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Heat load test of beryllium and CuCrZr joints

H. Yamada [a,*], M. Uchida [a], M. Uda [b], T. Iwadachi [b], M. Nakamichi [a], H. Kawamura [c]

[a] *Department of Japan Material Test Reactor, Oarai Research Establishment, Japan Atomic Energy Research Institute, 3607 Narita-cho, Oarai-machi, Higashi-Ibaraki-gun, Ibaraki-ken 311-1394, Japan*
[b] *Engineering Department, New Metal Division, NGK Insulators, Ltd., Maegata-cho, Handa-shi, Aichi-ken 475-0825, Japan*
[c] *Naka Fusion Research Establishment, Japan Atomic Energy Research Institute, Naka-machi, Naka-gun, Ibaraki-ken 311-0193, Japan*

Abstract

An improved bonding method by a hot isostatic pressing (HIP) with an interlayer has been developed as the joining technology of Be/CuCrZr that is a candidate material of ITER first wall. In this study, the heat load tests for the HIP joints were carried out for evaluation of the heat removal performance and the durability of these HIP joints. Result of the tests showed an approximately linear relationship between the heat flux and the temperature at the surface of all types mock-ups. The heat removal performances of these improved joints were similar to those of conventional Be/DSCu joints. After the heat load tests, the boundaries of HIP joint were observed by scanning electron microscopy and no crack nor detachment was detected. On the other hand, the surface temperatures of all type mock-ups increase slightly with increasing the cycle number of the heat load.

1. Introduction

In International Thermonuclear Experimental Reactor (ITER), beryllium (Be) and copper alloy (CuCrZr) have been selected as candidate materials for armor and the heat sink. Be and the copper alloy are joined by hot isostatic pressing (HIP) method, and the HIP condition for the first wall of the ITER blanket has been developed as the joint technology for fabrication of the ITER blanket [1–3]. However, the joining of Be and CuCrZr is difficult due to different thermal expansion of each material and the residual stress. From viewpoints of Be recycling and fabrication of sound joints, improved HIP joint methods (with a new interlayer or a lower HIP temperature) have been proposed and mock-ups were fabricated in these methods [4]. The first wall of the ITER will be exposed to a severe heat load from the plasma, therefore one of the essential issues is the development of a bonding technology between the Be and copper heat sink to withstand the loading conditions.

In the present study, heat load tests of the mock-ups were performed with OHBIS (Oarai hot-cell electron beam irradiation system) at Oarai Research Establishment of Japan Atomic Energy Research Institute (JAERI). And the heat removal performances were evaluated using Be/CuCrZr joint mock-ups fabricated by the improved joint methods.

2. Experimental procedure

2.1. Mock-ups for heat load tests

Hot press Be (S65C) and CuCrZr alloy were used as the armor material and the heat sink material, respectively. Chemical compositions of S65C and CuCrZr are shown in Table 1. These materials were bonded by HIP methods. The HIP conditions are shown in Table 2. Three types (type-A, type-B and type-C) of mock-ups

* Corresponding author. Tel.: +81-29 264 8369; fax: +81-29 264 8481.
E-mail address: yamada@oarai.jaeri.go.jp (H. Yamada).

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Table 1
Chemical composition of material

Part	Material	Chemical composition (wt%)
Armor	S65C	Be:99.5
Heat sink	CuCrZr	Cr:0.8, Zr:0.07, Cu:Bal.

Table 2
HIP joint condition

Joint type	HIP temperature (°C)	Interlayer material (thickness)
Type-A	610	Cr(1 μm)/Cu(10 μm)
Type-B	520	Cr(1 μm)/Cu(10 μm)
Type-C	520	BA4004[a]/Al(10 μm)/ Cr(1 μm)

[a] BA4004: Si:10.3 wt%, Mg:1.6 wt%, Al:Bal.

were fabricated for heat load tests in the present study by NGK insulators, Ltd. The HIP pressure for all type mock-ups was 150 MPa and the holding time was 1 h.

The HIP condition for type-A is the established condition for joining S65C and CuCrZr [5]. The HIP temperature for type-B is lower than that for type-A. The effect of HIP temperature on the thermal properties was estimated in this study. The HIP condition for type-C is an advanced condition for beryllium recycling. The interlayer material of type-A and type-B was the same, and it was a Cr film. However, the interlayer of type-C was an Al and Cr film. Therefore, it is considered that the beryllium of type-C will be more easily removed from CuCrZr than the other types of mock-up, because the melting temperature of the type-C interlayer is lower. The mock-up of beryllium and CuCrZr HIP joints for heat removal tests are shown in Fig. 1.

2.2. Facility for heat load tests

The temperature at the bonding boundary between beryllium and CuCrZr was measured by a thermocouple. The temperatures at the Be surfaces were measured by an infrared camera. An outline of heat load test facility is shown in Fig. 2. Mock-ups are cooled by pure water (electric conductivity: <1 μS/cm, volume flow rate: 11 m^3/s, temperature: 35 °C), and the vacuum chamber was evacuated (about 3×10^{-3} Pa) during the heat load tests.

2.3. Heat load tests

In this study, heat removal performances and durability for thermal cycle were evaluated. Condition of heat load test is shown in Table 3. Heat removal property was evaluated by the temperature change at joint boundary of Be and CuCrZr as a function of time, durability for thermal cycle was evaluated by the change of temperature at different locations as a function of heat load.

3. Results and discussion

3.1. Comparison between type-A mock-ups and type-B mock-ups

The temperatures at the three types mock-ups are shown in Fig. 3. Trend of these temperatures were similar. Results of the heat removal performance tests are shown in Fig. 4. The temperatures of Be and CuCrZr for all type mock-ups increased approximately linearly with the heat load power and it is similar to the case of S65C/DSCuAl-25 mock-ups [5].

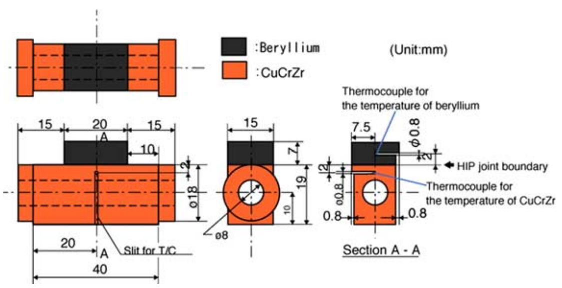

Fig. 1. Specimen of Be/CuCrZr.

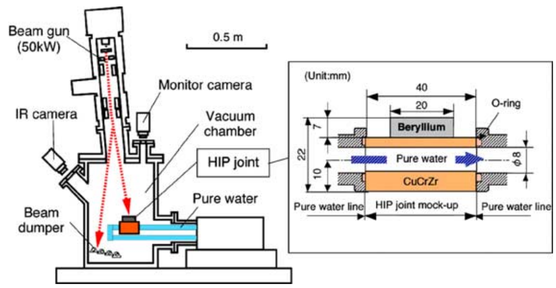

Fig. 2. Outline of heat load test apparatus, OHBIS.

Table 3
Conditions of heat load tests

Test	Heat load (MW)	Cycle	Load period (s)	Interval period (s)
Heat removal test	0.5–5	1	15	–
Thermal cycle test	5	1000	15	15

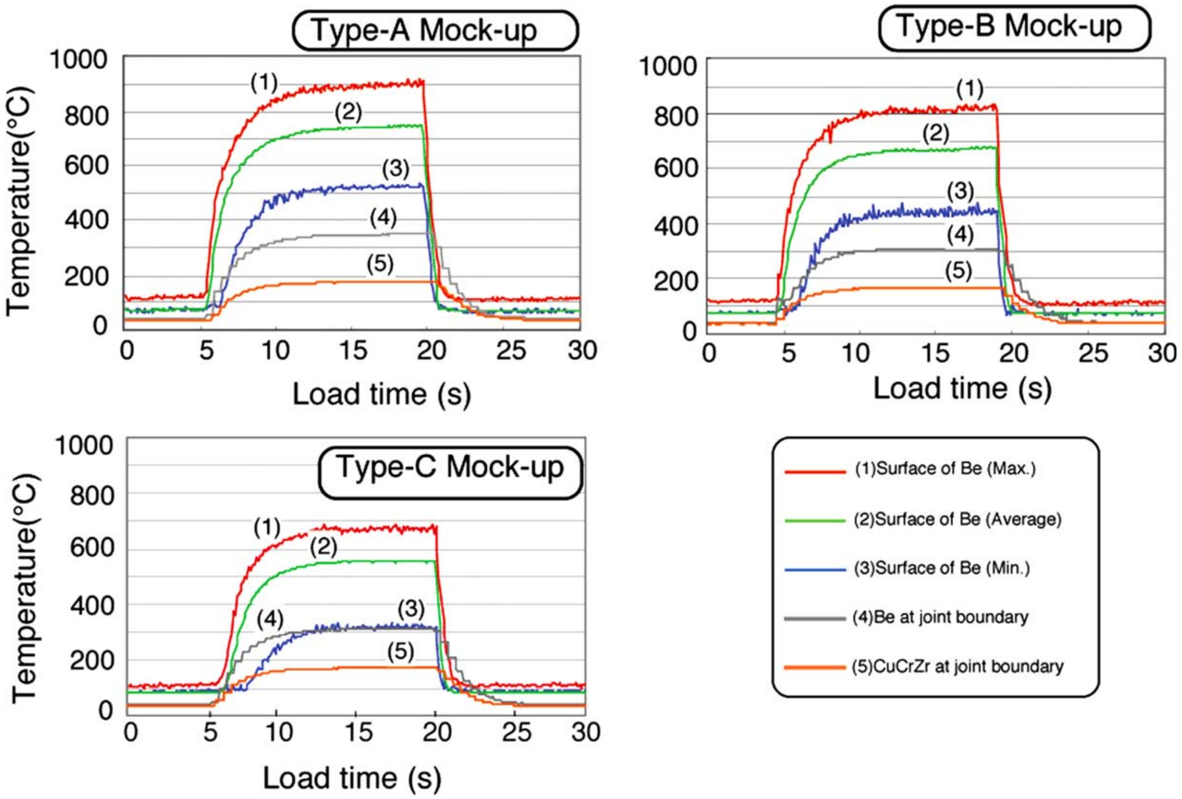

Fig. 3. Temperature trend of mock-ups in heat load tests.

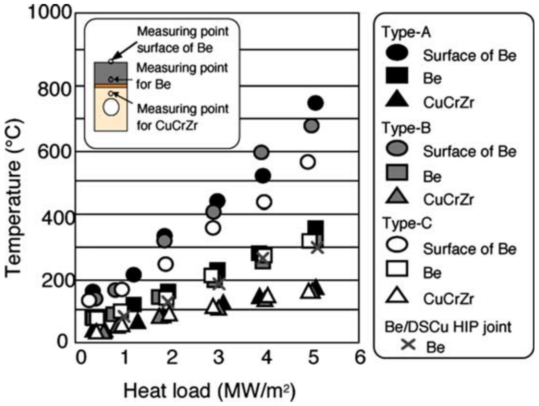

Fig. 4. Results of heat removal tests for type-A, type-B and type-C joints.

It also shows that heat removal performances of type-A and type-B mock-ups are almost the same. However, the temperature at heat load surface, type-A mock-ups was 10% higher than that of type-B mock-ups. It is considered that the precipitate condition of Cr, Zr in CuCrZr changed in the HIP joint procedure and that correspondingly the thermal conductivity of CuCrZr changed. As for an age hardening type alloy like CuCrZr, thermal conductivity is the lowest generally after the quenching, and improves as prescription the process. It is considered that Cr was made solution to the matrix of copper after precipitation in this temperature range. Therefore, the change in thermal conductivity of CuCrZr was cause by the differenced HIP temperature.

The results of the durability test are shown in Fig. 5. Temperatures at Be and CuCrZr did not change by the number of the heat load cycles for both types of mock-ups. The results also indicate that type-A and type-B mock-ups have similar durability to the thermal cycles.

In the thermal cycle test, beryllium surface temperature of type-A mock-up was higher than that of type-B mock-up and both temperature increased with the thermal cycle number. But, However the temperature of Cu and Cr part on both types mock-ups did not change gradually with the heat load cycle. It is considered that surface radiation rate varied by heat load and temperature of the mock-up.

After thermal cycle test, no crack or detachment was observed by scanning electron microscopy (SEM) for these mock-ups. Thus it is indicated that rigid joints can be fabricated by HIP condition for both type-A and type-B, and that integrity of these joints was kept in the 1000-cycle heat load tests.

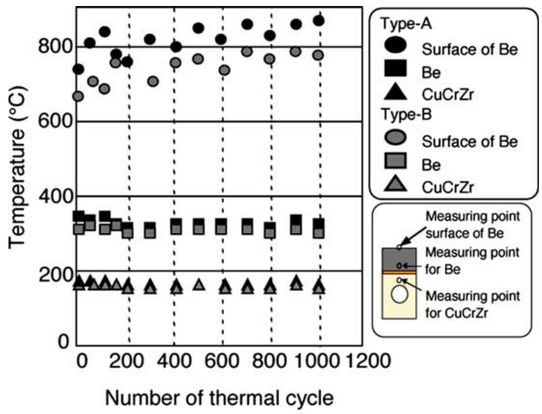

Fig. 5. Results of thermal cycle tests for type-A, type-B and type-C joints.

3.2. *Type-C mock-ups*

The heat removal property of type-C mock-up is shown in Fig. 4. The temperature at the Be surface on type-C mock-up was lower than those of the other mock-ups. This result suggests that joint state are improved by the interlayer (Al, Cr) of type-C mock-up and that the thermal conductivity of the type-C mock-up HIP joint was higher than the HIP joints of type-A and type-B.

4. Conclusion

Three types (type-A, type-B and type-C) of mock-ups were fabricated by the HIP methods.

The following were clarified from the present heat road tests.

- The approximately linear relationship was observed between the heat load power and the surface temperature of all these types of mock-ups.
- At heat removal test, surface temperature of Be at type-C mock-up was lower than that of the other mock-ups. At thermal cycle test, surface temperature of Be at type-B mock-up was lower than that of type-A mock-up. Therefore, heat removal property of type-B and type-C mock-ups was better than that of type-A joints and conventional Be/DSCu mock-up. This result is considered to be due to the increase in the thermal conductivity from the improved HIP condition.

This study clarified that improved HIP condition can be used and the results show that lower HIP temperature makes higher thermal conductivity of CuCrZr, heat removal property of the HIP joint can be improved. Furthermore, HIP condition using Al interlayer is better than the HIP condition using Cr interlayer, as indicated by better heat removal property of type-C HIP joint than type-A and type-B joint.

It is considered that Be/CuCrZr joints by improved HIP procedure can be able to apply to the shielding blanket under the heat load condition of ITER.

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