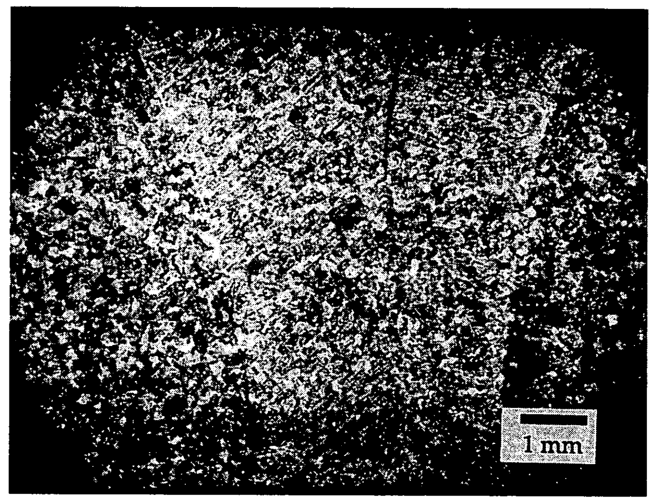

FIGURE 8 Microstructure of the MTW etched with Kalling's reagent to expose the directional patterns of solidification (patterns not as prevalent as in STW).

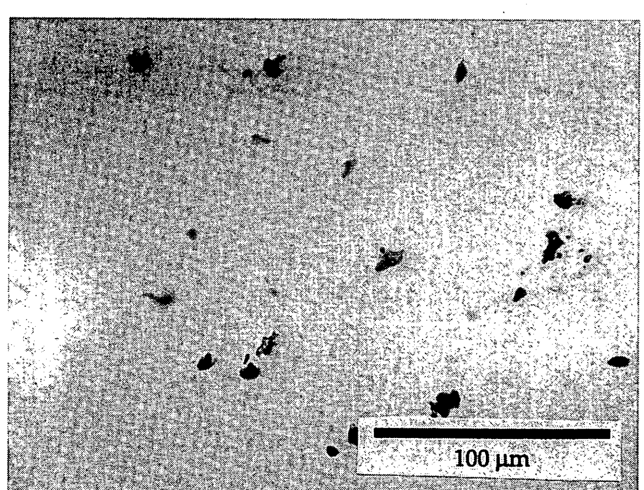

FIGURE 9 Typical photomicrograph used to measure metallurgical discontinuities (unetched).

was imposed approximately 20 sec after the pour had completed. This timing and method of displacement resulted in 40.6 mm (1.6 in.) of rail-end motion.

Metallographic Observations

The average width of the weld metal in STW (Figure 5) was close to 38 mm (1.5 in.), and the width of the HAZ as measured from the line of fusion was about 25 mm (1 in.). The average width of the weld metal in MTW (Figure 6) was approximately 6 mm (0.25 in.), and the width of the heat affected zone as measured from the line of fusion was about 19 mm (0.75 in.). In the center of the MTW weld metal, a light colored phase was visible (Figure 6).

As seen in Figure 7, there is a marked contrast between the microstructure of the STW weld metal and its HAZ. The MTW did not exhibit such a contrast (Figure 8). This difference between the two welds suggests that the deformation of the MTW while in the liquid or partially solidified state disrupted the directional patterns of solidification.

The largest pearlite colonies were observed in the STW weld metal (122 μm); the smallest pearlite colonies were observed in the rail base metal (81 μm). The MTW weld metal exhibited an intermediate pearlite colony size (96 μm).

Measured Porosity and Inclusion Contents

The average measured volume percents of porosity and inclusions in the weld metal of STW were 1.53 percent and 0.40 percent, respectively. The average measured volume percents of porosity and inclusions in the weld metal of MTW were 1.08 percent and 0.23 percent, respectively.

Results of Hardness Tests

The Rockwell-C hardness traverses for the STW and MTW specimens are plotted in Figures 10–15. The average Rockwell-C hardness for the STW weld metal was 29. The average Rockwell-C hardness for the MTW weld metal was difficult to obtain because of the narrow fusion zone, but a value of 26 seems reasonable (Figures 13 through 15). The results for the STW were similar to those obtained by Jha (*7*) for standard thermite welds. It was found that the weld metal is generally harder than the rail-base metal except for a minimum hardness region in the grain refined HAZ for

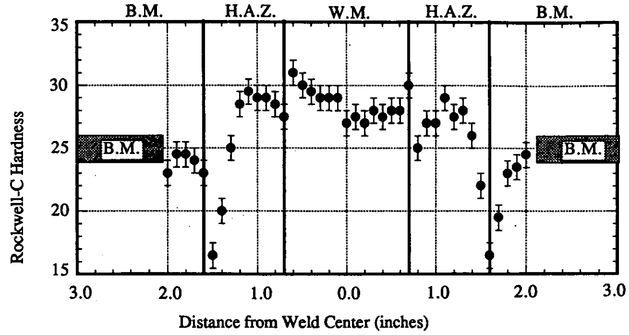

FIGURE 11 Rockwell-C hardness traverse across the weld in the web region of the STW.

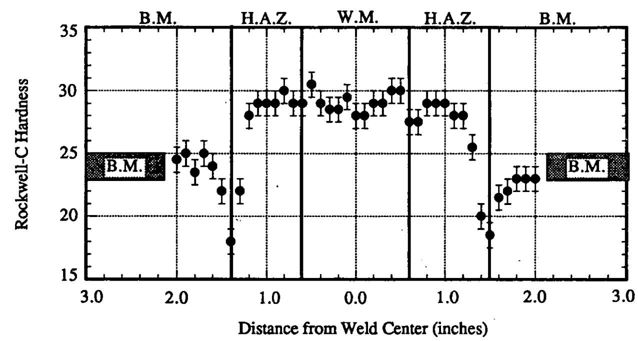

FIGURE 12 Rockwell-C hardness traverse across the weld in the base region of the STW.

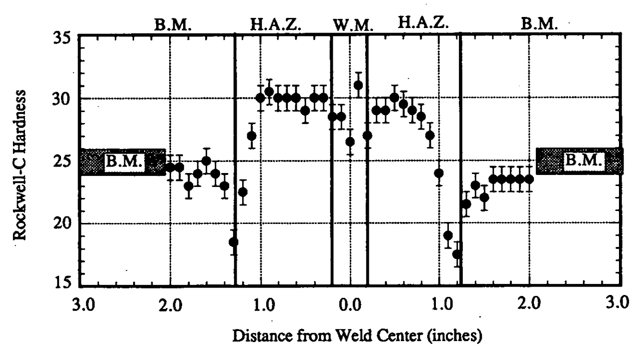

FIGURE 13 Rockwell-C hardness traverse across the weld in the head region of the MTW.

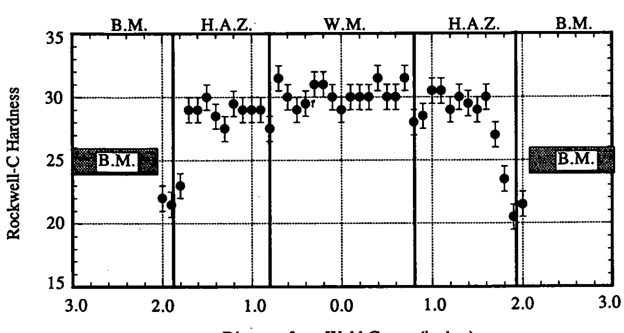

FIGURE 10 Rockwell-C hardness traverse across the weld in the head region of the STW.

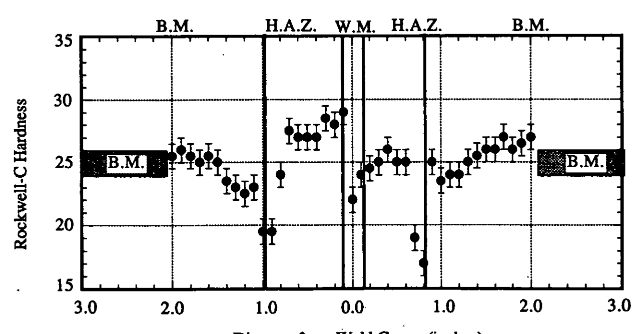

FIGURE 14 Rockwell-C hardness traverse across the weld in the web region of the MTW.

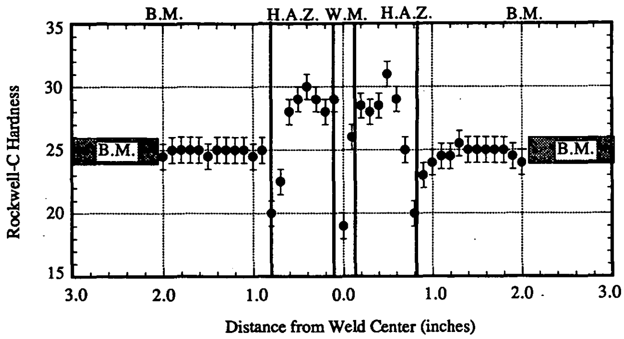

FIGURE 15 Rockwell-C hardness traverse across the weld in the base region of the MTW.

both STW and MTW specimens. Along the line of fusion in the head and web of STW, a region of reduced hardness was observed. The Rockwell-C hardness measurements used too large an impression to characterize adequately the narrow MTW fusion zone.

To indicate reliably the difference in hardness between the STW and MTW weld metal and the rail base metal, Vickers micro hardness tests were performed on the metallographic samples. The Vickers micro hardness tests showed that the STW weld metal (373 VHN) and the MTW weld metal (364 VHN) were significantly harder than the rail base metal (290 VHN), but that the STW weld metal was only slightly harder than the MTW weld metal.

Tensile Test Results

The results of the tensile tests are presented in Figures 16, 17, and 18. The MTW exhibited greater ductility (8.4 percent) than the STW (2.6 percent) and less ductility than the rail base metal (13.6 percent). All five of the STW samples fractured in the weld metal. Three MTW samples fractured in weld metal and two fractured in the HAZ. The results for STW were similar to those obtained by Jha for standard thermite welds (*7*). The results for MTW were similar to those obtained by Wisnowski (*8*) for electric-flash-butt rail welds.

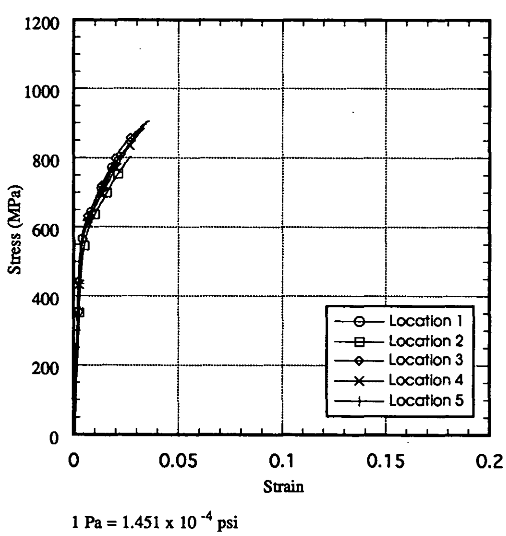

FIGURE 16 Stress-strain curves for the STW (average maximum elongation of 2.6 percent).

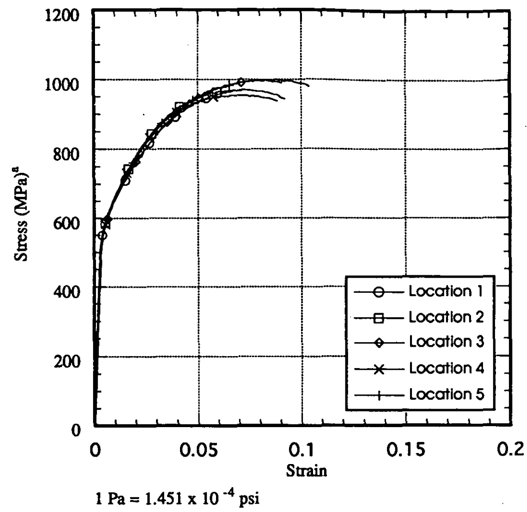

FIGURE 17 Stress-strain curves for the MTW (average maximum elongation of 8.4 percent).

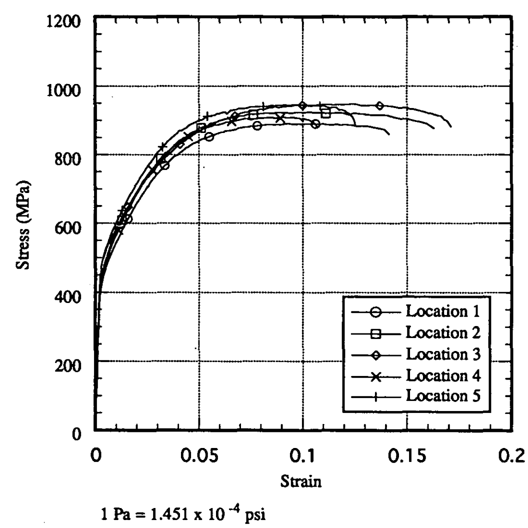

FIGURE 18 Stress-strain curves for the rail base metal (average maximum elongation of 13.6 percent).

DISCUSSION OF RESULTS

Optimum Conditions for the Fabrication of a Modified Thermite Weld

The best timing of the actuator motion during the fabrication of the modified weld appeared to be immediately after the pour was complete, that is, when the crucible had emptied. Sooner actuator motion resulted in a lack of fusion because a large quantity of molten weld metal was lost through cracks which opened along the mold-rail interface during the motion of the rail; thus an insufficient amount of weld metal remained to complete the weld. Later application of force resulted in small rail-end displacements, less than 25.4 mm (1 in.), because the solidified weld metal had gained enough strength to prevent much motion.

Comparison of Modified and Standard Thermite Welds

Chemical analyses, hardness tests, and measurements of metallurgical discontinuity content all indicated that the STW and MTW weld metals were similar. The directional patterns of solidification are pronounced in STW (Figure 7) and not as pronounced in MTW (Figure 8).

The most notable difference between the STW and the MTW was the toughness apparent in the tensile tests. MTW exhibited superior toughness to STW: compare the area under the MTW stress-strain curve (Figure 16) to the area under the STW stress-strain curve (Figure 17). The tensile properties of MTW approach those of electric-flash-butt rail welds (*8*).

CONCLUSIONS

The application of force during solidification disrupts directional solidification and causes refinement of the pearlite colonies. Further, modified thermite rail welds exhibit tensile properties superior to standard thermite rail welds and similar to electric-flash-butt rail welds.

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