Cu/SS HIP Joining for Fabrication of ITER Shied Blanket

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1. Introduction

International Thermonuclear Experimental Reactor (ITER) is designed to demonstrate the operation and safety of fusion plasma machine as an integrated system. The basic function of the blanket systems of ITER is to provide the main thermal and nuclear shielding to the vacuum vessel and external machine components. The basic structure of the blanket is a modular structure attached on the vacuum vessel by a mechanical attachment system. The module consists of a shield block on which separate first wall (FW) panels are mounted. The first wall of the ITER shielding blanket is composed of a plasma facing component, a Cu alloy heat sink layer containing austenitic stainless steel (SS) circular tube for coolant channel and an austenitic SS backing plate as a structural layer. For fabrication of these multi-layered structures, Hot Isostatic Pressing (HIP) has been considered as a promising technology to keep both mechanical stiffness and cooling capability of a blanket system [1-4]. In this study, Cu/SS joint fabricated by HIP was examined. Mircrostructure observation and mechanical tests has been performed on the Cu/SS HIPed joint to investigate the optimal condition for the fabrication of FW.

2. Experimental procedure

Materials proposed for FW are Be for plasma facing component, DSCu or CuCrZr for heat sink layer and SS316L(N)-IG for structure materials and coolant tube embedded in Cu heat sink. For fabrication of Cu/SS joint in this study, SS316L was used instead of SS316L(N)-IG by assumption that the joining properties was not greatly changed with minor alloying elements such as C and N which is precisely controlled in the ITER grade SS. Two kinds of Cu alloys, CuCrZr and dispersion strengthend Cu (DSCu), were used to examine which Cu alloy is more appropriate for Cu/SS joint. The chemical compositions of CuCrZr and DSCu used in this study were confirmed to be within the range of ITER standard specification.

SS and Cu alloys were cut into the block with dimension of 80x80x50mm by electro discharge machine (EDM). The surface of the block was ground to have the surface roughness value (Ra) less than 1 μm. Cu and SS blocks were cleaned with an acetone, assembled and canned with SS304 with a thickness of 2mm by TIG welding. The canned materials were degassed at 500^{o}C for 3 hr in vacuum of less than 10^{-3} torr. HIP was performed at 1050^{o}C for 2 hr. The HIP pressures employed in this study were 100MPa and 150MPa to investigate the effect of pressure on the joining strength. The same HIP conditions were applied regardless of Cu alloys. However, for CuCrZr/SS joint, the post heat-treatment after HIP was performed at 980 ^{o}C for 30 min followed by water quenching and aging at 565 ^{o}C for 2 hr to recover the properties of CuCrZr to as-received state. After HIP, the SS304 was removed by EDM. The joint specimens for tensile, shear and Charpy impact test were manufactured from the Cu/SS joint block by keeping the joint interface at the center of each test specimen.

The microstructure of the joining interface was observed by use of optical microscopy (OM) and scanning electron microscopy (SEM). The distribution of alloying elements in the joining interface was investigated by electron probe micro analyzer (EPMA) to evaluate the diffusion layer formed by HIP joining of Cu/SS. A series of mechanical tests including tensile test, shear test and Charpy impact test was performed for the Cu/SS joint specimens together with Cu and SS base metal specimens to evaluate the bond strength of the Cu/SS joint.

3. Results and discussion

3.1. Microstructure

The optical microstructure of CuCrZr and DSCu alloy was examined by OM and SEM before HIP. CuCrZr had recrystallized structure with a grain size of about 70 μm containing Cr-rich precipitates with a size less than 1 μm However, DSCu showed a deformed structure in which small particles of Al_2O_3 was finely distributed.

The morphology of the interface of the Cu/SS joint after HIP was observed by OM and SEM. Figure 1 shows the joining interface of Cu/SS joint. In CuCrZr/SS joint, Cr-rich interlayer with a thickness of 10μm was formed at the SS-side of the interface and Zr-rich interlayer with a thickness of about 1μm was formed between Cr-rich interlayer and CuCrZr. The interface morphology was not greatly changed with HIP pressure form 100MPa to 150MPa. On the other hand, no interlayer was found in DSCu/SS joint, but Fe and Cr-rich intermetallic phases were observed in DSCu up to 50 μm away from the joining interface. In both joints, no defect such as cracks and pores was observed in the joining interface which means that the HIP condition employed is proper to fabricate the sound Cu/SS joint.

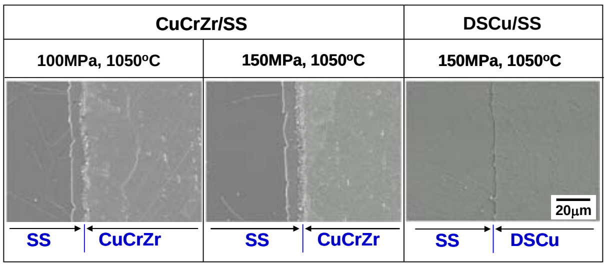

Figure 1. Scanning electron micrographs for the interface of CuCrZr/SS316L and DSCu/SS316L joints.

3.2. Tensile test

Tensile tests were preformed for the joint specimens as well as Cu and SS base metals at room temperature with a strain rate of $2.78x10^{-3}$/sec using the round-type specimen whose diameter and gauge length are 3mm and 30mm, respectively. SS base metal showed the highest tensile strength (600MPa) and ductility (>60%) among the three kinds of specimens. Cu base metal showed the tensile strength of around 300MPa and ductility in the range of 20 to 30%. Joint specimens showed a similar tensile strength to the Cu alloy in both Cu joint. The entire specimens showed a cup and cone-type fracture. In Cu/SS joint specimens, the fracture was not occurred at the interface but in the Cu base metal part suggesting that the interface is stronger than Cu base metal.

3.2. Shear test

Shear test was performed at room temperature according to ASTM D3846 specification. All the joint specimens showed similar load–displacement behavior irrespective of Cu alloy and HIP pressure. All specimens showed bending behavior without shearing in the joining interface up to the shear load of 2000kgf. No crack was observed at the interface which means that the joining interface is strong enough to withstand the shear load up to 2000kgf.

3.2. Charpy impact test

Charpy impact test was performed for the Cu/SS joint specimens together with Cu and SS base metal at room temperature using the V-notch specimen with a dimension of 10x5x55 mm. Figure 2 shows the Charpy impact values of the Cu/SS joints and base metals. The impact value of CuCrZr base metal (136J/cm^2) was almost two times higher than that of DSCu (73J/cm^2). CuCrZr/SS joint showed a higher impact value (22J/cm^2) than DSCu/SS joint (7J/cm^2), which seems to be due to a higher impact value of CuCrZr as compared to DSCu. The joint specimen was fractured at the Cu side of the joining interface showing a brittle fracture appearance while Cu and SS base metals showed a ductile fracture appearance.

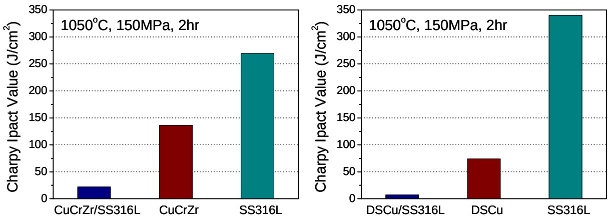

Figure 2. Charpy impact values of CuCrZr/SS316L and DSCu/SS316L joints HIPed at 1050ºC and 150MPa for 2 hr.

4. Conclusions

CuCrZr/SS316L and DSCu/SS316L joints were successfully fabricated by HIP at 1050ºC, 2 hr and 100 to 150MPa. Microstructure observations revealed that no defect such as cracks and pores was observed in the joining interface. Cr-rich interlayer was formed in the interface of CuCrZr/SS joint while Fe and Cr-rich intermetallic phase was found in the DSCu side of DSCu/SS joint. From the mechanical test including tensile test, shear test and Charpy impact test, it was found that the strength of the joining interface was higher than that of Cu base metal and the failure of the joining interface was not observed. Based on the results obtained, CrCrZr is more desirable to Cu alloy for the fabrication of ITER shied blanket.

Acknowledgements

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