4.3 Manufacturing Study of Beryllium Bonded Structures

M. Onozuka, S. Hirai, K. Kikuchi, Y. Oda, and K. Shimizu

Mitsubishi Heavy Industries, Ltd.
Nuclear Systems Engineering Department
Minatomirai 3-3-1, Nishi-ku, Yokohama 220-8401 Japan

A manufacturing study has been conducted on Be-bonded structures employed in the first- wall panel of the blanket system for the ITER. For Be tiles bonded to the Cu-Cr-Zr alloy heat sink with stainless-steel cooling pipes, a one-axis hot press with two heating processes has been used to bond the three materials. First, Cu-alloy and SS materials are bonded diffusively. Then, Be tiles are bonded to the pre-bonded structure under 20 MPa and at 560°C. An Al-Si base interlayer has been used to bond Be to the Cu-alloy. The heating processes have been selected to match the required heat treatment conditions for the Cu-alloy. Because of the limited heat processes using a conventional hot press, the manufacturing cost can be minimized. Using the above bonding techniques, a partial mockup of a blanket first-wall panel with 16 Be tiles (with 50 mm in size) has been successfully manufactured.

1. INTRODUCTION

For the International Thermonuclear Experimental Reactor (ITER), beryllium (Be) has been selected as a plasma-facing material for the blanket system. This material is structurally bonded to the actively cooled components to provide high heat removal capability. Various bonding techniques have been considered, including Hot Isostatic Pressing (HIP), diffusion bonding, and brazing. One of the key issues regarding bonding is to ensure the reliability of the plasma facing components, while staying within reasonable manufacturing costs.

Most previous efforts have focused primarily on joining Be to dispersion-strengthened copper (DSCu) materials [2]. However, Cu-Cr-Zr alloy has been the preferred material in the ITER design, because of its lower cost, higher fracture toughness, and better irradiation resistance.

This study has been conducted to optimize the manufacturing process for joining Be to the heat sinks or actively cooled components, which are made of Cu-Cr-Zr alloy (hereafter, referred to as Cu-alloy) [3]. Careful consideration was given to minimizing fabrication costs. Some results of this study are presented.

2. MATERIALS AND BONDED STRUCTURE

Figure 1 illustrates the first-wall panels of the ITER blanket module. The first-wall panels consist of Be (Be:>99%) tiles, Cu-alloy heat sink, and a stainless-steel (SS316L) structural block [1]. SS cooling pipes are integrated in the Cu-alloy heat sink and SS block. Those parts are structurally bonded to form the first-wall panel. As mentioned above, Cu-Cr-Zr alloy (Cu:remaining, Cr:0.6-0.8%, Zr:0.07-0.15%, O:<0.001%, other impurities:<0.05%) is the preferred heat sink material for ITER. However, to maintain its mechanical properties, this Cu-alloy requires adequate heat treatment, i.e. solution annealing and aging. Based on the material survey of the Cu-alloy, it was found that the optimal

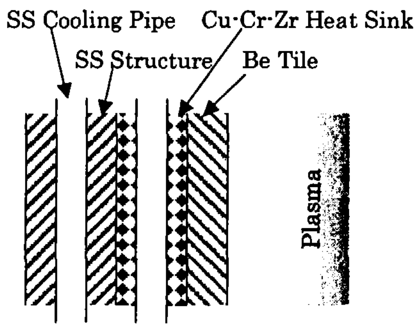


Figure 1. Material composition of first wall panel.

temperatures for solution annealing and aging were 980°C and 475°C, respectively. The effect of the aging-temperature increase has been also examined. Figure 2 shows the results [3]. Both the tensile strength and 0.2% yield strength are presented. The annealing temperature was kept at 980°C. As shown in the figure, the aging temperature can be increased up to 600°C, with a modest reduction of 15% in the mechanical strength. These heating conditions will be used for the bonding processes.

The three materials must be bonded to handle a peak heat flux of 0.5 MW/m2. For ITER, the HIP technique has been closely considered for bonding [2]. This method generally provides reliable structural integrity, i.e. reliable joining properties. However, because of the complex preparation required prior to the HIP process and machining after the HIP, as well as the limited number of available HIP facilities, the manufacturing cost is an issue.

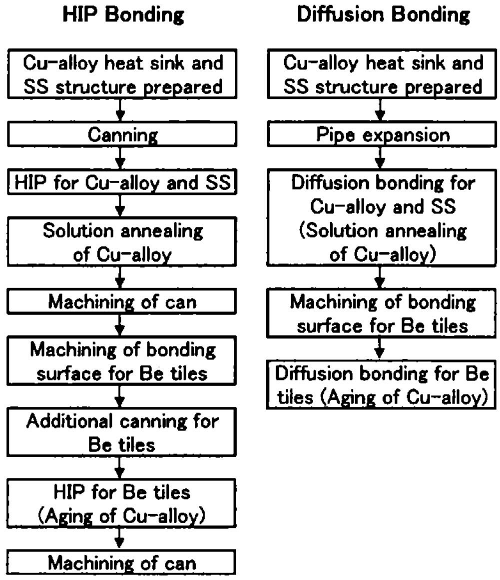


Figure 3. Comparison of bonding techniques.

3. HOT PRESS BONDING TECHNIQUE

In this study, a one-axis hot pressing method, which requires a limited number of heat processes, has been chosen to diffusively bond the three materials. The comparison between the HIP and hot-pressing method for the fabrication of the first-wall panels is summarized in Figure 3. The HIP requires three heating processes: HIP for the Cu-alloy and SS material, solution annealing for the Cu-alloy and SS, and HIP for Be tiles. The proposed hot-pressing technique, on the other hand, requires two heating processes. The heating conditions for hot pressing have been selected to match the heating treatment conditions required for the Cu-alloy, as obtained in the above. In addition, diffusion bonding does not require any canning and removal of the canning by machining, which are necessary for the case of HIP. Furthermore, unlike HIP, since hot pressing is a conventional method and has been widely used for industrial applications, more facilities are available for diffusion bonding than HIP. Therefore, it is considered that the manufacturing costs using the proposed process would be less than that for HIP.

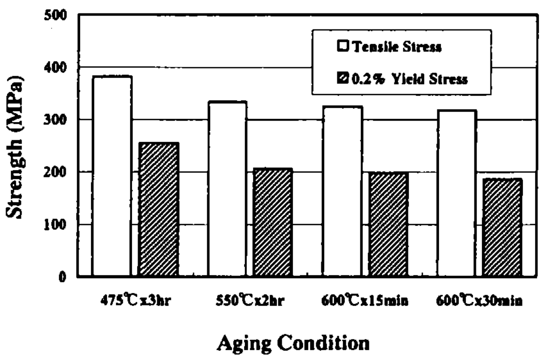


Figure 2. Effect of aging conditions on the mechanical properties for Cu-alloy.

4. BERYLLIUM BONDING TEST

The bonding conditions for Be and Cu-alloy using a hot press, with consideration given to the aging process of Cu-alloy, have been studied in order to obtain a bonded strength that is comparable to that obtained using HIP. To avoid direct interaction (i.e. eutectic reaction) between Be and Cu, an interlayer has been used between the two elements [2]. Several materials were considered for the interlayer. From them, aluminum (Al) and silicon (Si) elements have been selected, because they do not form intermetallic compounds with Be.

Bonding tests were conducted to examine various types of interlayers based on Al and Si. Test specimens were fabricated for mechanical testing. Figure 4 depicts a test specimen and apparatus used for mechanical testing. A circular plate of Be, measuring 20 mm in diameter and 1.5 mm in thickness, was bonded to a Cu-alloy ring to make a test sample. Bonded strength was then evaluated by the pushing force applied to the push rod to punch out the Be tile. A photograph of one of the test specimens is shown in Figure 5.

The results of the mechanical tests are summarized in Figure 6 [3]. In this figure, the bonded strength relative to that for HIP is shown. Reference samples were fabricated for HIP under the applied pressure of 140 MPa and at a temperature of 595°C for two hours. While further optimization is required, it was found that by using an Al-Si base interlayer (50 micrometers thick) and preconditioning the Cu-alloy surface with Ni-plating (up to 20 micrometers thick), Be and Cu-alloy were successfully bonded diffusively by a hot press under a pressure of 20 MPa and at a temperature of 560°C, which is around the optimal aging temperature of Cu-alloy. The achieved bonded strength was 80% of that obtained using HIP. It is noted that the strength for HIP is close to that of Be. The microstructures of the Be and Cu-alloy bonded region for the cases of HIP and diffusion bonding are shown in Table 1. As shown in the table, the Al-Si interlayer and Ni plated layer were observed for the diffusion bonded microstructure.

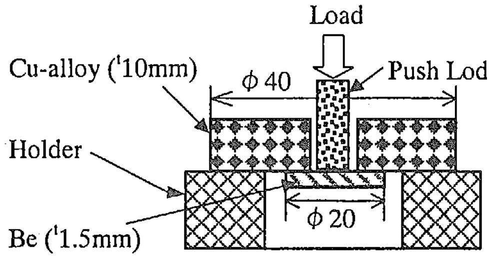


Figure 4. Mechanical testing and its test specimen.

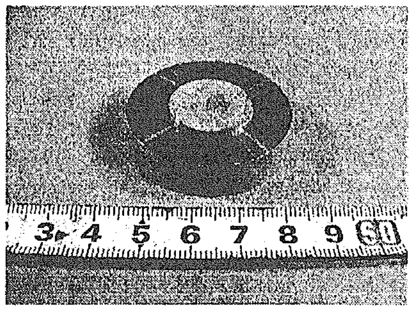


Figure 5. Photograph of mechanical test specimen.

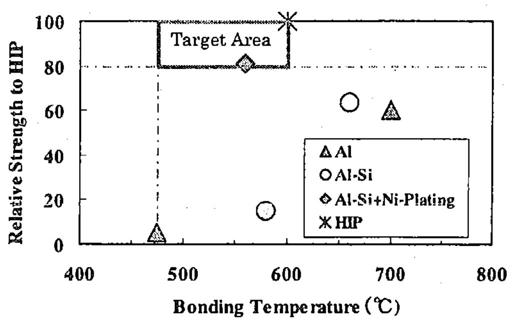
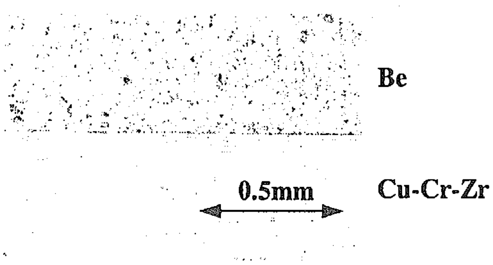
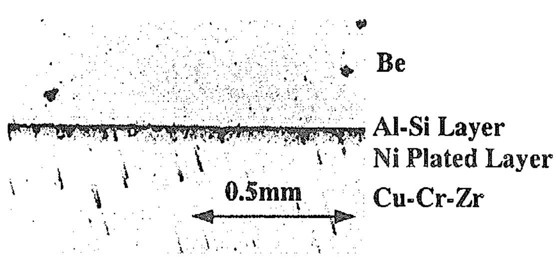


Figure 6. Bonded strength of the Be and Cu-alloy. (Relative strength for the case of HIP)

Table 1
Microstructures of bonded region between Be and Cu-alloy.

HIP bonded	Hot press bonded
	

5. HEAT SINK FABRICATION

In addition to the diffusion bonding between Be and Cu-alloy, one-axis hot pressing has been applied to the complex structure of the heat sink, which consists of a Cu-alloy heat sink, SS bent pipe, and SS structural block. A pipe expansion technique has also been applied to provide for adequate joining properties between the pipe and the heat sink. Hot pressing was conducted at 980°C, which is the solution annealing temperature of the Cu-alloy. A test sample was fabricated and examined. Figure 7 shows the cross-section of the tested sample and the microstructure of the bonded regions [3]. The bonded structures appear to be sound.

6. PARTIAL MOCKUP FABRICATION

Using the above bonding techniques, a partial mockup of a blanket first-wall panel has been successfully manufactured. First, Cu-alloy heat sink and four sets of SS316L pipes with both ends bent and a SS316L structural block are bonded diffusively by a hot press at 980°C. Next, 16 Be tiles, measuring 50 mm in width and 10 mm in thickness, are bonded diffusively to the pre-bonded structure by a hot press under the maximum pressure of 20 MPa and at 560°C. Figure 8 shows a schematic view of the mockup and photos of the completed mockup and assembled component [3]. As shown, the Be tiles in several inclined angles to the heat sink were successfully bonded using one-axis hot pressing with appropriate fixtures. Because of the limited heat processes using a conventional one-axis hot press, the manufacturing cost can be minimized.

7. FUTURE WORK

In this study, a cost-saving method for manufacturing the first-wall panel has been investigated and revealed encouraging results. However, to ensure the applicability of the method, additional high heat-flux testing of the bonded structures is required.

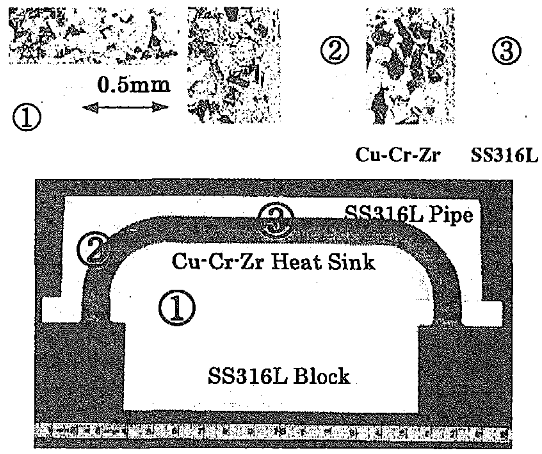


Figure 7. Cross-section of heat sink test sample and microstructures of Cu-alloy and SS316L bonded region.

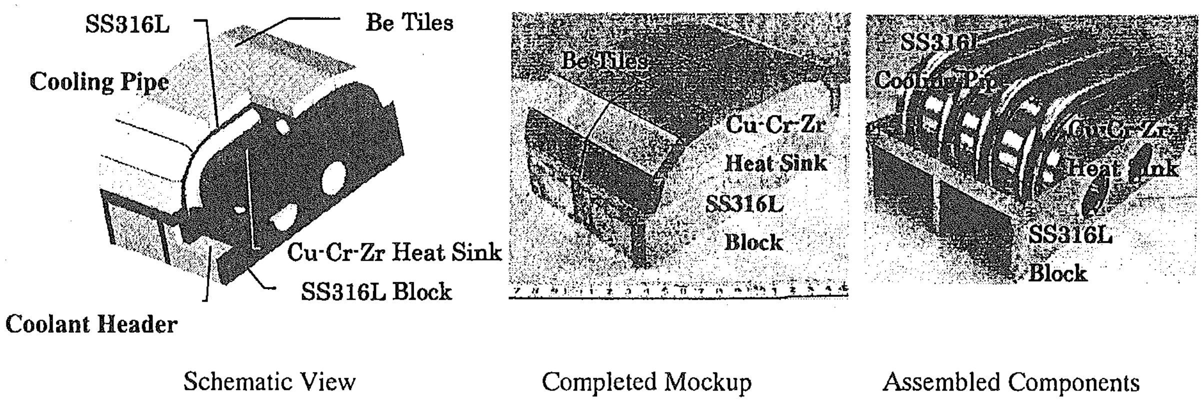


Figure 8. First-wall panel mockup.

8. CONCLUSIONS

A manufacturing study has been conducted to reduce the manufacturing cost of the Be bonded structures used in the first-wall panel of the ITER blanket. For Be tiles bonded to the Cu-alloy heat sink with SS cooling pipes, a one-axis hot press with two heating processes has been applied to bond the three materials. Cu-alloy and SS materials are bonded diffusively by a hot press at 980°C, which is the solution annealing temperature of the Cu-alloy. Then, Be tiles are bonded diffusively to the pre-bonded structure by a hot press under 20 MPa and at 560°C, which is the aging temperature of the Cu-alloy. An Al-Si base interlayer has been used to bond Be to the Cu-alloy. The heating processes have been selected to ensure that the mechanical characteristics of the Cu-alloy are not degraded. Because of the limited heat processes employed in the use of a conventional one-axis hot press, the manufacturing cost can be minimized. Using the above bonding technique, a partial mock-up of a blanket first-wall panel has been manufactured. The mock-up has 16 Be tiles, which are approximately 50 mm in size. The actively cooled component consists of a Cu-alloy heat sink, a SS block and four sets of SS cooling pipes. The above bonding technique has been successfully applied to the partial mock-up.

ACKNOWLEDGEMENT

The authors would like to express their gratitude to Dr. V. Barabash of the ITER International Team and Dr. M. Enoeda of JAERI for their valuable input.

REFERENCES

[1] ITER Technical Basis, ITER EDA Documentation Series No. 24, IAEA, Vienna, 2002.
[2] V. Barabash, et al. Armor and heat sink materials joining technologies development for ITER plasma facing components, J. Nucl. Mater. 283-263 (2000) 1248.
[3] M. Onozuka, et al. Manufacturing Study of Be, W and CFC Bonded Structures for Plasma Facing Components, presented at 11th International Conference on Fusion Reactor Materials, Kyoto, Japan, December 7-12, 2003.