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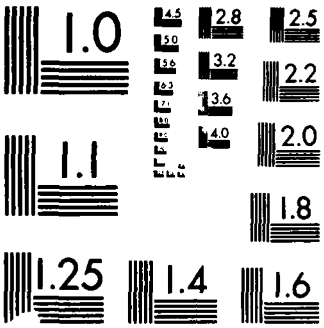

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THE EFFECT OF NOTCH ROOT RADIUS ON THE DETERMINATION OF TOUGHNESS IN ULTRAHIGH STRENGTH STEEL FRICTION WELDS

WILLIAM S. RICCI
FABRICATION & TECHNOLOGY DEMONSTRATION BRANCH

ERIC B. KULA
METALS RESEARCH BRANCH

June 1988

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US ARMY
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ABSTRACT

The plain strain fracture toughness and Charpy impact energy of friction welds in ultrahigh strength AISI 4340 steel were determined. Fracture toughness values for the weld zone were found to exceed those of the base metal. This is believed to be due to the larger prior austenite grain size in the weld zone resultant from the weld thermal cycle. Charpy impact energy data for the weld zone, however, were approximately 50 percent lower than those of the base metal. This was due to the adverse reorientation of sulfide inclusions in the weld zone resulting from the forging stage of the welding cycle. Discrepancies between fracture toughness and Charpy impact test data can be attributed to notch root radius effects. The use of both sharp notch and rounded notch toughness tests are recommended for the determination of weld joint ductility in ultrahigh strength steels. Keywords: Inertia Welding; Friction Welding; Notch toughness. (AW)

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INTRODUCTION

Inertia welding, a form of friction welding, is a solid state joining process that produces bonding using the heat developed between two surfaces during mechanically induced rubbing motion. The inertia welding cycle can be divided into two stages: the friction stage, and the upsetting or forging stage. Welding heat is developed during the first stage, and the weld is consolidated and cooled during the second stage. A complete description of the inertia welding process is presented elsewhere.[1]

It is well known that for any steel worked principally in one direction, the mechanical properties, especially ductility, in the direction of working are different from those in the perpendicular or short transverse direction.[2,3] On application of forging pressure during an inertia weld, metal is forced out in a radial direction normal to the forging direction. Consequently, any inclusions in the weld zone initially oriented parallel to this major working direction are reoriented into a direction normal to this axis within the bond zone during the forging stage. Short transverse base metal properties should, therefore, be expected across inertia welded joints.[4]

The effects of sulfur concentration and precrack location on the plain strain fracture toughness properties of inertia welds in 4340 steel at moderate strength and low sulfur levels have previously been evaluated.[4] Speich[5] demonstrated that variations in sulfide inclusion shape and concentration have a negligible effect on Charpy impact energy at high strength levels for 4340 steel. Ritchie showed that the contradictory results of the plain strain fracture toughness (K_{IC}) and Charpy impact energy tests can be rationalized in terms of the response of notch root radius on toughness. The purpose of the work reported here was to evaluate the use of percent elongation, plain strain fracture toughness, and Charpy impact energy as measures of ductility for inertia welded joints in AISI 4340 steel at ultrahigh strength levels, approximately 300 ksi.

EXPERIMENTAL

Seamless tubing (6.25" outer diameter with a wall thickness of 0.5") from an electric furnace melted heat of AISI 4340 steel was inertia welded. The chemical composition of the material tested is shown in Table 1. Carbon and sulfur were measured by combustion techniques; all other elements were analyzed by emission spectroscopy.

Table 1. CHEMICAL COMPOSITION OF THE MATERIAL TESTED

	Weight Percent									
	C	S	Mn	P	Si	Ni	Cr	Mo	Cu	Al
Heat #1	0.45	0.006	0.70	0.015	0.26	1.82	0.81	0.27	0.11	0.04
Typical 4340	0.38-0.43	0.04	0.60-0.80	<0.035	0.20-0.30	1.65-2.00	0.70-0.90	0.20-0.30	-	-

1. Welding Handbook, vol. 3, *Resistance and Solid-State Welding and Other Joining Processes.* 7th Edition, W. H. Kearns, ed, American Welding Society, Miami, Florida, 1980, p. 244.
2. PORTER, L. F. *Lamellar Tearing in Plate Steels (a Literature Survey).* AISI, August 1975.
3. SKINNER, D. H., and TOYAMA, M. *Through Thickness Properties and Lamellar Tearing.* Welding Res. Bull., 1977, v. 232, p. 1-20.
4. RICCI, W. S., KULA, E. B., COLGATE, J. D. *Effects of Sulfur Content on the Plain Strain Fracture Toughness of Inertia Welds in 4340 Steel.* U.S. Army Materials Technology Laboratory, MTL TR 87-53, September 1987.
5. SPEICH, G. R., and SPITZEG, W. A. *Effect of Volume Fraction and Shape of Sulfide Inclusions on Through Thickness Ductility and Impact Energy of High Strength 4340 Plate Steel.* Metall. Trans. A, v. 13A, December 1982, p. 2239-2258.

All welds were fabricated in accordance with MIL-STD-1252 for Type I, Class B welds. A fly wheel speed of 1225 rpm and forging pressure of 3400 psi were used. Work pieces were heat treated, prior to and after welding, according to the process schedule shown in Figure 1.

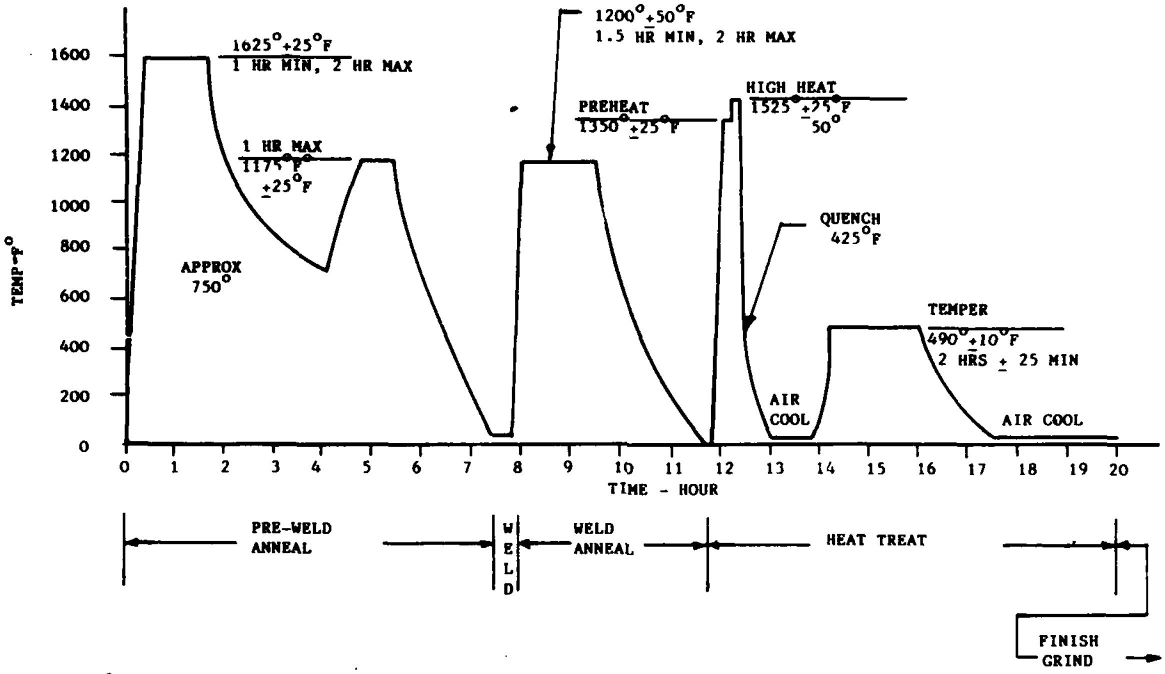

Figure 1. Heat treatment schedule.

Type TR-3A, 0.252" diameter, threaded, round, tensile specimens and Type CV-2, 0.394" x 0.394" x 2.165" Charpy V-notched specimens were machined from each quadrant of the welded section. Flood coolant conditions were used to prevent burning. The weld line was located in the center of each specimen. Notches were machined in the Charpy specimens to provide an L-C crack plane orientation. The specimens used to evaluate fracture toughness were Charpy specimens precracked by bending fatique loading. Fracture toughness data were obtained in slow bending, in accordance with ASTM E 399. Charpy specimens were broken in a pendulum type impact machine with the hammer velocity of approximately 17 feet per second, in accordance with ASTM E 23.

RESULTS AND DISCUSSION

Mechanical property data including tensile, Charpy impact, and fracture toughness data for the base metal and weld are shown in Table 2.

Weld zone fracture toughness data exceeded that of the base metal. This is believed to have been due to the larger prior austenite grain size in the weld zone resultant from the weld thermal cycle.[6] Other indicators of weld joint toughness

6. RITCHIE, R. O., FRANCIS, B., and SERVER, W. L. *Evaluation of Toughness in AISI 4340 Alloy Steel Austenitized at Low and High Temperatures.* Metall. Trans. A, v. 7A, June 1976, p. 831-838.

Table 2. MECHANICAL PROPERTIES OF BASE METAL AND WELD JOINTS

	YS 0.2% Offset (ksi)	UTS (ksi)	Elon. (%)	Charpy Impact Energy, 77°F (ft-lb)	Charpy Impact Energy, -25°F (ft-lb)	K_Q, 77°F (ksi $\sqrt{in.}$)	K_Q, -25°F (ksi $\sqrt{in.}$)
Base Metal	226.9 (0.73)*	298.1 (0.87)	11.9 (0.1)	11.9 (0.35)	9.7 (0.64)	37.8 (0.64)	36.28 (1.23)
Weld	218.7 (2.31)	294.0 (5.29)	4.85 (0.64)	6.37 (0.45)	5.5 (1.63)	45.93 (1.25)	39.42 (1.70)

*Standard Deviation

and ductility, i.e., Charpy impact energy and percent elongation, showed weld zone values approximately 50 percent lower than the unaffected base metal values. Weld zone results for these tests approximated those expected for the short transverse orientation in the base metal.

The major differences between the fracture toughness and Charpy tests can be summarized as follows: 1) the Charpy specimen contains a V-notch (ρ = 0.25 mm), whereas the fracture toughness specimen contains a fatigue precrack ($\rho \rightarrow 0$), 2) the strain rate for the Charpy test is greater than that of the fracture toughness test, and 3) the Charpy test measures the energy required to initiate and propagate a crack and, therefore, includes a contribution from plain stress, whereas the fracture toughness test measures the stress intensity at a crack tip necessary to cause plain strain crack growth only. Ritchie[6] determined that the observed discrepancy between the fracture toughness and the Charpy impact tests was primarily due to notch root radius effects. The evaluation of friction weld joint toughness should not, therefore, be based on either tensile fracture toughness or Charpy impact data alone but should include both infinitely sharp notch and rounded notch toughness tests.

SUMMARY

Fracture toughness tests of friction welded joints in ultrahigh strength steels showed weld joint values exceeding those of the base metal. The reason for this is believed to be due to the larger prior austenite grain size in the weld zone resultant from the weld thermal cycle.

Charpy impact energy data for the weld zone in friction welded joints were found to be approximately 50 percent lower than those of the unaffected base metal. The reason for this is the adverse reorientation of nonmetallic inclusions in the weld zone resultant from the forging stage of the welding cycle.

Discrepancies between the Charpy impact and the fracture toughness test data are believed to be primarily due to notch root radius effects. Both sharp crack fracture toughness and rounded notch impact energy tests are, therefore, required for the complete evaluation of friction weld joint toughness and ductility.

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