Journal of Nuclear Materials 386–388 (2009) 491–494

Contents lists available at ScienceDirect

Journal of Nuclear Materials

journal homepage: www.elsevier.com/locate/jnucmat

Development of low activation ferritic/martensitic steel welding technology for the fabrication of KO HCSB TBM

Seungyon Cho *, Duck-Hoi Kim, Mu-Young Ahn

ITER Korea, National Fusion Research Institute, Gwahngno 113, Yuseong-gu, Daejeon 305-333, Republic of Korea

ABSTRACT

The conceptual design of the Korean helium cooled solid breeder test blanket module has been performed and the fabrication feasibility of the test blanket module concept has been investigated. It is necessary to develop fabrication technology, such as joining technologies of structural material, because low activation ferritic/martensitic steel has been considered for the structural material of the Korean helium cooled solid breeder test blanket module. Several types of the low activation ferritic/martensitic steel have been proposed, but their welding characteristics are still under investigation. In this paper, electron beam welding technologies for the low activation ferritic/martensitic steel were investigated in detail. Tensile, hardness, impact, and microstructure characteristics of the welded specimens before and after post-welded heat treatment have been investigated, and the results show that welding quality and the process applied in this study were found to be reasonable.

1. Introduction

One of the main missions of ITER is to test and validate design concepts of tritium breeding blankets relevant to DEMO or fusion power plants. The Korean solid breeder test blanket module (TBM), helium cooled solid breeder (HCSB), has been developed with the overall objective of achieving this goal. Fig. 1 shows the HCSB that utilizes a Li_4SiO_4 pebble bed as breeder, a beryllium pebble bed as multiplier, a graphite pebble bed as reflector and low activation ferritic/martensitic (LAFM) steel as structural material. On the plasma facing component, beryllium armor is joined to protect the TBM [1].

At present, LAFM steel is a structural material candidate for the Korean DEMO blanket design. For the manufacturing of the HCSB using LAFM steel, different fabrication methods, such as machining, hot isostatic pressing (HIP), welding, etc., will be utilized. Among these, knowledge on joining technologies for LAFM steel is still insufficient even though many interesting results about welded joints of LAFM steel have been recently published [2–4]. In addition, since welding technologies would be the key factors for successful TBM fabrication, the development of various welding methods, such as electron beam welding (EBW), laser, tungsten inert gas (TIG), submerged arc welding (SAW) and shielded metal arc welding (SMAW), is on-going. Among them, EBW technologies for low activation ferritic/martensitic steel were investigated in detail in this paper. The final goal of this study is to check the mechanical property variation across the joints and to find optimal welding processes and post-welded heat treatment (PWHT) conditions.

2. EB welding technology development

2.1. Preparation of welding specimen and test procedures

The material used in this research is IEA-modified F82H (F82H-IEA) LAFM steel. The chemical composition of LAFM is shown in Table 1. This material was normalized at 1040 °C followed by air cooling and tempered at 750 °C for 60 min followed by air cooling.

The power capacity of the EBW machine used for this study was 6 kW. To investigate the welding characteristics of the HCSB structure, two types of welding plates were used with thicknesses of 8 mm and 15 mm. The molten weld pools were realized without pre-heating on both plates. The plates were rigidly clamped to a massive supporting structure providing a severe constraint condition. All of the electron beam weld pools crossed the thickness of the plates. The welding parameters are summarized in Table 2. The PWHT condition was 1 h at 720 °C estimated from the results in previous studies [2,5].

Each welding plate was transversally sectioned, mechanically polished, etched and then observed by optical microscopy and a scanning electron microscope (SEM) at low and high magnification. The morphology and the extended molten and heat affected zones (HAZ) were analyzed. Before and after PWHT, the properties were investigated by using micro Vickers hardness measurement. For the evaluation of mechanical properties, plate type tensile specimens were used. Tensile specimens with 50 mm gage length were machined perpendicular to the weld line. Temperatures applied to

* Corresponding author. Tel.: +82 42 710 1835; fax: +82 42 710 1809.
E-mail address: sycho@nfri.re.kr (S. Cho).

0022-3115/$ - see front matter © 2008 Elsevier B.V. All rights reserved.
doi:10.1016/j.jnucmat.2008.12.165

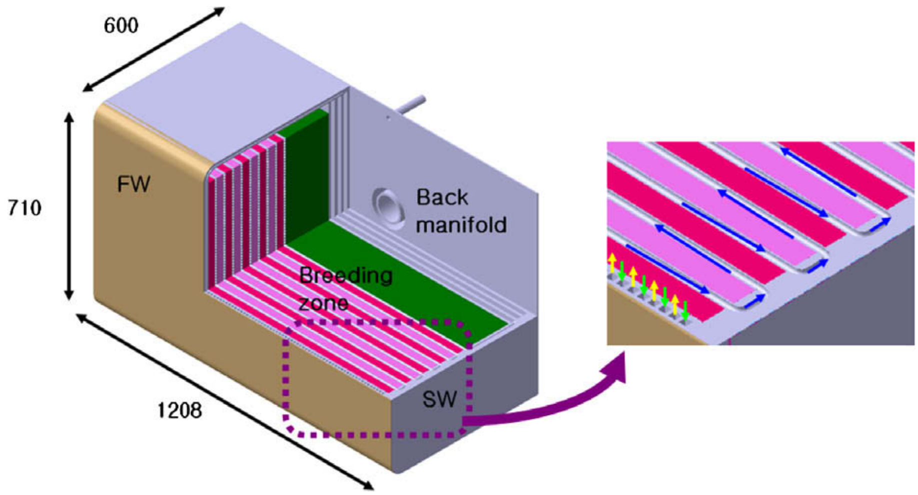

Fig. 1. Bird view of Korean TBM, HCSB, SW: side wall; FW: first wall.

tensile tests were room temperature, 300 °C, 450 °C and 550 °C. Charpy V-notched specimens of standard type were fabricated from three zones of the welded plate; base metal, HAZ and weld metal. Full size impact specimens of 10 mm × 10 mm × 55 mm were fabricated from a 15 mm welded plate and the V-notch with 2 mm depth was machined parallel to the weld line. Fabrication of all specimens and test procedures were performed in accordance with ASTM standards [6].

2.2. Results and discussion

The optical microscopy image of a 15 mm welded plate before PWHT is shown in Fig. 2. The melting zone head had the maximum width of 2.1 mm, and the maximum HAZ extent of 0.6 mm was found at the root of the nail stem. The classical nail-like aspects in both 8 mm and 15 mm plates were found.

Fig. 3 shows SEM images in three zones on a 15 mm welded plate. All images show the typical martensitic structures. In the base metal, similar features and grain size are shown regardless of PWHT. The microstructure at the HAZ before PWHT (as-welded) has a mean size slightly larger than that after PWHT (as-PWHT).

To investigate the hardness changes due to PWHT, Vickers hardness measurements were carried out across the EBW joint. The trends of the hardness variation were obtained before and after heat treatment and the results are shown in Fig. 4. In as-welded condition, weld zones exhibited typical hardness values of a martensitic structure. The maximum hardness in HAZ was 400 kgf/mm^2 and decreased to 230 kgf/mm^2 after PWHT. And the hardness in the base metal close to HAZ slightly decreased from 204 kgf/mm^2 to 187 kgf/mm^2 after PWHT.

Fig. 5 shows the temperature dependence of the tensile strength and total elongation for base and welded materials with 8 mm thickness. Tensile strengths of both materials decreased as the temperature increased. Tensile strengths of welded materials were slightly higher than those of base materials except at room temperature. On the other hand, total elongations of base materials were greater than those of welded materials. Most specimens were fractured at the base metal. It can be concluded that tensile test would not show any noticeable property deteriorations due to the hardening in the weld zone, even though some experimental errors are found in high temperature tests.

The behaviors of Charpy impact testing of EBW joints using 15 mm specimens are shown in Fig. 6. The impact test results calculated by the hyperbolic tangent curve fitting method are summarized in Table 3. The ductile brittle transition temperatures (DBTT) of all specimens were below 273 K. The DBTT of weld metal was slightly decreased compared to those of other materials, while upper shelf energy (USE) was greater. Even though the hardening in HAZ was detected from hardness measurements, no shift in

Table 1
Chemical composition of LAFM steel (wt%).

C	Si	Mn	P	S	Cu	Ni	Cr	Mo
0.09	0.11	0.16	0.002	0.002	0.01	0.02	7.7	0.003
V	Nb	B	N	Al	Co	Ti	Ta	W
0.16	0.0001	0.0002	0.005	0.001	0.005	0.01	0.02	2.00

Table 2
Electron beam welding parameters for LAFM steel plate joining.

Plate thickness (mm)	Accelerating voltage (kV)	Focusing current (mA)	Welding current (mA)	Federates (mm/min)
8	55	14.6	30	600
15	60	14.7	50	300

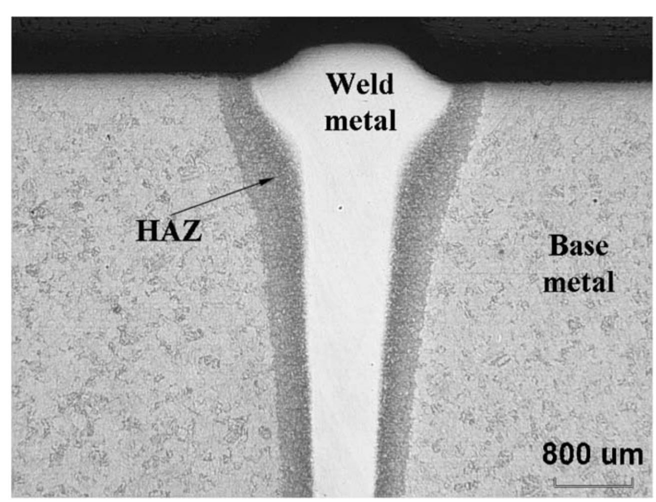

Fig. 2. Typical aspects for EBW pool of 15 mm welded plate before PWHT.

DBTT was observed and USE decreased showing similar Charpy impact behavior to the base metal.

Based on the results of the above fracture tests, it was found that 8 mm and 15 mm plates have been successfully joined by EBW processes without obvious defects. However, in order to enhance the quality of the joining and to remove undesirable phenomena such as hardening in the weld zone and shift in DBTT of the weld metal, more R&D on electron beam welding technology for LAFM steel should be performed.

3. Current activities and plans for HCSB fabrication technologies

The current status and plans related to the development of fabrication technologies for HCSB TBM are briefly described herein. As shown in Fig. 1, the TBM structure consists of several types of plate walls which contain cooling channels and tubes to remove power deposited by neutron wall loading and surface heat flux from the plasma. One main difficulty in manufacturing the TBM is to fabricate rectangular cooling channels in the first wall without weld joints to minimize possible tritium permeation through welded regions. For the fabrication of rectangular cooling channels without weld joints, two kinds of methods, drawing and cold rolling, are being developed. The drawing method consists of simple processes compared to cold rolling, though it is still difficult to make long channels.

As shown in Fig. 1, the HCSB TBM first wall (FW) consists of Be tiles, cooling tubes and structure plates. Therefore, bonding by hot isostatic pressing (HIP) has been investigated as a practical fabrication process to join the FW to the TBM structure. At present, technical development for joining Be/LAFM and LAFM/LAFM is ongoing.

4. Summary and conclusion

The current status and activities for HCSB TBM fabrication technology development were described. In the early stage, technical

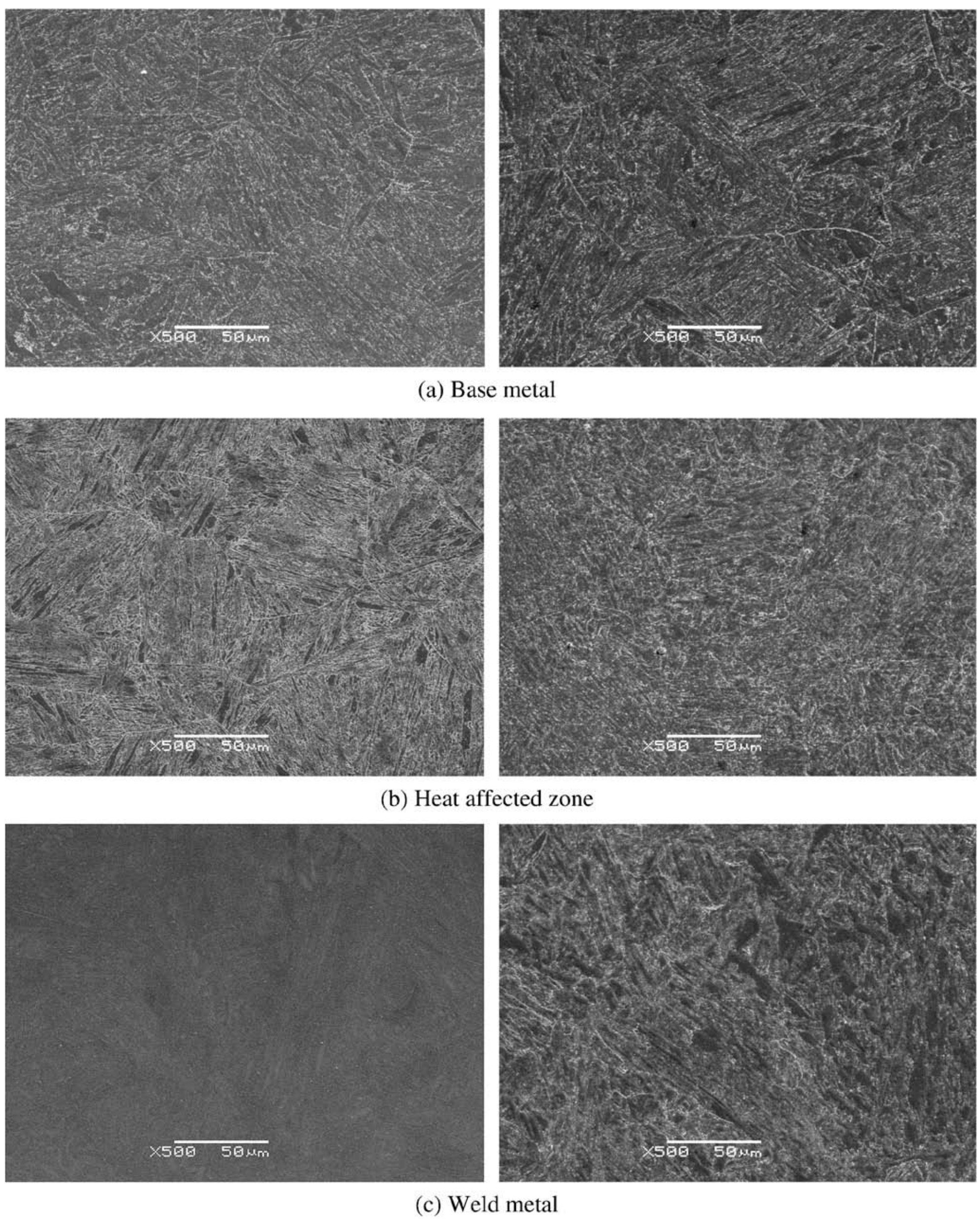

Fig. 3. SEM images of the microstructure of 15 mm EBW plates (left: before PWHT, right: after PWHT).

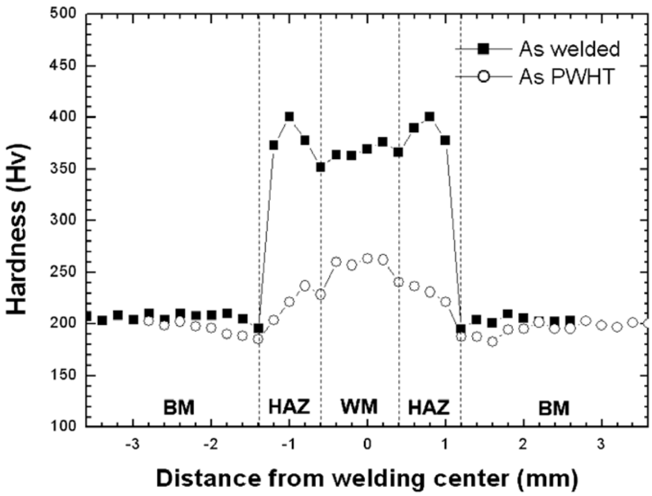

Fig. 4. Vickers hardness trends across an EBW joint before and after PWHT of 1 h at 720 °C.

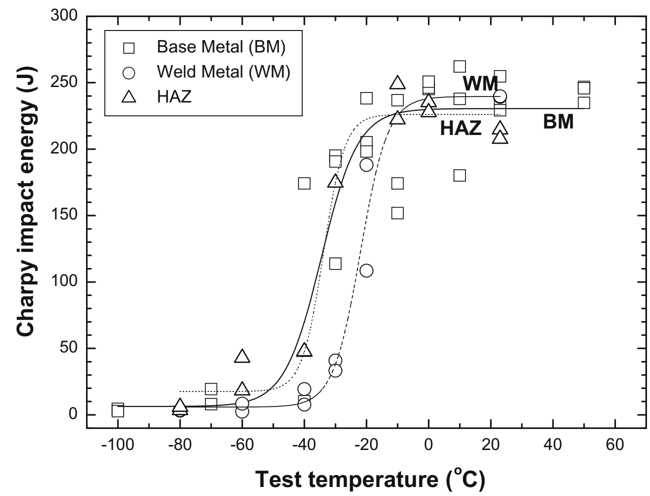

Fig. 6. Charpy impact behavior of LAFM EBW specimens with 15 mm thickness.

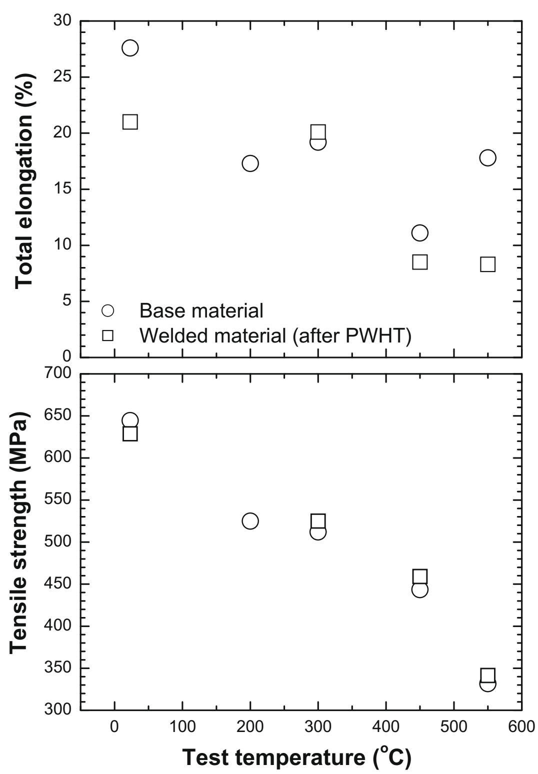

Fig. 5. Tensile strength and total elongation of base and welded materials with 8 mm thickness.

development for successful TBM fabrication has been concentrated on joining technologies such as welding and HIP. In addition, the development of major components, such as rectangular cooling channels requiring a special fabrication technique for TBM, is in progress.

Especially, this paper presented the welding technologies for LAFM joining in detail. The EBW was utilized to make welding pools on two kinds of LAFM steel plates with thicknesses of 8 mm and 15 mm. The PWHT condition for recovery from hardening and toughness degradation was selected to be 1 h at 720 °C. To evaluate the welding quality, microstructure investigation and fracture tests were performed. All microstructures except weld metal before PWHT were typical martensitic structures. Fracture tests did not show any noticeable property deteriorations, but hardening in weld zones after PWHT was still found. In order to enhance joining quality and to remove undesirable phenomena such as hardening in weld zones and DBTT shift of weld metal, more R&D on electron beam welding technologies for LAFM steel will be performed.

Table 3
Charpy impact test results for base and welded materials.

Material	Upper shelf energy (J)	Lower shelf energy (J)	DBTT (°C)
Base metal	230.5	6.3	−35
HAZ metal	226.1	17.6	−34
Weld metal	239.6	5.8	−22

Acknowledgements

This work is supported by the Ministry of Education, Science and Technology of the Republic of Korea under the ITER Project Contract. Authors are grateful for the great efforts of Im-Sub Choi and Man-Ho Choi from Soles Co. Ltd., and In-Ho Kim from LN Laser Co. Ltd., for their assistance in the experiment. Authors also appreciate H. Tanigawa from Japan Atomic Energy Agency for his providing us with F82H-IEA under Korea-Japan Collaboration Program.

References

[1] S. Cho et al., Fus. Eng. Des. 83 (2008) 1163.
[2] G. Filacchioni, R. Montanari, M.E. Tata, L. Pilloni, J. Nucl. Mater. 307–311 (2002) 1563.
[3] K. Shiba, M. Enoeda, S. Jitsukawa, J. Nucl. Mater. 329–333 (2004) 243.
[4] T. Hirose, K. Shiba, M. Ando, M. Enoeda, M. Akiba, Fus. Eng. Des. 81 (2006) 645.
[5] H. Tanigawa et al., Fus. Eng. Des. 83 (2008) 1471.
[6] ASTM, Metals Test Methods and Analytical Procedures, American Society for Testing and Materials, Pennsylvania, 2003.