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# Mechanical Properties of TIG Welding of ARAA Material

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## 1. Introduction

Korea has developed a helium cooled ceramic reflector (HCCR) breeding blanket for developing the Korean DEMO and fusion reactor [1]. It will be installed and tested in ITER in the form of a test blanket module (TBM). 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 [2] and F82H [3] have been developed by countries that are conducting fusion reactor research. In Korea, an ARAA (Advanced Reduced Activation Alloy), a kind of RAFM steel, has been developed for the structural material of fusion reactor components including the HCCR TBM in ITER [4-7] 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 with similar and dissimilar material weld considering the TBM features [8-10]. Among them, TIG welding with similar metal using ARAA is introduced in this paper.

In this study, TIG welding and post weld heat treatment (PWHT) were conducted for 12-mm thick and 1350-mm long ARAA plates using the developed weld conditions and process to fabricate the test specimens for the mechanical property tests. To examine the TIG welding effect on the mechanical properties for ARAA, hardness tests, Charpy impact tests and tensile tests were applied to the heat affected zone (HAZ) and weld metal (WM) of the TIG welded joints after PWHT.

## 2. Mechanical property test of the TIG welded ARAA plate

### *2.1 Preparation of the test specimen*

ARAA steel was used to prepare the test specimen for the mechanical property test. This material was supplied with a form of plate from WA77 heat (2nd large-scale product). It was manufactured through the following process; the normalization at 1000 ºC for 40 min and then air cooling and tempering at 750 ºC for 70 min before additional air cooling. To fabricate the test specimen to investigate the mechanical properties for the TIG welding of an ARAA plate, 12-mm thick and 1350-mm long ARAA plates were welded using TIG welding using the developed weld conditions and process. Welding filler used for TIG welding was produced through slicing the ARAA plate with 2-mm x 2-mm thick. The TIG welding conditions were optimized for welding 12-mm thick plate and determined as a welding speed of 46~93 mm/min and a welding current of 175 A. 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 [6]. Figure 1 shows the microstructure of the welded 12-mm thick ARAA plate specimens with the optimized TIG welding. The test specimens used in this paper were fabricated from the welded ARAA plates according to European Harmonized Standard and RCC-MRx [11, 12].

### *2.2 Mechanical property test*

The mechanical property tests for the fabricated test specimens were conducted to investigate the 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 332 HV in the HAZ and 380 HV in the WM and after PWHT, the values decreased to 250 HV in the HAZ and 258 HV in the WM. The average hardness in the base metal close to the HAZ decreased slightly from 213 HV to 202 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 175 J at RT and 209 J at 0 ºC, respectively. The ductile brittle transition temperature (DBTT) for HAZ and WM were -50 ºC and -65 ºC, respectively. The DBTT of HAZ was higher than that of WM, while the upper shelf energy was lower.

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 at RT was dog-bone type specimen with 200 mmL x 25 mmW x 5mmT. The tensile test specimen higher than RT was cylindrical-type specimen with 100 mmL x dia. 4mmT. 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 yield strength (YS) and ultimate tensile strength (UTS) for TIG welded materials. At RT, the YS and UTS were 542 MPa and 652 MPa, respectively. Both YS and UTS were 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.

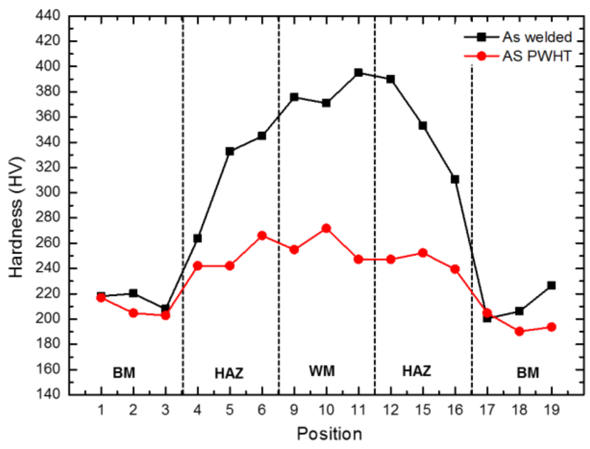


Fig. 1 Results of hardness test across the TIG welding joint of an ARAA plate before and after PWHT at 730 ºC/1h.

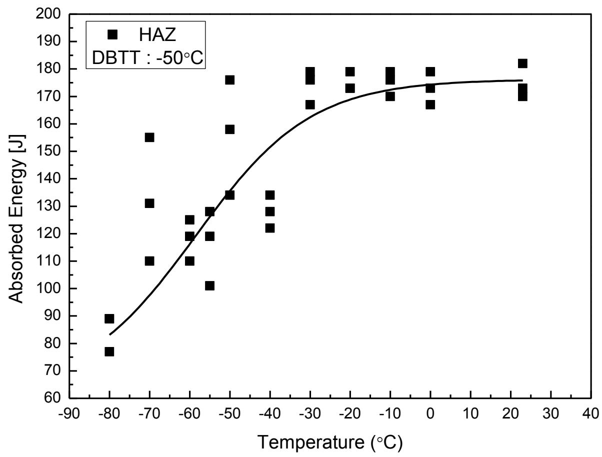


Fig. 2 Results of the Charpy impact test on the HAZ of the TIG welding joint of an ARAA plate after PWHT at 730 °C/1h.

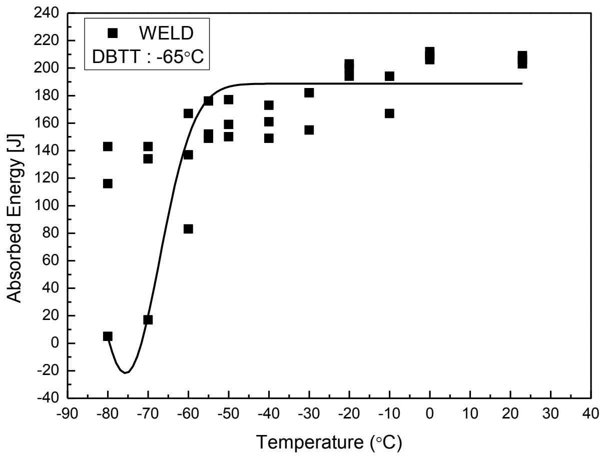


Fig. 3 Results of the Charpy impact test on the WM of the TIG welding joint of an ARAA plate after PWHT at 730 °C/1h.

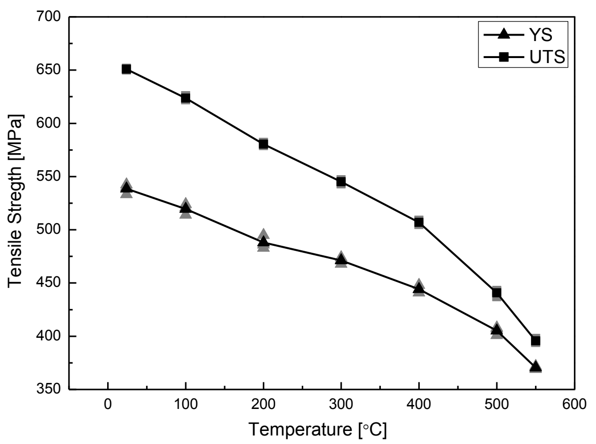


Fig. 4 Tensile strength of ARAA with temperature after PWHT at 730 ºC/1h.

## Conclusion

ARAA is a main candidate of the structural material for Korean DEMO and fusion reactor, and its TIG welding technology would be applied to many joints for their construction, especially for the breeding blanket fabrication. To investigate TIG welding properties from ARAA material, the mechanical property tests of a TIG welded ARAA 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. These plates were used to make the specimens for the tests. Micro-Vickers hardness test and micro-structure analysis were 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 were 332 HV in the HAZ and 380 HV in the WM, and after PWHT, the values decreases to 250 HV in the HAZ and 258 HV in the WM. The maximum Charpy impact values in the HAZ and WM regions are 175 J at RT and 209 J at 0 $^{o}$C, respectively. The ductile brittle transition temperatures (DBTT) of all specimens were -50 $^{o}$C on the HAZ and -65 $^{o}$C on the WM. The DBTT of the weld metal was slightly less than the DBTT of HAZ, while the upper shelf energy (USE) was greater. 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 yield strength (YS) and ultimate tensile strength (UTS) were 542 MPa and 652 MPa, respectively. Bend tests were conducted for the face and root bend tests without any failure. The effect of PWHT on the microstructure of TIG welded ARAA material was confirmed by micro-structure analysis.

## Acknowledgments

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