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Mechanical properties of dissimilar TIG welding using ARAA and SS316L

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1. Introduction

One of the main objectives of the ITER project to develop the next-generation technology is the investigation of heat extraction from blanket modules in fusion reactors and tritium extraction experiments [1–5]. Korea has developed a helium cooled ceramic reflector (HCCR) test blanket module (TBM) that will be installed and tested in ITER [6]. The reduced activation ferritic/martensitic (RAFM) steel is one of the candidates for the structural material in fusion reactor and various RAFM steels such as EUROFER [7] and F82H [8] have been developed by countries that are conducting fusion reactor research. In Korea, Advanced Reduced Activation Alloy (ARAA), a kind of RAFM steel, has been developed for the structural material of fusion reactor components including the HCCR TBM in ITER [9-12] and its welding technologies have also developed in parallel such as Electron Beam (E-Beam) welding, Tungsten Inert Gas (TIG) welding, Hot Isostatic Pressing (HIP) bonding considering the TBM features [13-15]. Among them, dissimilar TIG welding using ARAA and SS316L is introduced in this paper.

2. Mechanical property test of the TIG welded ARAA plate

2.1 Preparation of the test specimen

To fabricate the test specimen to investigate the mechanical properties for the dissimilar TIG welding using ARAA and SS316L plate, 12-mm thick and 1350-mm long ARAA and SS316L plates were welded using TIG welding using the developed weld conditions and process. Welding filler used for dissimilar TIG welding was produced through slicing the ARAA plate with 2-mm x 2-mm thick for buttering welding on the ARAA side and commercial filler of SS309L for the between butter welded surface and SS316L plate. The tests for optimum conditions of the PWHT were performed by conducting hardness, impact and histological tests on the specimens, which were post-heat treated for 1 h, 1.5 h and 2 h within the temperature range of 710 ºC, 730 ºC and 750 ºC. These conditions were selected considering the ARAA tempering conditions (750 ºC, 70min). From the tests for PWHT, the optimized condition of 730 ºC /h was determined [11]. The test specimens used in this paper were fabricated from the welded ARAA and SS316L plates according to European Harmonized Standard and RCC-MRx [16, 17].

2.2 Mechanical property test

The mechanical property tests for the fabricated test specimens were conducted to investigate the dissimilar TIG welding effect and the PWHT effect. For the hardness values of the welded part, the fabrication of test specimens and the hardness testing procedure followed EN ISO 6507-1 and EN ISO 9015-1 & 2 and Micro Vickers hardness measurements using a test force of HV 0.1-load (0.1kgf) were performed across the TIG welding joint. The micro-hardness results for the BM, HAZ and WM regions before and after PWHT, shown in Figure 1, indicates that the hardness value of the as-welded (before PWHT) point was much higher than that obtained after conducting the PWHT. The average hardness values before PWHT were 338 HV in the ARAA side HAZ and 199 HV in the WM and after PWHT, the values decreased to 223 HV in the HAZ and 201 HV in the WM. The average hardness in the base metal of ARAA close to the HAZ decreased slightly from 214 HV to 209 HV after PWHT.

For Charpy impact tests, the fabrication of test specimens and the testing procedure applied to NF EN ISO 148-1~3. The test specimens have a notch at the center of the HAZ and weld zone after their surfaces were polished and etched parallel to the weld surface. Impact test were conducted 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). Figure 2, 3 shows the Charpy impact test results in the HAZ and WM regions with using the hyperbolic tangent curve fitting method. The maximum values in the HAZ and WM regions are 196 J and 99 J at 0 RT, respectively.

For tensile tests at RT, EN ISO 6892-1 was applied and EN ISO 6892-2 was applied for tensile tests at higher than RT. The specimen type in tensile testing was cylindrical-type specimen with 100 mmL x dia. 6.35mmT. Tensile tests were performed at RT, 100 ºC, 200 ºC, 300 ºC, 400 ºC, 500 ºC and 550 ºC. Figure 4 shows the temperature dependence of the ultimate tensile strength (UTS) for TIG welded materials. At RT, the UTS was and 617 MPa, respectively. UTS was decreased as the temperature increased. The fracture of tensile test specimens occurred in the base metal and this result indicated that any obvious tensile property deterioration due to the hardening in the HAZ and weld region would not be shown in tensile tests. Bend test was performed according to EN ISO 7438 and EN ISO 5173. As a result of the bend test, no crack was found in the visual inspection. This result indicated that the specimen was resistant to the maximum strength.

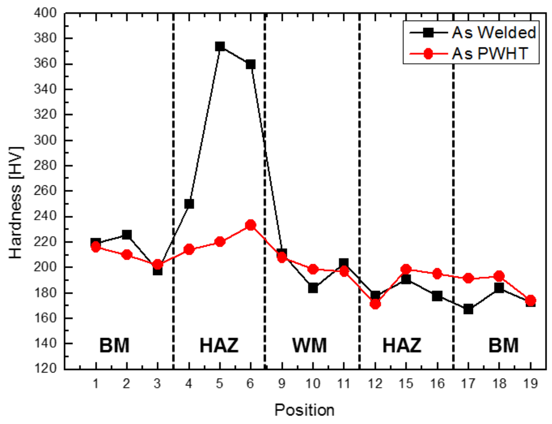

Fig. 1 Results of hardness test across the TIG welding joint of an ARAA plate before and after PWHT at 730 °C/1h.

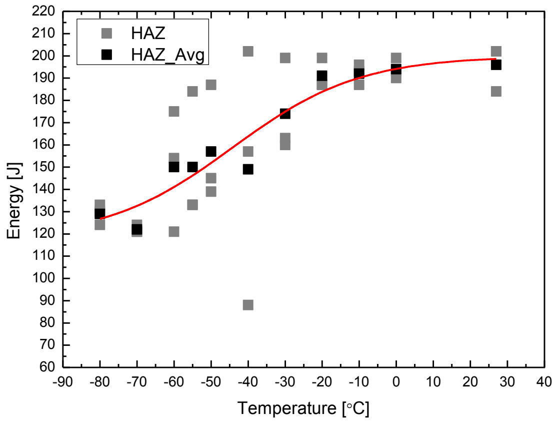

Fig. 2 Results of the Charpy impact test on the HAZ of the TIG welding joint of an ARAA plate after PWHT at 730 °C/1h.

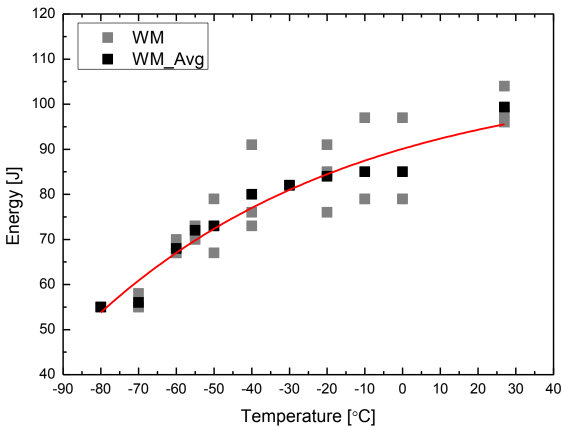

Fig. 3 Results of the Charpy impact test on the WM of the TIG welding joint of an ARAA plate after PWHT at 730 °C/1h.

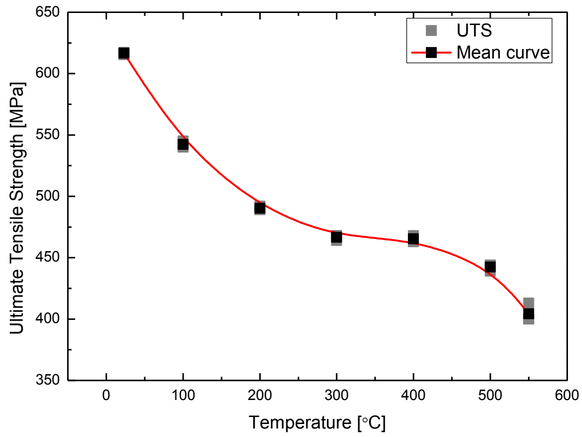

Fig. 4 Tensile strength of ARAA with temperature after PWHT at 730 °C/1h.

Conclusion

To investigate dissimilar TIG welding properties from ARAA and SS316L material, the mechanical property tests of a dissimilar TIG welded ARAA and SS316L plate were conducted according to RCC-MRx including EN ISO standards. The plates with 12-mm thick and 1350-mm long were prepared and welded according to the welding conditions for the ARAA materials. Micro-Vickers hardness test was conducted before and after PWHT to evaluate the effect of PWHT on the base metal and weld metal. Charpy Impact, tensile and bend tests were performed after PWHT. The micro-hardness results indicate that the profile of the hardness values for the materials after PWHT is more stable than before PWHT. The average hardness values before PWHT were 338 HV in the ARAA side HAZ and 199 HV in the WM and after PWHT, the values decreased to 223 HV in the HAZ and 201 HV in the WM. The average hardness in the base metal of ARAA close to the HAZ decreased slightly from 214 HV to 209 HV after PWHT.

The maximum Charpy impact values in the HAZ and WM regions are 196 J and 99 J at 0 RT, respectively.

The tensile test specimens were fabricated using dog-bone type specimens for room temperature, and cylindrical specimens for higher than room temperature. The tensile strength decreased as the temperature increased. The ultimate tensile strength (UTS) was 617 MPa. Bend tests were conducted for the face and root bend tests without any failure.

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