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Development of Joining Technology for KO TBM

Yang-Il Jung [*a], Jeong-Yong Park [a], Jung-Suk Lee [a], Byoung-Kwon Choi [a], Yong-Hwan Jeong [a], Bong-Guen Hong [b]
[a]*Fusion Technology Division, Korea Atomic Energy Research Institute,*
1045 Daedeok-dearo, Yuseong, Daejeon, 305-353, Republic of Korea
[b]*Fusion Engineering Division, Korea Atomic Energy Research Institute,*
1045 Daedeok-dearo, Yuseong, Daejeon, 305-353, Republic of Korea
[*]*Corresponding author: yijung@kaeri.re.kr*

1. Introduction

TBM(Test Blanket Module) is introduced to test the feasibility and practicability of the design concepts of tritium breeding high temperature blankets relevant to a future fusion power reactor, especially the next step beyond ITER DEMO. Materials for TBM are categorized into five parts: armor material, structural material, tritium breeding material, neutron multiplier, and coolant material. Table I demonstrates the materials briefly. In Korea, two types of TBM, i.e. He cooled solid breeder (HCSB) and He cooled molten Li Breeder (HCML), are considered [1]. For the fabrication of TBM, the joining technology for Be (as an armor material) and ferritic-martensitic steel (as an structural material) is also developing by the Korea Atomic Energy Research Institute.

In this paper, the joining of Be with FMS will be presented. The Be and FMS joined successfully by adopting (i) coating of a compliant layer, and (ii) diffusion barrier. The effect of the interlayer properties will be discussed in view of the diffusion and proper bonding strength.

Table I: Typical materials considered for TBM

Parts	Materials
Armor	Be, W
Structural material	FMS (ferritic-martensitic steel), ODS steel, Vanadium alloy, SiC_f/SiC composite
Tritium breeding	Solid type: Li, Li_2O, Li_4SiO_4, Li_4TiO_3 Liquid type:Pb–17Li, molten salts
Nuetron multiplier	Be, $Be_{12}Ti$ Pb–17Li
Coolant	He, water, Pb–17Li, molten slats

2. Methods and Results

The chemical compositions for the FMS were 8.05 wt% Cr, 1.98 wt% W, 0.20 wt% V, 0.10 wt% Si, 0.10 wt% Mn, 0.10 wt% C, 0.033 wt% Ta, and contained other several impurities. The used Be tiles (S-65C VHP, brushwellman engineered materials) were vacuum hot pressed and then cut perpendicular to the pressure direction. The Be tiles were coated with Cr, Ti, or Cu by physical vapor deposition to form interlayer for the diffusional bonding with FMS, as well as to prevent the oxidation of Be surface. FMS and coated Be were canned and then degassed to 10^{-5} torr of vacumm level. The canned materials are placed into the hot isostatic pressure (HIP) furnace. HIP was conducted at 600–750°C and 100–150 MPa for 2 h with the heating rate of 4°C/min and the furnace cooling. Because the mechanical properties of FMS are very sensitive to heat-treatment temperature, the HIP was carried out at 600–750°C retaining proper mechanical strength.

The destructive test was done by 4-point bend test. Be/FMS specimens with the dimension of 4 x 4 x 20 mm were machined from the HIPped joint. For the test, compressive stress with constant strain rate of 0.5 mm/min was applied.

2.1 Effect of the Interlayer Coating

Cr or Ti interlayer was coated on Be surface to investigate the effect of interlayer types. Both the cases of 1.5 μm Cr and 1.5 μm Ti interlayer were not able to join the Be with FMS. Excessive diffusion of Be atoms across the interlayer was detected in the samples, and brittle fracture at the FMS side was also observed. Even the thick 10 μm Ti interlayer cannot avoid the brittle fracture. However, there was absence of Be diffusion into FMS side in the case of thick interlayer – the failure occurred at the Ti interlayer region. For bonding the Be/FMS joint, diffusion of joining materials should be occurred; however, excessive diffusion of Be must be prevented since Be easily forms brittle intermetallic compounds [2].

Cu interlayer was adopted to increase flowability and to compensate the brittleness of the Be intermetallics. Figure 1 shows the microstructure of the Be/FMS joint with the Cr/Cu interlayer. Cr was coated 3 μm in thickness on Be surface, and then Cu was coated 10 μm in thickness. As shown in Fig. 1, there are four kinds of diffusion layers: Be-Cu inter-diffusion layer, Cu-rich layer, Cr layer, Be-FMS diffusion layer. When the joint is bend tested, the fracture is observed at the FMS side where the Be diffusion appeared. The 4-point bend strength was 156 MPa in average.

The Ti/Cu interlayer was also investigated with the 5 μm Ti and 10 μm Cu coating. In the case of Ti/Cu interlayer, as shown in Fig. 2, diffusion of Fe atoms in FMS was occurred, and Ti and Cu interlayer materials were completely mixed. The fracture after 4-point bend test took place at the FMS side where Be diffusion happened. On the contrary to the Cr/Cu interlayer, the fractured surface was formed as an irregular shape, and revealed higher strength of 257 MPa.

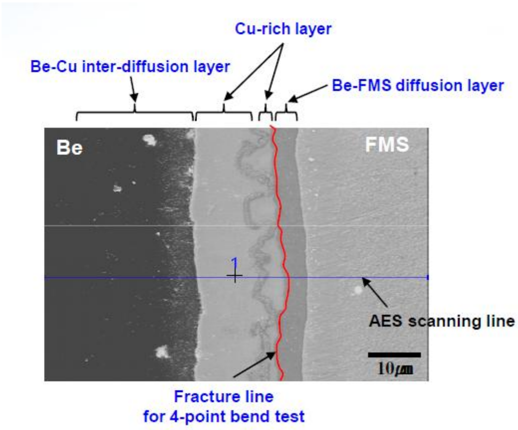

Fig. 1. SEM micrograph showing the Be/FMS joint with Cr/Cu interlayer.

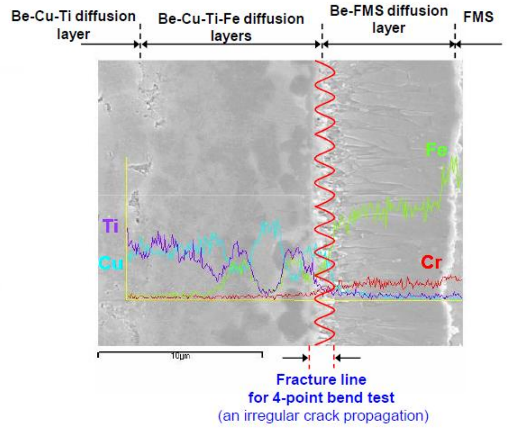

Fig. 2. SEM micrograph showing the Be/FMS joint with Ti/Cu interlayer.

2.2 Effect of Diffusion Barrier

Cu and Fe films were introduced to reduce the excessive diffusion of Be, and thus to avoid brittle fracture of the FMS. Figure 3 shows the microstructures of the HIP joined Be/FMS using 10 μm of inter-laid Cu film and 2 μm of Cr coated interlayer. The lines in the figure show the elemental distribution of Cu, Cr, and Fe. The Cu atoms in film passed through the Cr layer into the Be side. However, no brittle fracture was observed. The fractured surface after the 4-point bend test showed the fracture occurred at the Cu interlayer. In the case of Fe films, the joining of Be/FMS was possible without the brittle fracture of the joint.

The 4-point bend strength was 158 MPa for the Cu film joint, and 219 MPa for the Fe film joint. For the same HIP conditions, it was not able to bond the Be/FMS joint by using conventional coating method. As a diffusion barrier, Cu film as well as Fe film works successfully, still the diffusion occurs though. The introduction of film enabled to retard Be diffusion more effectively than conventional coating.

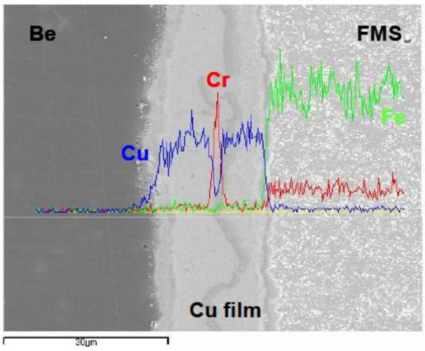

Fig. 3. SEM micrograph showing the Be/FMS joint with Cr/Cu(film) interlayer.

3. Conclusions

The effects of the interlayer types on the bonding strength were investigated. It was found that there is a proper combination of the interlayers to prevent an excessive diffusion of Be. The Cu compliant layer enabled to join the Be and FMS without brittle fracture of the Be/FMS joint. In addition, the diffusion barriers of the Cu and Fe films resulted in a successful joining of the Be/FMS by suppressing the inter-diffusion of Be and the interlayer materials.

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