Friction Welding Alloy 800

A high quality solid-state weld results when joining pins to the outer wall of tubing for a high-temperature gas-cooled reactor

BY K. H. HOLKO

ABSTRACT. Alloy 800 (ASME SB408) pins were friction welded to Alloy 800 (ASME SB163) tubes. The pins were located normal to the tube surfaces. Postweld heat treatment (PWHT) caused recrystallization and grain growth across the original solid-state weld interface. Light and electron microscopy revealed a high-quality solid-state weld with base metal microstructure.

Creep-rupture testing of welds in the PWHT condition resulted in failure in the base metal, away from the weld line at full base metal life. Creep-rupture testing of welds in the as-welded condition, however, resulted in failure at the weld in less than 2% of base metal life. Metallography showed the most probable reason for this short as-welded life to be a very fine grain structure at the weld.

Introduction

Several components in a high-temperature gas-cooled reactor (HTGR) are made from tubing. Typically, the tubes may contain high-pressure fluid and may undergo many expansion and contraction cycles from temperature variations around 1400 F (760 C). In certain components it is essential that the tubes be separated and protected from one another during service in order to avoid wear damage. One concept of accomplishing this utilizes standoff pins and wear pads. The pins must be joined to the tube outer wall and the wear pads joined to the pin as shown in Fig. 1. A high-quality joint is required between the pin and tube for strength and maintenance of the tube integrity. Additionally, a low cost per joint is sought since several thousand joints are needed per HTGR.

Friction welding was investigated for the pin-to-tube joint since it is known that base metal strength and microstructure can be obtained with this process. Friction welding is also fast, repeatable, and readily automated to be cost effective.

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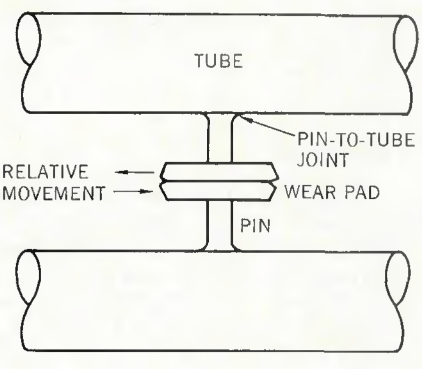


Fig. 1—Tube wear protection concept

Procedure

Materials

Alloy 800 (ASME SB408) pins were machined from ⅝ in. (1.6 cm) diameter bar stock. The bar was in the mill annealed condition and had the composition shown in Table 1. An ASTM grain size of 5 to 6 was measured.

The tube material was also Alloy 800 (ASME SB163) with the composition shown in Table 1. Tubing was in the mill annealed condition and measured 1 in. (2.54 cm) O.D. × 0.2 in. (0.5 cm) wall thickness.

Friction Welding

Friction welding was done at Interface Welding in Carson City, California on a Caterpillar "inertia welding machine." The kinetic energy of a flywheel was converted to mechanical work during weld formation. Three pin sizes—0.218, 0.250, and 0.312 in. (0.55, 0.64, and 0.79 cm) diameter—were welded to tubing with a 1 in. (2.54 cm) O.D. and a 0.2 in. (0.5 cm) wall thickness.

Examples of the 0.218 in. (0.55 cm) diameter pin welds are shown in Fig. 2, as-welded and with the upset removed. A round bar was fusion welded to the tube for fixturing. Welding parameters were developed for each pin size and then repeated to make several test specimens.

Table 1—Composition of Alloy 800, Wt-%

	Ni	Cr	Fe	Mn	C	Cu	Si	S	Al	Ti
Nominal	30.0-35.0	19.0-23.0	Bal.	1.5[a]	0.1[a]	0.75[a]	1.0[a]	0.015[a]	0.15 – 0.60	0.15 – 0.60
Tube	35.0	20.7	Bal.	1.2	0.03	0.02	0.07	0.007	0.43	0.38
Pin	33.0	20.6	Bal.	1.0	0.08	0.16	0.47	0.006	0.28	0.28

(a)Maximum.

Fig. 2—Friction welded pins to tubes: left, as-welded; right, upset removed

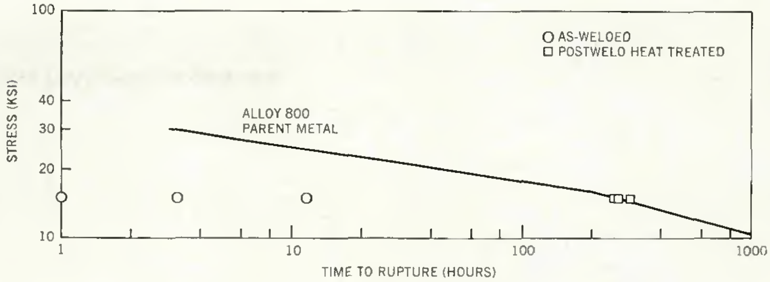


Fig. 3—Creep-rupture tests of friction welds compared to base metal, 1300 F/ air

Table 2—Creep-Rupture Test Results of Alloy 800 Friction Welds at 1300 F in Air

Specimen no.	Condition	Pin diameter (in.)	Stress, ksi	Time to rupture, h	Failure location
218-3	As-welded	0.218	15.0	3.2	Weld
250-4	As-welded	0.250	15.0	0.6	Weld
312-6	As-welded	0.312	15.0	11.7	Weld
218-9	PWHT	0.218	15.0	296.4	Base metal
250-9	PWHT	0.250	15.0	254.4	Base metal
312-7	PWHT	0.312	15.0	257.7	Base metal

Evaluation

Friction welds in all three pin sizes were evaluated in the as-welded and postweld heat treated (PWHT) conditions. Postweld heat treatment consisted of heating in air at 2025 F (1107 C) for 15 minutes.

Upset material was removed before creep-rupture testing and a 0.030 in. (0.08 cm) radius was machined at the pin/tube junction—Fig. 2. About 0.030 in. (0.08 cm) of the tube wall was removed to accomplish this. Creep-rupture testing was done by holding the tube in a pin and clevis and loading the pin parallel to its axis. Testing was done at 1300 F (704 C) since this is the maximum anticipated service temperature for the friction welds.

Metallography was done on sections through the friction welds near the pin diameter. Upset material at the weld was left intact for the metallographic specimens.

Results and Discussion

Both creep-rupture testing and metallographic investigation proved that high-quality friction welds had been attained. In fact, after PWHT, base metal strength and microstructure were observed.

Creep-Rupture Testing

Creep-rupture testing was selected for evaluation since it has been reported that this is a more discriminating mechanical test for solid-state welds than room-temperature or elevated-temperature tensile testing.[1]

As seen in Fig. 3 and Table 2, friction welds in the as-welded condition failed in short times compared to expected base metal life. About 2% of the base metal life was attained. Failure location was at the friction weld.

After PWHT, however, friction welds failed at full base metal life—Fig. 3 and Table 2. Failure location was in the base metal, well away from the friction weld. These results were the same for each pin size, as seen in Table 2.

Metallography

As-welded and PWHT macrostructures and microstructures are shown for the 0.218 in. (0.55 cm) pin size in Fig. 4. Structures were similar for the other two pin sizes.

The as-welded structure (Fig. 4A,B) is highly worked and has a very fine grain size. There appear to be numerous elongated grain boundaries perpendicular to the tube axis within this

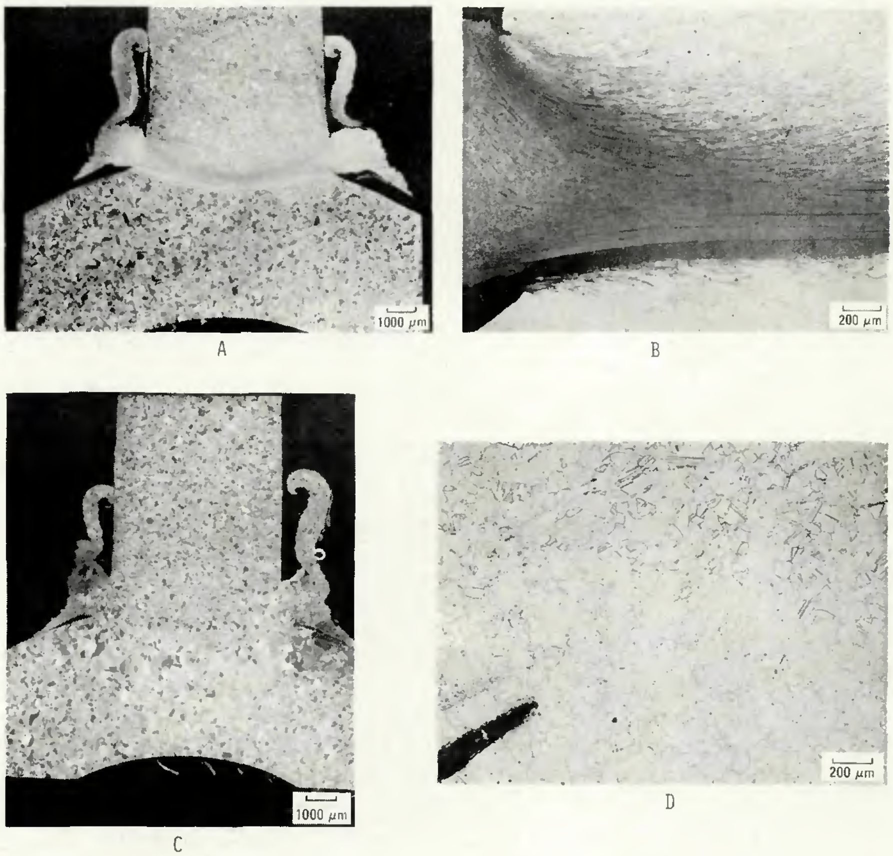
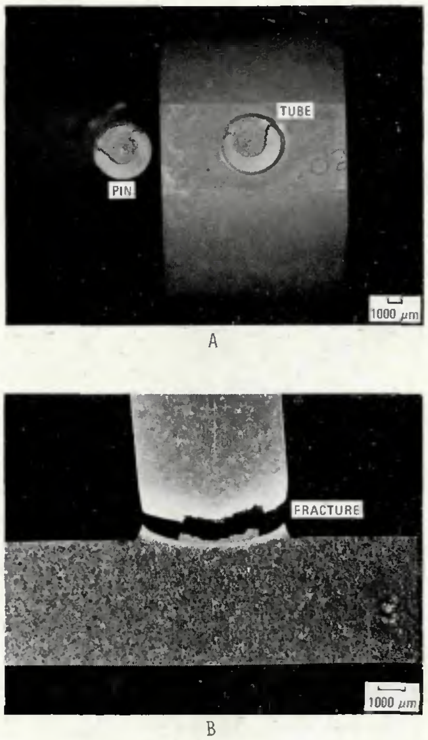


Fig. 4—Metallographic sections through friction welds in Alloy 800; etchant—oxalic acid, electrolytic: A,B—as-welded condition; C,D—postweld heat treated



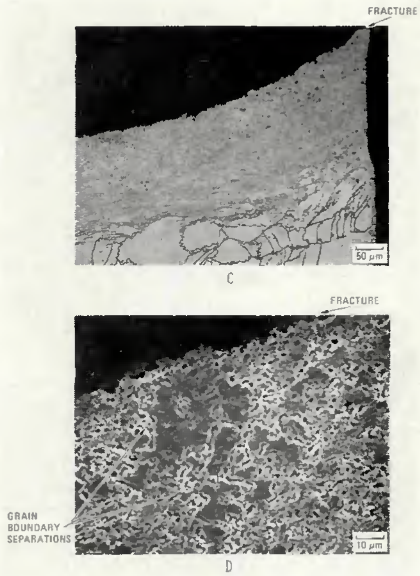
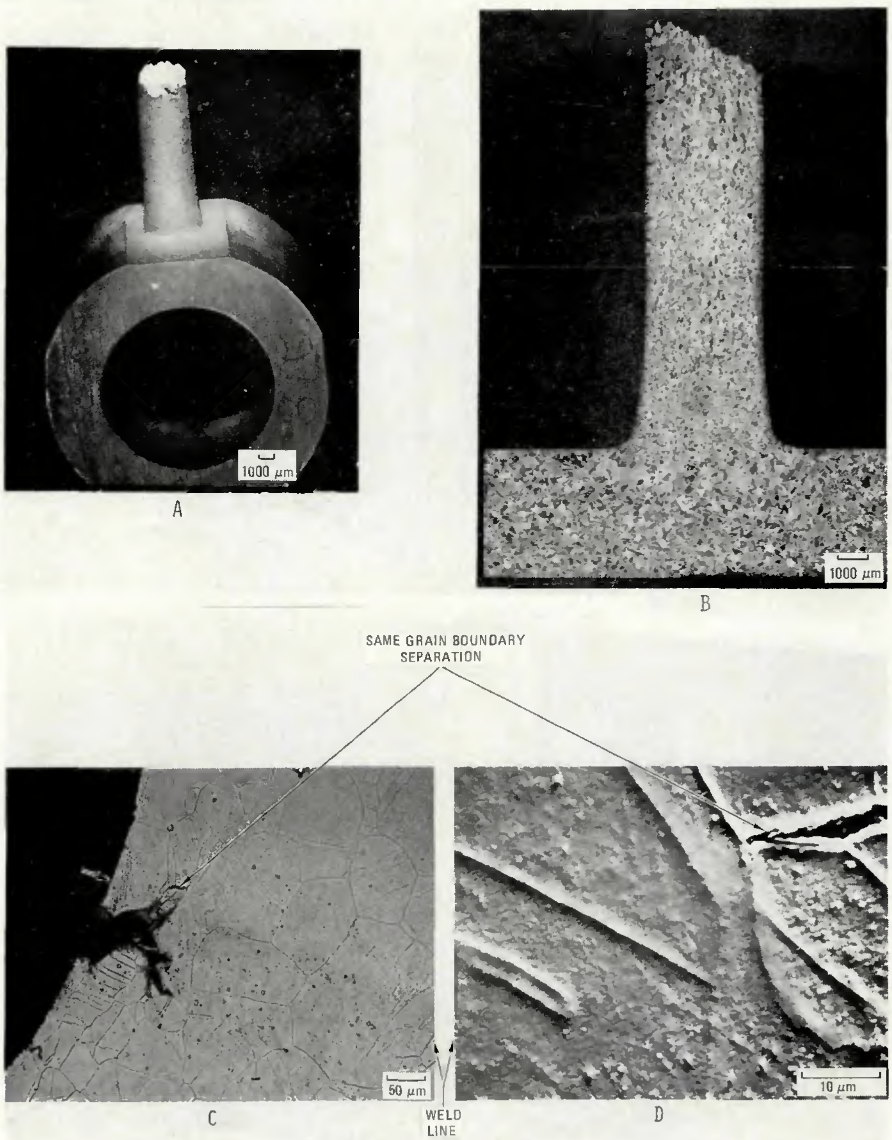


Fig. 5—Creep-rupture fracture in as-welded friction weld, No. 218-3; etchant—oxalic acid, electrolytic: A—planar view; B—macrosection; C—microsection; D—SEM section



worked material. It is difficult to resolve the grain size with light microscopy.

Postweld heat treatment is effective in causing recrystallization and grain growth of the worked material, as shown in Fig. 4C,D. A slight difference in contrast from etching between the pin and tube materials locates the original weld interface. Significant grain growth has occurred across this interface. An ASTM grain size of 5 to 6 was measured in the vicinity of the weld line, indicating that the pin and tube grain size had been restored.

Figure 5 illustrates a typical as-welded creep-rupture failure. Fracture has occurred at aligned grain boundaries as would be expected from the combination of elevated temperature and low strain rate.[2] The scanning electron microscope (SEM) photographs taken at the fracture surface show grain boundary separation around the small grains. The small grain size is probably responsible for the poor creep-rupture life in the as-welded condition.

A typical PWHT creep-rupture failure is shown in Fig. 6. It is evident that failure has occurred in the pin well away from the weld line. High weld quality is evidenced by the fact that the grain boundary separations occurring near the weld line did not propagate along the weld line as seen in the microsection and SEM photographs of Fig. 6. The recrystallization, grain growth across the weld line, and base metal grain size are responsible for the attainment of base metal creep-rupture life.

Conclusions

From the friction welds made and evaluated in this program it can be concluded that:

1. High quality pin-to-tube joints can be made by friction welding.
2. Base metal microstructure and creep-rupture strength can be attained in Alloy 800 friction welds if they are postweld heat treated.
3. The heats of Alloy 800 used in this program are readily friction weldable.

References

1. Moore, T. J., and Holko, K. H., "Solid-State Welding of TD-Nickel Bar," *Welding Journal*, 49 (9) Sept. 1970, Research Suppl., pp. 395-s to 409-s.

2. Manjoine, M. J., "Fracture at Elevated Temperatures: Mechanical Aspects," *Fracture of Engineering Materials*, American Society for Metals, 1964, 78 to 82.

Fig. 6—Creep-rupture fracture in PWHT friction weld, No. 21B-9; etchant—oxalic acid, electrolytic: A—planar view; B—macrosection; C—microsection; D—SEM section