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8. ~~X~~ SHIELDED METAL-ARC WELDING FOR LMFBR COMPONENTS

W. O. Harms G. M. Slaughter

The objective of this program is to evaluate the shielded metal-arc (stick electrode) welding process for fabricating and repairing certain stainless steel components for liquid-metal fast breeder reactors (LMFBR). We very slightly modified the flux coatings of electrodes and are determining the influence of minor elements on the mechanical properties of the weld metal at elevated temperature. Flux coatings traditionally have been evaluated and selected by the relative ease with which weld metal can be deposited, and bead contour, arc stability, and deposition efficiency are usually prime considerations. The effect of the coating on the properties at elevated temperatures has not been seriously considered.

As part of this effort, we are also providing weld specimens to Battelle Memorial Institute Pacific Northwest Laboratory (BNWL) for a program of irradiations for the Fast Flux Test Facility (FFTF).

Preparation of Weldment Samples for Irradiation and Control

Procurement and Machining of Samples for FFTF Irradiation Program
(G. M. Goodwin)

The "prototypic" FFTF submerged-arc weldments¹ were completed and are now being examined nondestructively. The welds were prepared in 2-in.-thick plate under conditions identical to those used for the test welds previously made for BNWL. A double-welded joint eliminated the need for massive mechanical restraint. After inspection, these welds will be sectioned, heat treated, and machined into specimens for tests of mechanical properties and sent to BNWL for irradiation testing.

Effect of Variations in Flux Coating

Preparation and Creep-Rupture Testing of Weldments (N. C. Binkley,
G. M. Goodwin, D. G. Harman)

Fractography and tests of mechanical properties were continued on the 14 stainless steel shielded metal-arc weldments made with type 308

stainless steel electrodes containing controlled minor differences in the type or composition of the coating. A simplified reference guide to the type of electrode coating and chemical analysis of the weld deposit was presented previously.²

Optical metallography of welds 4 through 14 completed this phase of the study. Examination of both the weld metal and the fusion lines in these welds revealed virtually no difference from one weldment to the other. All attempts to find any unique microstructural features in one weldment as compared to the others were unsuccessful. It is very significant, therefore, that there are major differences in the creep-rupture behavior of the various welds at 650°C (1200°F).

We previously reported² results of creep-rupture tests at 650°C (1200°F) of welds made with electrodes that had the three standard types of coatings - lime, lime-TiO₂, and TiO₂. We had found that the weld made with the lime-coated electrode was consistently weaker than welds made with the other two types of electrodes. All three welds showed significant reductions in creep elongation with increasing rupture time, but the weld made with the electrode coated with lime-TiO₂ was the worst.

We conducted additional experiments to gain more information concerning the low ductility. We held a specimen from the weld made with the electrode coated with lime-TiO₂ in the test furnace at 650°C for 700 hr before applying a stress of 25,000 psi. Figure 8.1 shows the creep curve for this specimen compared with that for an identical specimen that was not held 700 hr at 650°C before testing. The aged specimen lost significantly in both rupture time and elongation. Table 8.1 lists the rupture life, elongation, and minimum creep rate for both specimens. Note that only the third stage of creep was significantly affected. Both specimens entered third-stage creep after about 0.5% elongation, but the aged specimen accelerated more quickly to high strain rates and fractured after only 2.8% third-stage deformation. The specimen that was not aged, on the other hand, survived to 9.7% third-stage elongation.

In these tests, the third stage of creep is essentially a fracturing process, and a significant percentage of the fracture occurs along the boundaries between austenite and ferrite.³ The effect of thermal aging on the third-stage deformation, therefore, indicates a metallurgical

Fig. 8.1. Effect of Aging Before Testing on the Creep Behavior of Type 308 Stainless Steel Weld Metal at 650°C. Both specimens were from the standard weldment made with an electrode coated with lime-titania, had their axes parallel to the weld direction, and were tested at 25,000 psi. The aged specimen was held 700 hr at 650°C before loading.

Table 8.1. Effect of Aging Before Testing on Creep of Shielded Metal-Arc Weld Made with an Electrode with Commercial Lime-Titania Coating

	Creep Properties at 650°C (1200°F), 25,000 psi		
	Rupture Life (hr)	Total Elongation (%)	Minimum Creep Rate (%/hr)
Tested as welded	44	10.2	0.034
Held 700 hr at 650°C (1200°F) before test	22	3.3	0.034

instability of the ferrite at the substructure boundaries. Microprobe analyses⁴ show that the ferrite typically contains about 26% Cr and is, therefore, susceptible to transformation to sigma phase at 650°C (1200°F), as shown by the Fe-Cr phase diagram. This has always been a problem in stainless steels, and its embrittling effect is well documented.⁵

Our fracture studies have also demonstrated the effect of longer rupture times on the percentage of fracture along substructure boundaries. Figure 8.2 compares the appearance of two specimens of weld metal after fracturing at 27 and 490 hr, respectively. The specimen that failed at the shorter rupture time showed a considerable amount of shear fracture connecting short segments of fracture between phases, while the specimen that failed after 490 hr fractured almost entirely along the phase boundaries. The fracture surface of a weld specimen that ruptured after 575 hr with only 0.14% elongation is shown in Fig. 8.3. Essentially the entire fracture surface was comprised of phase-boundary surface area.

Figure 8.4 shows the fracture surface of the aged specimen discussed above. We see that large portions of the surface fractured between phases. The comparable specimen that was not aged showed only small areas of this fracture mode.

We are also comparing the creep-rupture behavior of specimens machined from several of the welds made with electrodes that had controlled variations in the composition of their coatings. Table 8.2 lists the results from the tests conducted at 650°C (1200°F) and 18,000 psi. The largest strengthening effects were caused by B, P, C, and Si, in that order. The S content, from 0.006 to 0.027%, had no apparent effect on creep properties. Lowering the level of C or Si improved creep ductility under these test conditions.

The significant effect of some compositional variables is illustrated by the case of C; Fig. 8.5 compares the creep curves obtained when weld specimens containing 0.035, 0.044, and 0.074% C are tested at 650°C (1200°F) and 18,000 psi. All three specimens entered third-stage creep after about the same amount of strain. The compositional effects on minimum creep rate and third-stage deformation, however, provide appreciable contributions to overall creep properties. Fractography showed

Fig. 8.2. Effect of Stress Level on Appearance of Fracture in Shielded Metal-Arc Weld Specimens Tested at 650°C (1200°F). (a) Specimen stressed 27 hr at 25,000 psi. (b) Specimen stressed 490 hr at 18,000 psi.

Fig. 8.3. Fracture Surface of Specimen of Shielded Metal-Arc Weld Metal Tested at 650°C (1200°F) that Failed after only 0.14% Elongation.

Fig. 8.4. Fracture Surface of Weld Specimen Aged 700 hr at 650°C Before Testing at 650°C (1200°F). A significant amount of fracture between phases is evident.

Table 8.2. Effect of Variation in Composition of Electrode Coating on Creep Properties of Shielded Metal-Arc Welds in Stainless Steel

Coating Variation	Creep Properties at 650°C (1200°F) and 18,000 psi		
	Rupture Life (hr)	Total Elongation (%)	Minimum Creep Rate (%/hr)
			$\times 10^{-4}$
Commercial lime-TiO ₂ coating ^a	576	0.50	1.9
Low C (0.35%)	490	4.5	10
High C (0.74%)	1004	0.46	< 0.5
Low Si (0.29%)	592	3.2	
High Si (0.73%)	710	1.3	
Low P (0.009%)	b	b	b
Medium P (0.023%)	b	b	b
High P (0.034%)	1655	0.97	
Low S (0.006%)	526	0.75	8.3
High S (0.027%)	548	0.67	3.9
Medium B (0.004%)	2250+	c	
High B (0.006%)	b		

^aThe commercial lime-TiO₂ coating contains the following amounts of the elements considered in this study: 0.044% C, 0.47% Si, 0.012% P, 0.016% S, and 0.001% B.

^bTo be tested.

^cTest in progress.

Fig. 8.5. Effect of Carbon Content on the Creep of Type 308 Stainless Steel Weld Metal at 650°C (1200°F) and 18,000 psi.

an increasing amount of shear fracture with decreasing C content for these three tests.

Mechanical testing of the remaining welds is continuing.

Notes

1. G. M. Goodwin, Fuels and Materials Development Program Quart. Progr. Rept. Dec. 31, 1969, ORNL-4520, p. 164.
2. N. C. Binkley, G. M. Goodwin, and D. G. Harman, Fuels and Materials Development Program Quart. Progr. Rept. Dec. 31, 1969, ORNL-4520, pp. 165-172.
3. We commonly refer to "fracture between phases" when the fracture path follows the boundaries between austenite and ferrite. It should be noted, however, that the solidification substructure boundaries represent regions of substantial solute segregation and will influence the fracture mode whether or not the degree of solute segregation is sufficient to promote the formation of the ferrite phase.
4. G. M. Goodwin and Nancy C. Cole, Fuels and Materials Development Program Quart. Progr. Rept. Sept. 30, 1969, ORNL-4480, pp. 109-110.
5. T. Lyman (ed.) Metals Handbook, 8th ed., pp. 591-592, vol I, American Society for Metals, Metals Park, Novelty, Ohio, 1961.