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Mechanical Properties of Electron Beam Welds of ARAA Material

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1. Introduction

Korea has developed a helium cooled ceramic reflector (HCCR) test blanket module (TBM) and it will be installed and tested in ITER [1]. Fabrication technologies for the HCCR TBM have been developed and confirmed through the fabrication of mockups using ferritic martensitic steel (FMS), SS316L steel, and ARAA [2–4]. Joint technologies, such as tungsten inert gas (TIG) welding, electron beam (E-beam) welding and hot isostatic pressing (HIP) joining, have also been developed and evaluated for RAFM steel through several mechanical tests [5-7]. The reduced activation ferritic/martensitic (RAFM) steel is the primary candidate structural material for the HCCR TBM. In addition, an advanced reduced activation alloy (ARAA) steel with a nominal composition of 9Cr-1.2W-0.2V-0.01Zr is under development and evaluation as a structural material for the HCCR TBM. The purpose of this study was to conduct and analyze tests for mechanical properties of the E beam weld joints of the ARAA steel and verify these properties through the various tests on the mechanical properties.

In this study, 7-mm thick and 1350-mm length ARAA plates were prepared, and E-beam welding and PWHT were performed using the developed weld conditions and process to fabricate test specimens for the mechanical property tests. Micro-hardness measurements, Charpy impact tests and tensile property tests were performed on the heat affected zone (HAZ) and weld metal (WM) of E-beam welded joints after post weld heat treatment (PWHT). Microstructural observations of the welded joints were also analyzed at the HAZ and WM area after PWHT.

2. Mechanical property test of the E-beam welded ARAA plate

2.1 Preparation of the test specimen

The material used for the mechanical property test was ARAA steel. This material was normalized at 1000 ºC for 40 min and then air cooled and tempered at 750 ºC for 70 min before additional air cooling. To investigate the mechanical property test for the E-beam welding of an ARAA plate, 7-mm thick and 1350-mm length ARAA plates were welded using E-beam welding. After the E-beam welding was completed, PWHT was conducted using the previously investigated and optimized condition of 730 ºC/1h [4].

2.2 Mechanical property test

The test specimens were fabricated and the mechanical property tests conducted. To investigate the effect of PWHT for the hardness values, Vickers hardness measurements using test force of HV0.1-load were performed across the E-beam welding joint. Figure 1 shows the micro-hardness results for the BM, HAZ, and WM regions before and after PWHT. The micro-hardness results indicate that the hardness value of the as-welded (before PWHT) point was much higher than that obtained after performing PWHT. The average hardness values before PWHT were 375 HV in the HAZ and 352 HV in the WM, and after PWHT the values decreased to 242 HV in the HAZ and 263 HV in the WM. The average hardness in the base metal close to the HAZ slightly decreased from 210 HV to 196 HV after PWHT.

Charpy impact specimens were fabricated with notches at the center of the HAZ and weld zone after their surfaces were polished and etched parallel to the weld surface. The dimensions of the specimen were 55mmL × 10mmW × 5mmT. Impact tests were performed at temperatures of −80 ºC, −70 ºC, −60 ºC, −55 ºC, −50 ºC, −40 ºC, −30 ºC, −20 ºC, −10 ºC, 0 ºC, and room temperature (RT). The Charpy impact value in the HAZ and WM regions are shown in Figs. 2 and 3. The impact test results that were calculated by the hyperbolic tangent curve fitting method are summarized in Table 1. The ductile brittle transition temperatures (DBTT) of all specimens were -42 ºC on the HAZ and -43 ºC on the WM. The DBTT of weld metal was slightly less than the DBTT of HAZ, while the upper shelf energy (USE) was greater.

Tensile property specimens were fabricated with dog-bone type specimens for room temperature and cylindrical specimens for higher than room temperature. The dimensions of the dog-bone type specimens and cylindrical specimens were 200mmL × 25mmW × 5mmT, and 100mmL × dia. 4mmT, respectively. Tensile tests were conducted at room temperature (RT), 100 ºC, 200 ºC, 300 ºC, 400 ºC, 500 ºC and 550 ºC. Figures 4 shows the temperature dependence of the tensile strength for welded materials. Tensile strength decreased as the temperature increased. The yield strength (YS) and ultimate tensile strength (UTS) were 553 MPa and 652 MPa, respectively. The tensile specimens were fractured at the base metal as shown in Fig. 5. It appeared that the tensile test would not show any noticeable property deterioration due to the hardening in the HAZ and weld zone. Bend tests were conducted for the face and root bend tests without any failure (Fig. 5).

Table 1. Charpy impact test results for the HAZ and WM.

Material	Upper shelf energy (J)	Lower shelf energy (J)	DBTT (°C)
HAZ metal	230	10	-42
WM metal	240	20	-43

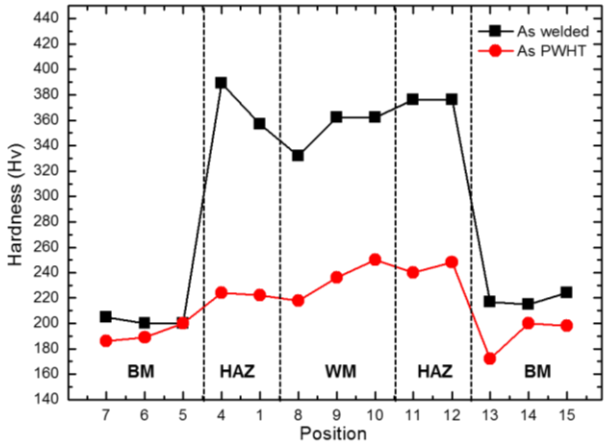

Fig. 1. Results of hardness test across the E-beam welding joint of an ARAA plate before and after PWHT at 730 ◦C/1h.

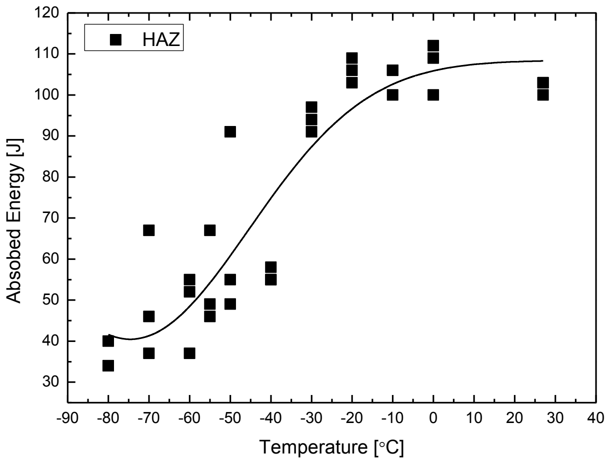

Fig. 2. Results of the Charpy impact test on the HAZ of the E-beam welding joint of an ARAA plate after PWHT at 730 ◦C/1h.

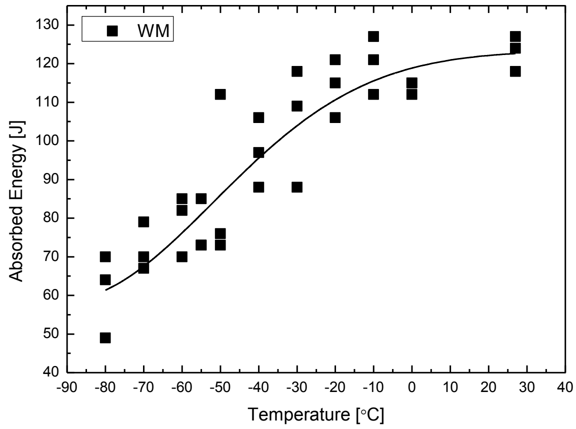

Fig. 3. Results of the Charpy impact test on the WM of the E-beam welding joint after PWHT at 730 ◦C/1h.

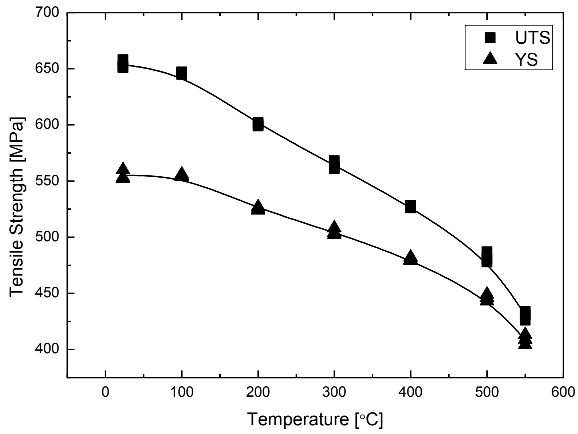

Fig. 4. Results of the tensile strength with temperature after PWHT at 730 ◦C/1h.

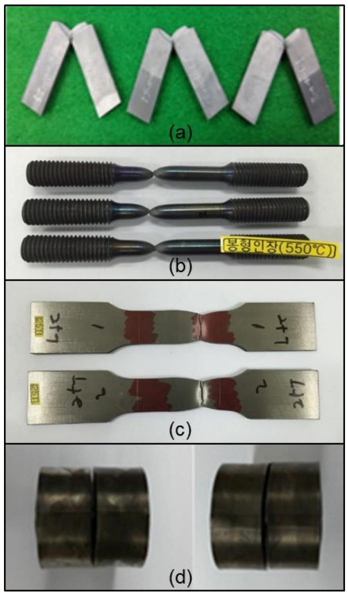

Fig. 5. Results of mechanical property tests (a) Charpy impact test specimens (b) tensile test specimens of dog-bone type (c) tensile test specimens of cylindrical type (d) bend test specimens.

Conclusion

The E-beam welding technology was applied to many joints during the fabrication process of the HCCR TBM. To conduct mechanical property tests of the E-beam welded ARAA plate, 7-mm thick and 1350-mm length specimens were prepared for testing. Tensile, hardness, impact, bend, and microstructure characteristics were studied before and after post-weld heat treatment to evaluate the welded specimens under the determined welding conditions.

Acknowledgments

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