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HIP joining of Be/FMS for the Development of the ITER TBM First Wall

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1. Introduction

The test blanket module (TBM) systems for the international thermonuclear experimental reactor (ITER) have been investigated with the aim to check on thier safety, reliability and compatibility under a nuclear fusion state, i.e., tritium production and recovery, high-grade heat generation and radiation shielding [1,2]. ITER participant teams are developing their own TBMs to be tested from a Day-1 operation of the ITER. Korea has also proposed a helium cooled molten lithium (HCML) and helium cooled solid breeder (HCSB) blanket [3].

One of the main issues about the R&D on the TBM is to develop the fabrication technologies for the TBM first wall. The TBM first wall is multilayer components consisting of plasma facing armor materials and structural materials. Beryllium (Be) and ferritic/ martensitic steel (FMS) are the primary candidate alloys for the armor and structural materials of the TBM, respectively [4,5]. For a successful fabrication of such complex components, the hot isostatic pressing (HIP) method has been considered as the most feasible method. In this study, Be and FMS were joined by HIP techniques, and several interlayer materials had been applied in order to manufacture high strength joints.

2. Experimental procedure

In this study, the structural material was chosen as FMS which was produced by KOUFU Co., LTD., Japan. Be, S-65C was selected as the armor material due to its lowest BeO and other impurity contents, and high ductility at an elevated temperature. The details of the chemical compositions are listed in Table 1.

For the HIP joining of Be/FMS, Be and FMS were machined in the form of a block with the dimensions of 50(W) x 10(t) x 50(L) mm and 50(W) x 25(t) x 50(L) mm, and then cleaned in ethyl alcohol using an ultrasonic cleaner, respectively. The interlayer was coated onto a Be surface by a physical vapor deposition (PVD) method after a chemical and ion etching which were performed to remove the oxide layer on the Be surface. The coated Be tiles and FMS blocks were assembled and encapsulated with 1.5 mm SS304 plates by a TIG welding method. The canister was out-gassed at 400℃ for 3hrs in a vacuum of less than 10^{-5} torr and then HIPed at 850℃, 100 MPa and 2 hrs.

In this study, two types of interlayer, Cr/Cu and Ti/Cu were coated to investigate the effect of an interlayer type on the Be/FMS joint properties. To evaluate the strength of the HIP bonded Be/FMS joints, a four-point bending and shear test were performed in accordance with the ITER recommendations for standard test methods [6]. The fracture surface of the tested specimens and the interface of the Be/FMS joints were observed by a scanning electron microscopy (SEM), an energy dispersive spectroscopy (EDS) and an auger electron spectroscopy (AES).

3. Results and discussions

In a previous result, in the case of using only a Cr or Ti interlayer, Be was diffused to the FMS side and a Be-Fe intermetallic compound was formed because of its high relativity and a thin coated interlayer (1-5㎛). The joints were broken at the Be-FMS diffusion layer and the fracture surface showed a very brittle morphology. Be, being chemically active, tends to form stable intermetallic compounds with almost every element in the Periodic Table [7]. These compounds are typically both strong and brittle; their presence in a bond joint can reduce the mechanical properties to unacceptably low levels of a ductility and toughness. Hence, the application of a soft interlayer is expected to act as a compliant layer between a coated interlayer and FMS. In this respect, Cu can be considered as a potential candidate to be used as an interlayer to further improve the joint quality. Because the melting point of Cu is lower with respect to Ti, Cr and Fe. So, an increase in the flow-ability of the same at a higher temperature will encourage a good contact between the joining surfaces. Therefore, in this study, Ti and Cr were selected as a diffusion barrier layer and Cu was selected as a compliant layer.

The HIP joined specimen with a Ti/Cu interlayer showed a higher bending strength (257 MPa) and shear strength (130.4 MPa) when compared with a Cr/Cu interlayer which showed a relatively low bending strength, 156 MPa. Fig. 1 and Fig. 2 show the auger line profiling of the HIP joined Be/FMS interface for the specimens applied with a Cr/Cu and a Ti/Cu interlayer, respectively. From these results, it was found that several diffusion layers were observed for the HIP processing temperature. In both cases, the coated Cu interlayer was diffused through the Cr or Ti interlayer, and then two different diffusion layers of about a 50-

Table 1. Chemical compositions of the Be and FMS used in this study (wt.%).

FMS										
Fe	Cr	W	V	Si	Mn	C	Ta	Mo	Nb	Others
Bal.	8.05	1.98	0.20	0.10	0.10	0.10	0.033	<0.01	<0.001	0.026 max

Be (S-65C VHP)						
Be	BeO	Fe	Al	Si	C	Others
Bal.	0.5	0.08	0.04	0.02	0.01	0.04 max

60 ㎛ thickness close to the Be side were formed by the inter-diffusion between Be and Cu. Also, a Be-FMS diffusion layer less then 10 ㎛ was observed on the FMS side. In the case of the Cr/Cu interlayer, the coated Cr interlayer was maintained as it stands due to its low reactivity. On the other hand, in the case of the Ti/Cu interlayer, a 10 ㎛ Be-Cu-Ti ternary layer was formed. The results of the fracture surface observation; the joint specimen with a Cr/Cu interlayer was mainly fractured at a Be-FMS diffusion layer. On the other hand, in the case of the Ti/Cu interlayer, the fracture was propagated at an interface between a Be-FMS diffusion layer and a complex Be-Cu-Ti-Fe diffusion layer. In the future, we need to analyze the microstructure of a joining interface and a fracture surface further.

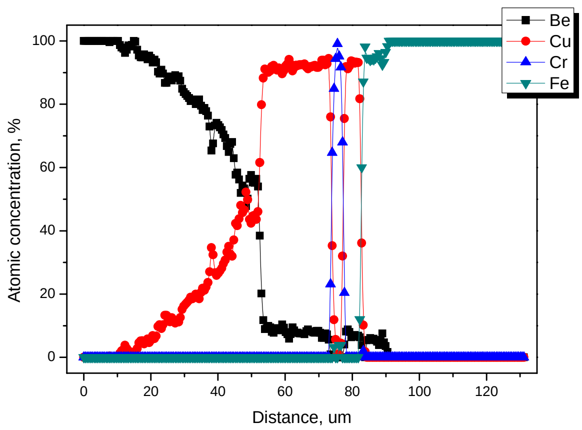

Fig. 1. Auger line profiles for the joint specimen with a Cr/Cu interlayer.

4. Conclusion

In this study, a Cu compliant interlayer was applied to further improve the Be/FMS joint quality. Be and FMS were joined successfully by the application of a Ti/Cu interlayer and a HIPing at 850℃, 100 MPa and 2hrs without a delamination of the Be/FMS joint interface. The four-point bend strength was a relatively high bending strength, 257 MPa, among the interlayer types studied. The joined interface showed very complex diffusion layers due to a relatively high HIP temperature and these diffusion layers acted as a beneficial effect which could be compensated for by the formation of a brittle Be-FMS intermetallic compound.

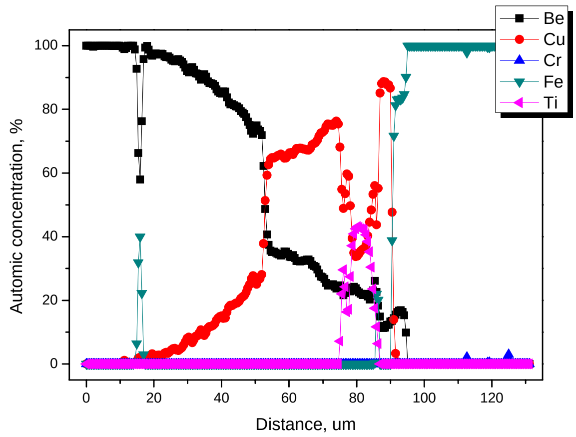

Fig. 2. Auger line profiles for the joint specimen with a Ti/Cu interlayer.

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