Strength Evaluation of Heat Affected Zone in Electron Beam Welded ARAA for HCCR TBM in ITER

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1. Introduction

The Korean helium cooled ceramic reflector (HCCR) test blanket module (TBM) has been developed for ITER, and Korean reduced activation ferritic martensitic (RAFM) steel, called advanced reduced activation alloy (ARAA), has also been developed for a structural material of the HCCR TBM [1-5]. One case of limited optimized electron beam (EB) welding conditions was selected based on previous work, and the weldability of an EB weld was evaluated for TBM fabrication. The micro-hardness was measured from the base to the weld region, and the microstructures were also observed. A small punch (SP) test considering the HAZ was carried out at room and high (550 ^{o}C) temperatures. The empirical mechanical properties of HAZ in the EB weld were evaluated, and the fracture behavior was investigated after the SP test. The SP results show that the estimated yield and tensile strength of the HAZ were higher than the base metal at both temperatures. A rupture occurred in the base metal region, and an elongated ductile fracture was observed on the fractured surface at both temperatures.

2. EB welded material and SP test

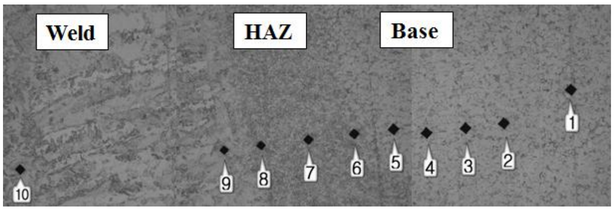
One of the program alloys of ARAA (F206) was made by 80% hot rolling after a preheat of 1150 ^{o}C for 2 hr, and the heat condition was normalized at 980 ^{o}C for 40 min and tempered at 760 ^{o}C for 80 min after the hot rolling. Table 1 shows the results of the mechanical tensile test from the ARAA (F206) material at room and high temperatures (550 ^{o}C). For the room temperature, the average value of the yield strength (σ_{ys}) was 506.3 MPa and that of the tensile strength (σ_{ut}) was 627.9 MPa, whereas the average value of σ_{ys} was 363.8 MPa, and that of σ_{ut} was 374.8 MPa at high temperature. The SP test [6] was carried out at room and high temperatures (550 ^{o}C) and it consists of a punch bar made by Inconel 738 alloy with a 2.4 mm diameter, a punch rod made by SiO_2 with a 2.4 mm diameter, a punch ball made by zirconia with a 2.38 mm diameter, and upper and lower dies made by Inconel 718 alloy to escape plastic deformation during the SP test at high temperature. The EB welded SP specimen size was 10 x 10 x 0.5 (t, mm), and the HAZ was located at the center to evaluate the HAZ strength in the EB weld. The SP test speed was 0.5 mm/min, and an SP test at high temperature was carried out after holding at 550 ^{o}C for 30 min. The fracture morphology using SEM was also observed after the SP test to distinguish the fracture configuration at room and high temperatures.

TABLE I: Results of mechanical tensile test of ARAA (F206)

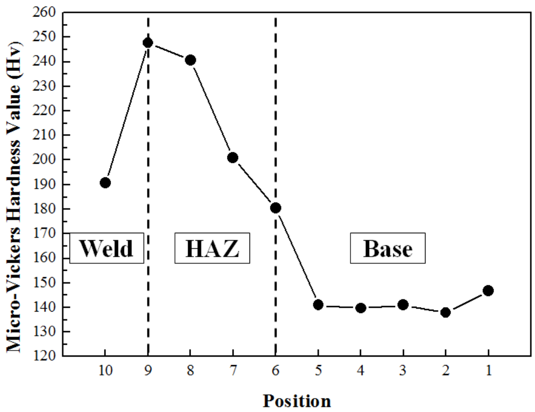
Temperature (^{o}C)	Specimen No.	σ_{ys} [MPa]	σ_{ut} [MPa]	Total strain (%)
24	RT-1	510.2	630.3	28.6
	RT-2	497.9	629.6	29.2
	RT-3	510.9	627.9	28.5
Average value		506.3	629.3	28.8
550	550-1	362.4	378.6	23.4
	550-2	375.7	375.3	23.1
	550-3	353.4	374.8	24.1
Average value		363.8	376.2	23.5

2. Result and Discussion

A micro-hardness measurement was carried out from the base to the weld zone, and the force load of the micro-Vickers hardness test was 300 g. Figure 2 shows the micro-hardness distribution from the base metal to the weld region. The average hardness of the base metal was 141.3 Hv. However, it was increased to 240.6 Hv in the HAZ, and was higher than the weld region, which had an average hardness value of 191 Hv. Figure 3 shows (a) a photograph of the SP specimen, (b) microstructures of the upper region, and (c) microstructures of the middle region of the base, HAZ, and weld in the EB welded SP specimen from the ARAA (F206). The optical micro observation was prepared by polishing and etching, which was used in Villella's reagent (5 % HCL, 1 g picric acid, 95 % Alcohol). The base metal shows evenly dispersed carbide precipitates in the grains and at the grain boundaries, as shown in Fig. 3 (b) and (c). On the other hand, the irregular microstructures, which were a tempered zone, a partially transformed zone, and fine and coarse grain zones in the HAZ were observed, but the width of the HAZ in the EB weld was much narrower than in the TIG weld [6].



(a) micro-Vickers hardness profile



(b) micro-Vickers hardness values

Fig. 2. Photograph of the micro-Vickers hardness profile (a) and values (b) from a base to weld region (×50).

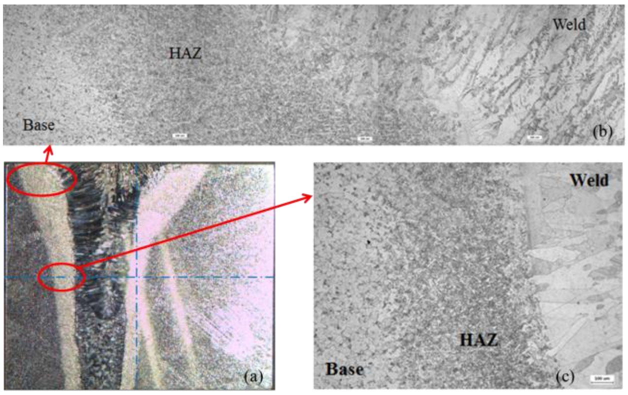


Fig. 3. Photograph of SP specimen (a), Microstructures of upper region in SP specimen (b) and microstructure of middle region (c) in EB welded ARAA (F206) material.

3. Conclusions

Korean RAFM steel, ARAA, was developed as a TBM structural material. Using one of the program alloys in ARAA (F206), one case of a limited optimized EB welding condition was selected based on previous works, and the weldability of an EB weld using the SP test was evaluated for TBM fabrication at room and high (550 ^{o}C) temperatures. From a micro-Vickers hardness evaluation, the HAZ gave the highest values compared with the other regions. The irregular grain boundaries in the HAZ were observed, but its width was narrower than the TIG weld from the previous results. The estimated mechanical properties of the HAZ were higher than the base metal at both temperatures. In addition, they showed a ductile fracture mode on the fractured surface at both temperatures. The optimized welding methods such as the TIG, EB, and laser weld, and the welding procedure considering the PWHT are being established, and the weldability evaluation is also progressing according to the development of the ARAA for the fusion material application in Korea.

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