Effect of interlayer on HIP joining of Be/CuCrZr

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1. Introduction

ITER first wall was designed to consist of the Be armor, the CuCrZr heat sink layer and the stainless steel (SS) plate. The joining of three different materials has been the critical issue in the fabrication of ITER first wall. The hot isostatic pressing (HIP) has been considered as the most promising joining technology to realize a sufficient mechanical integrity of a joint under the anticipated high neutron and stress fields. The HIP joining of CuCrZr to SS has been successfully demonstrated by fabrication of mock-ups and by high heat flux tests [1,2]. However, the joining technology of Be to CrCrZr still need to be further developed before starting the mass production of ITER first wall.

Several HIP conditions with specific interlayers were reported to be promising in the previous reports [3,4]. However, it was considered that the HIP joining condition should be further optimized to fabricate ITER first wall with a reliable performance.

In this study, the effects of the interlayer types and the temperature on Be/CuCrZr joining have been investigated to develop the fabrication technology of ITER first wall. Be/CuCrZr joining samples with different interlayer types were fabricated by HIP at different temperatures. The microstructure of the joining interface was observed and the mechanical tests were performed for the joining samples.

2. Experimental procedure

S-65C VHP has been selected as the reference Be grade for the fabrication of ITER first wall due to its lowest BeO and other impurity contents and high ductility at the elevated temperature. CuCrZr was selected as a primary candidate material because of its lower cost, higher fracture toughness and better irradiation resistance when compared to DSCu.

Be tiles with a dimension of 50x50x10mm were mechanically polished and cleaned in acetone using a ultra sonic cleaner. Interlayer were coated on Be surface by a physical vapor deposition method after the ion cleaning was performed to remove the oxide film on the Be surface. Two types of interlayer, Cr/Cu and Ti/Cu, were formed to investigate the effect of interlayer type on the Be/CuCrZr joining properties. On the other hand, CuCrZr was cut into a block with a dimension of 50x50x30mm by an electro discharge machine. The joining surface of CuCrZr block was ground to have a roughness value (Ra) of less than 1 μm and cleaned in acetone.

Be and CuCrZr were assembled and canned with SS304 plate with a thickness of 1.5 mm by a TIG welding. The canned assemblies were degassed at 400^{o}C for 3 hr in a vacuum of less than 10^{-5} torr and then subjected to a HIP. In order to investigate the effect of HIP temperature on the joining strength, the HIP temperature was change from 580^{o}C to 620^{o}C while the pressure and time were constant as 100MPa and 2 hr, respectively.

The microstructure of the joining interface was observed by use of a scanning electron microscopy (SEM). The distribution of the alloying elements in the joining interface was investigated by an electron probe micro analyzer (EPMA) to examine the diffusion layer and intermetallic compounds formed by the HIP joining. The mechanical strength of the joining interface was measured by four-point bend test using the joint specimens with a joining interface at middle of the joint specimens.

3. Results and discussion

No intermetallic compounds and defects such as porosity and cracks were observed in the interface after a HIP in the joint sample was fabricated by a HIP at 580^{o}C, 100MPa and 2 hr. From the elemental distribution depicted in the micrograph, thin Cr interlayer with a thickness of 1 μm was clearly distinguished. This implies that the Cr layer effectively functioned as a diffusion barrier between Be and Cu to prevent from forming the intermetallic compounds. Cr peaks were also observed in the CuCrZr matrix, which was thought to originate from the Cr-containing precipitates. The microstructure of the joining interface was not significantly changed with an increase of HIP temperature from 580^{o}C to 620^{o}C.

As in the joint specimen with Cr/Cu interlayers, no intermetallic compounds and defects were observed in the interfaces of the joint specimen with Ti/Cu interlayers. It was reported that direct bonding of Be to Cu alloys at temperature as low as 350^{o}C to 400^{o}C is sufficient to form the intermetallic compounds of BeCu and Be_2Cu [5]. The application of diffusion barriers can isolate the Cu alloys from Be allowing higher joining temperatures to be used. In this study, Ti layer was effective as the diffusion barrier to prevent from forming the intermetallic compounds such as BeCu and Be_2Cu. Moreover, no diffusion layer was observed between Be and Ti. In the previous study for the Be/Cu aloys joint specimen with Ti interlayer HIPed at 850°C [3], several types of intermetallic layers, e.g., $TiBe_{12}$, $TiBe_2$, Ti_2Cu, TiCu with total thickness of about 50 μm have been observed between Be and Ti layer. In this study, however, no intermetallic compounds were observed in Be and Ti layer, which is attributable to lower HIP temperatures used in this study. However, it was found that a diffusion layer with a thickness of about 3 μm was formed between Ti and Cu layer after a HIP and it was slightly increased with an increase of HIP temperature from 580°C to 620°C.

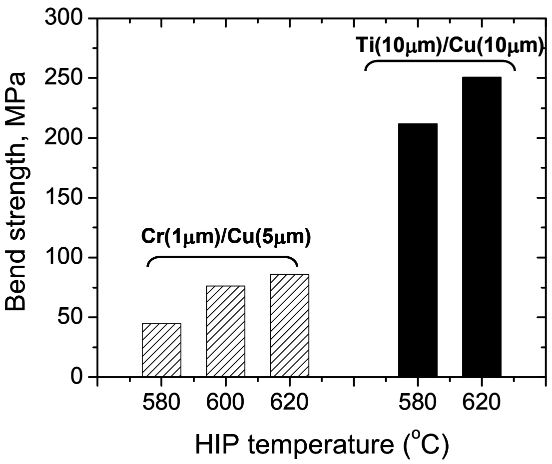

Figure 1. Four-point bend test result of Be/CuCrZr joint specimens.

Figure. 1 shows the result of four-point bend test of the Be/CuCrZr joint specimens. The joint specimens with Ti/Cu interlayers showed more than 2 times higher fracture strength in the four-point bend test irrespective of HIP temperatures. For the same interlayer, the bend strength was increased with increasing the HIP temperature.

In the previous result [3], the Be/Cu alloys joint specimen with a Ti interlayer which was manufactured by a HIP at 850°C showed the shear strength of 108MPa at room temperature and it had many types of intermetallic compounds in the interface. In this study, however, the shear strength of the joint specimen was slightly higher when compared to the previous one [3] even though the HIP was performed at lower temperatures from 580°C to 620°C. As mentioned before, the Be/CuCrZr joining interface has no intermetallic compounds in this study. Therefore, it is suggested that the beneficial effect obtained by increasing the HIP temperature could be compensated by formation of the brittle intermetallic compounds at the joining interface. Moreover, Cu layer which was coated on the diffusion barrier layer seems to be one of the reasons for a higher shear strength since it act as a compliant layer to absorb most of the stresses generated by the thermal expansion gradient between Be and Cu.

The fracture surface of the joint specimen was observed after the four-point bend test as well as the shear test. It was found from the fracture surface that the joint specimens with Ti/Cu interlayers was fractured mainly at the interface between Be and Ti by the four-point bend test. The specimen with Cr/Cu interlayers was also fractured mainly at Be/Cu interface after the four-point bend test. Although the fracture occurred at the interface between Be and adjacent diffusion barrier layers such as Ti and Cr, the Be/Ti interface was stronger than the Be/Cr interface in the four-point bend test when they are subjected to the identical HIP condition.

4. Conclusions

The effects of the interlayer type and the temperature have been investigated in order to optimize the HIP joining condition of Be to CuCrZr. Ti/Cu and Cr/Cu interlayers were coated on the Be surface before the HIP joining. HIP temperature was changed from 580°C to 620°C. No intermetallic compounds and defects were formed in the interface of the joint specimens. The joining strength measured by the four-point bend test was higher in the joint specimen with Ti/Cu interlayers when compared to that with Cr/Cu interalyers and increased with an increase of the HIP temperature from 580°C to 620°C.

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