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High Heat Flux Test with 80x80x1 Be/Cu/SS Mock-ups for the ITER Blanket First Wall

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1. Introduction

The first wall (FW) of the International Thermonuclear Experimental Reactor (ITER) is an important component which faces the plasma directly and therefore, it is subjected to high heat and neutron loads. The FW is composed of a beryllium (Be) layer as a plasma facing material, a copper alloy (CuCrZr) layer as a heat sink and type 316L authentic stainless steel (SS316L) as a structure material. To fabricate the FW, the Hot Isostatic Pressing (HIP) bonding method has been investigated. Surface heat flux of the FW is about 0.3 MW/m^2 and the volumetric heating in the FW is in the order of 15-20 MW/m^3 due to a neutron wall loading [1]. To investigate the thermo-mechanical performance of the FW, including the integrity of the HIP bonded interfaces, high heat flux (HHF) tests are essential. This work has three steps; Cu/SS mock-ups test at JEBIS (JAEA electron beam irradiation stand), Be/Cu mock-ups test in the TSEFEY-M facility (Russia), and Be/Cu/SS mock-ups test in JUDITH-1 (Germany). Some test results such as for the Cu/SS mock-ups and 50x50x1 Be/Cu mock-ups have already been introduced [2, 3] and other tests are being prepared through a preliminary analysis to determine the test conditions and mock-ups are being designed and fabricated. In the present study, the test procedure and results are introduced for the 80x80x1 Be/Cu/SS mock-ups tested with the JUDITH-1 at FZJ in Germany among them.

2. Preparation of the 80x80x1 Be/Cu/SS mock-ups

The optimum joining condition of a HIP for the ITER FW has been developed by using Be of S-65C grade, CuCrZr, and SS316L. Here, CuCrZr/SS316L (tube and block) and Be/CuCrZr including SS316L tube mock-ups were fabricated to investigate their integrity through several tests. They were successfully HIPped at 550 ^{O}C, 100 MPa, and 2 hour for Be/CuCrZr and at 1050 ^{O}C, 100 MPa, and 2 hours for CuCrZr/SS316L [4].

In the present study, Be/CuCrZr mock-ups were fabricated to investigate their integrity for their joining parts, especially for their interlayer effect. Three kinds of mock-ups were fabricated according to the interlayer at the Be and Cu interface; Cr/Cu, Ti/Cr/Cu, and Ti/Cu, which are the secondary interlayers for a Be/Cu HIPping. They were successfully HIPped at 580 ^{o}C, 100 MPa, and 2 hours as shown in table 1. In order to be installed in the facility, two manifolds were fabricated with the tubes. Dimensions of the mock-ups were 80 mm long, 80 mm wide and 74 mm thick (10 mm of Be tile, 25 mm of Cu block, 49 mm of SS block) with two cooling tubes in the Cu block and with two cooling holes in the SS block. Two thermocouples were installed to measure the temperature in a mock-up according to a certain distance from the heat source. Figure 1 shows the schematic and the fabricated mock-ups. Ultrasonic test to find defect in the interfaces were performed but there is no defect. He leak test were performed to find a leakage and then some of them were rewelded when there is a leakage. Finally, manifolds were welded to be installed at JUDITH-1 as shown in figure 2.

Table 1 Fabrication conditions for the 80x80x1 Be/Cu/SS mock-ups

Mockup ID	HIP condition of CuCrZr/SS316	Interlayer between Be and CuCrZr	HIP condition of Be/CuCrZr
1	1050C / 100MPa / 2hr	Cr(1㎛)/Ti(1㎛)/Cu(10㎛)	580C / 100MPa / 2hr
2	1050C / 100MPa / 2hr	Cr(1㎛)/Ti(1㎛)/Cu(10㎛)	580C / 100MPa / 2hr
3	1050C / 100MPa / 2hr	Ti(2㎛)/Cr(0.5㎛)/Cu(10㎛)	580C / 100MPa / 2hr
4	1050C / 100MPa / 2hr	Ti(2㎛)/Cr(0.5㎛)/Cu(10㎛)	580C / 100MPa / 2hr
5	1050C / 100MPa / 2hr	Ti(2㎛)/Cu(20㎛)	580C / 100MPa / 2hr
6	1050C / 100MPa / 2hr	Ti(2㎛)/Cu(20㎛)	580C / 100MPa / 2hr

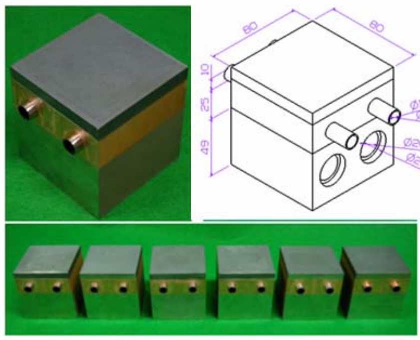

Figure 1 Schematic of the Cu/SS mock-up and its fabrication procedure

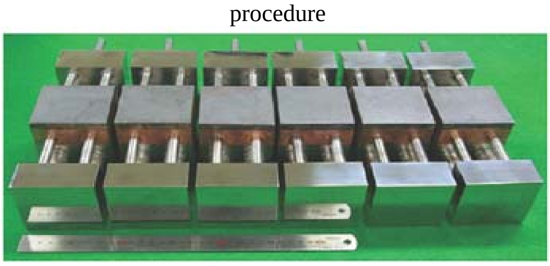

Figure 2 Fabricated mock-ups with manifolds

3. Preliminary analysis for the HHF test

In order to determine the HHF test condition, preliminary analysis with ANSYS were performed as shown in figure 3; the heat flux is assumed to be 1.5, 2.0, 2.5 MW/m^2 so as not to exceed the Be temperature limitation; water cooling conditions are determined from the JUDITH-1 facility conditions (25 ^{o}C and 0.1 MPa). For enough cooling, water speed is assumed to be 4.67 m/sec in the SS tubes. By considering the steady condition, heating and cooling time were determined to be 45/45 sec. Figure 3 shows the temperature and strain distribution by an analysis when heating (405 sec) for 1.5 MW/m^2. Maximum temperature at Be surface reaches 367.1 C, which is 92.9 % of the steady heating (395.0 C). Maximum deformation at a Be tile is 0.307 mm and the Maximum von Mises strains are 0.2264 % and 0.2563 % at the Cu block and SS tubes, respectively.

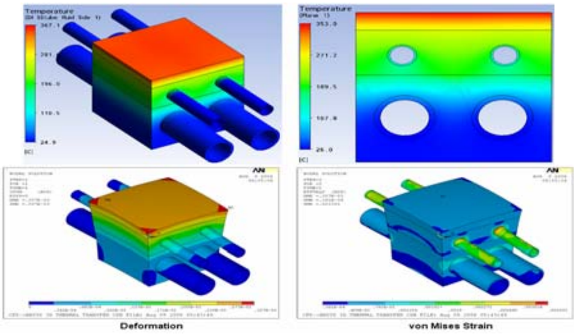

Figure 3 Temperature and strain distribution at heating time (405 sec, 5th cycle)

4. HHF test of the fabricated mock-ups

Before HHF testing, the IR camera for surface temperature measurement was calibrated and the heat flux by e-beam was measured; screening tests were performed to calibrate the E-beam on the target at 0.5, 1.0, 1.5 MW/m^2 step by step up to saturation of the outlet water temperature. Since all mock-ups except mock-up #01 showed the delamination in the Be/Cu interface, the tests were stopped and the mock-ups were evacuated from the chamber. The Be tiles were detached or delamination from the HIPped Cu block as shown in figure 4. The test results are summairzed as shown in table 2. For mock-up #01, HHF test was performed for 20 cycles with 1.5 MW/m^2 after screening test. And then, it showed delamination during increasing the heat flux to 2.0 MW/m^2. The temperature measured during test was compared with the analysis results and it shows a good agreement as shown in figure 5.

5. Conclusions

HHF test of HIP bonded mock-ups has been performed at the JUDITH-1 facility for 80x80x1 Be/Cu/SS mock-ups. The test conditions such as the heat flux, coolant speed, duration time, and required number of cycles to a failure were determined through a thermo-mechanical analysis with ANSYS code. The analysis results like temperature evolution shows a good agreement with the test results. In all the mock-ups, the Be tiles were detached during the test before the life time and it shows that the proposed interlayers seems to be not proper to join the Be to Cu.

Table 2 HHF test results

Mockup ID	Tested condition	comments
1	During screening test, failed (1.45 MW/m2) => A half coolant flow	*20 cycle at 1.5 MW/m2 and 2 cycle at 2.0 MW/m2 (two corners) More severe condition for cooling (half mass flow rate of coolant)*
2	During screening test, failed (1.45 MW/m2)	*Detached at screening 1.5 MW/m2*
3	During screening test, failed (0.95 MW/m2)	*Fully detached at screening test*
4	During screening test, failed (1.05 MW/m2)	*Fully detached at 3rd srceening below 1.5 MW/m2*
5	During screening test, failed (1.40 MW/m2)	*Lower half delaminated*
6	During screening test, failed (1.45 MW/m2)\	*Detached at screening test*

Figure 4 Tested mock-ups at JUDITH-1

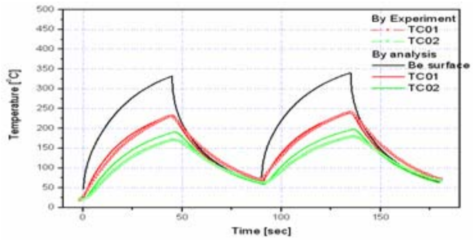

Figure 5 Comparison with temperature evolutions

REFERENCES

[1] A. Cardella, et al, Technical Basis for the ITER EDA plasma facing components, Fusion Eng. Des. 39-40 (1998) 377-384

[2] Dong Won Lee, Young Duk Bae, Bong Guen Hong, Jeong Yong Park, and Yong Hwan Jeong, "High Heat Flux Test of a HIP Bonded Cu/SS Mock-up for the ITER First Wall," Journal of Korean Vacuum Society, Vol.15, no.3, pp37-44, May 2006.

[3] Dong Won Lee, Young Dug Bae, Bong Guen Hong, Jong Hyuk Lee, Jeong Yong Park, Yong Hwan Jeong, Byung Kown Choi, "High heat flux test with HIP bonded Cu/SS mock-ups for the ITER first wall," Fus. Eng. Des., FUSENGDES-D-07-00378R1 (2008)

[4] J. Y. Park et. al., "Optimization of joining condition for ITER first wall fabrication," Journal of the Korean Physical Society, Vol.49, pp S442-S446, Dec. 2006.

[5] ITER Material Properties Handbook, File code : ITER-AA02-2402