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Microstructure Characterization of the Fusion Zone of an Alloy 600-82 Weld Joint

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Characterization of the microstructure of the fusion zone of an Alloy 600-82 weld joint was conducted, with focus on the weld residual strain distribution and the comparison of the microstructure of heat affected zone (HAZ) with that of cold worked alloy. Peak of the residual strain was observed to approach to the fusion boundary in HAZ while the strain increased from the top of the weld to the root. Strain distribution in the HAZ was found to be concentrated adjacent to grain boundaries (GBs), with a peak of approximately three times of that in grain. Further, triple junctions of the GB appear to cause a higher strain concentration than single GBs. The microstructure of HAZ consists of partially tangled dislocations, which is different from slip bands of high density dislocations in cold worked alloy. This may cause a relatively higher intergranular cracking resistance of HAZ due to the difficulty in transferring tangled dislocations to GB in HAZ under deformation.

1. Introduction

Weld joints between nickel base weld metals and nickel base alloys, such as Alloy 600-182, Alloy 600-82, etc. are key structures for head and bottom penetration, and divider plate to stream generator joint in pressurized water reactors (PWRs). In recent years, concerns have been raised on the reliability of the weld joint since both Alloy 600 and its weld metals are found to be susceptible to stress corrosion cracking (SCC) in high temperature water[1–4]. The preliminary cause for the SCC of the weld joint is the uniqueness of the weld structure, including the weld residual strain in the fusion zone, the change in microstructure and property of the heat affected zone (HAZ) in the base metal, and the dendritic structure of the weld metal, etc. Weld residual strain is formed in the fusion zone due to the thermal mismatch between the base and weld metals. The corresponding residual stress in the fusion zone could be higher than the yield strength of the alloy, so that SCC may initiate without external stress[5]. Hardening and change in grain boundary microstructure and microchemistry in the HAZ lead to a higher SCC susceptibility of the HAZ than that of the base metal[6–8]. Dendritic boundaries of the weld metal are usually random grain boundaries (RGBs) with segregated P and S, and thus are prone to SCC[9].

While research on the microstructure of the fusion zone of the weld joint has been conducted, further understanding of the mechanism of the enhanced intergranular SCC in the fusion zone requires improved understanding of microstructure of the fusion zone. In particular, there is still a lack of detailed understanding of the interaction between weld residual strain and grain boundaries. Since SCC usually initiates locally at grain boundaries, the local residual strain adjacent to the grain boundary should play an important role in SCC behaviour. In addition, it is interesting to compare the deformation structure in HAZ with that in cold worked alloy. While both HAZ and cold worked structure of Alloy 600 show enhanced SCC susceptibility, the difference in deformation process by weld residual strain and cold working may lead to the difference in the deformation microstructure as well as in the SCC behaviour.

In this work, characterization of microstructure of the fusion zone of an Alloy 600-82 weld joint was conducted, with focus on the strain localization adjacent to grain boundaries, and the comparison of the deformation microstructure of HAZ with that of cold worked Alloy 600, in an effort to attain a better understanding of the correlation between microstructure and SCC in the fusion zone.

2. Experimental

2.1. Materials and specimen

The weld joint was prepared by filling Alloy 82 into a J-groove in a plate of Alloy 600 by multi-pass argon arc welding (current: 140–220 A, voltage: 23 V, interpass temperature: <120 °C, speed:

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Table 1
Chemical compositions of base metal and weld metal (wt%)

	Fe	Cr	Ni	Mn	Si	C	Cu	S	P	Nb + Ta
Alloy 600	8.67	15.25	75.60	0.21	0.18	0.03	0.055	0.003	0.002	
Alloy 82	1.23	18.92	74.53	2.74	0.24	0.04	0.035	0.003	0.002	2.26

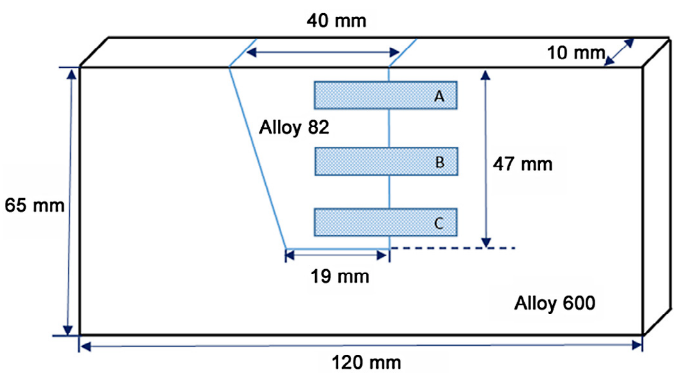

Fig. 1. Schematic showing the geometry and dimensions of the weld joint and the location of the three specimens.

18–20 cm/min, 30 passes) followed by post welding heat treatment at 620 °C for 24 h. Chemical composition of base and weld metals is listed in Table 1. Geometry and dimensions of the weld joint are schematically shown in Fig. 1. Specimens A, B and C were used for microstructure characterization. They are strips, which were extracted from the top, middle and root locations across the fusion zone of the weld joint, as shown in Fig. 1.

2.2. Microstructure and mechanical property characterization

Microstructure of the weld joint was observed by using a Zeiss Axiovert 200 MAT optical microscope. An FEI-XL30 scanning electronic microscope (SEM) equipped with a camera that was used for analysing the misorientation of grain boundaries and distributions of residual strains by electron backscatter diffraction (EBSD) in connection with the TSL software was used for grain boundary character and residual strain analysis of the weld joint. Areas about 1 mm × 3 mm across the fusion boundary (FB) from HAZ to weld metal were examined by EBSD on the surfaces of each specimen. The step size for EBSD scanning was set as 1.5 μm using the voltage of 20 kV. Prior to EBSD analysis, the specimen surface was mechanically ground by silicon carbide paper up to 2000 grit, then polished using diamond paste of 1 μm, and finally polished using 0.04 μm colloidal silica polishing slurry.

The qualitative strains were estimated by measuring the amount of kernel average misorientation (KAM)[10–12], which was calculated by indexing and averaging the misorientations of neighbour-to-neighbour points within the grains, which were obtained by EBSD analysis. For a given point, the average misorientation of that point with all of its neighbors was calculated with a criterion that misorientations exceeding a tolerance value (5° here) are excluded from the calculation. The average KAM in HAZ was calculated in 200-μm segments (grains located within 0 μm to 200 μm from the FB were assigned to the 100 μm location, 200 μm to 400 μm were assigned to 300 μm in HAZ, and so on).

The microstructure in terms of the density and morphology of dislocations adjacent to grain boundaries in HAZ was observed by transmission electron microscopy (TEM, JEOL-2010). Samples for the TEM observation were sliced from the HAZ in the root area of the weld joint. They were punched into pieces of 3 mm in diameter, followed by ion milling to reduce the thickness sufficiently small for the TEM observation.

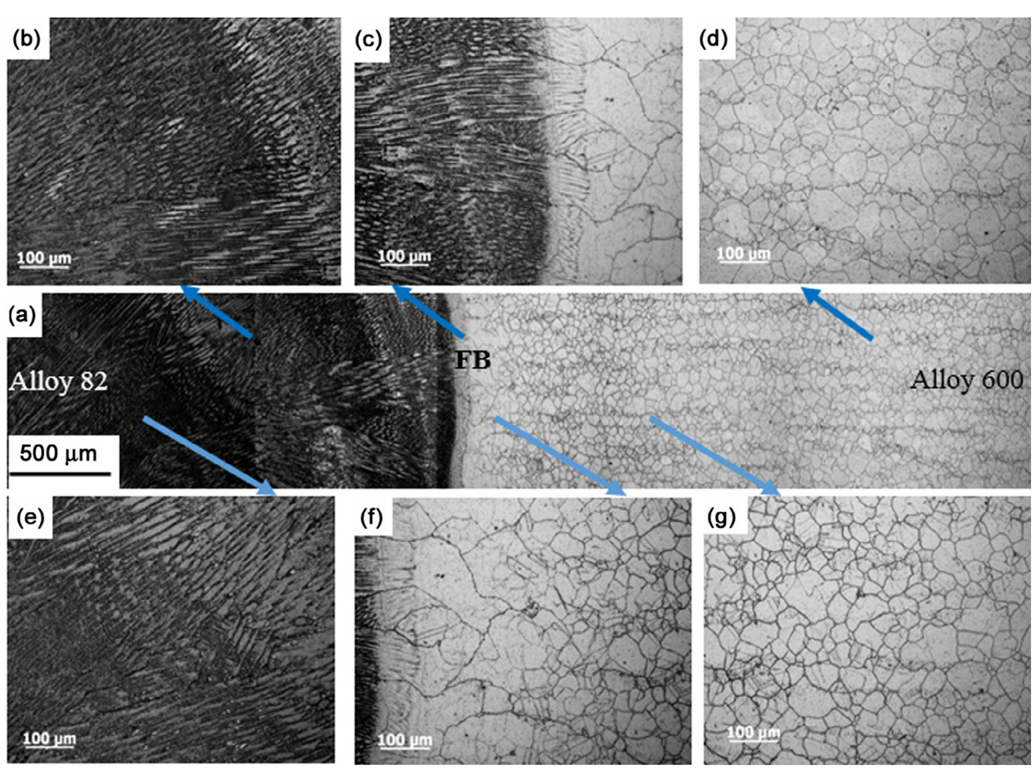

Fig. 2. Optical observation of the fusion zone of the weld joint: (a) overall observation, (b–g) higher-magnification observation of the weld metal, FB, HAZ and base metal.