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High heat flux test with the HIP bonded mock-ups for the ITER first wall

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1. Introduction

The first wall (FW) of the International Thermonuclear Experimental Reactor (ITER) is the important component facing the plasma directly and therefore, it is subjected to high heat and neutron loads. The FW is composed of a beryllium (Be) layer as plasma facing material, a copper alloy (CuCrZr) layer as a heat sink and type 316L authentic stainless steel (SS316L) as 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 volumetric heating in the FW is in the order of 15-20 MW/m^3 due to neutron wall loading [1]. To investigate the thermo-mechanical performance of the FW, including the integrity of the HIP bonded interfaces, a high heat flux (HHF) tests are essential. In this paper, the results of the HHF test for Cu/SS performed in JEBIS (JAEA electron beam irradiation stand) and the preparation process of the HHF test for Be/Cu mock-up in TSEFEY-M facility (Russia) are introduced.

2. Preparation of mock-ups

The optimum joining condition of a HIP for ITER FW has been developed 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 the several tests. They were successfully HIPped at 550 ^{O}C, 150 MPa, and 1 hour for Be/CuCrZr and at 1050 ^{O}C, 100 to 150 MPa, and 2 hours for CuCrZr/SS316L as shown in Fig. 1. Microstructure observation and mechanical tests were performed to confirm the joining technology [2]. In order to be installed in JEBIS, thermocouples and manifolds are added in the Cu/SS mock-up as shown in Fig. 2. Dimensions of the mock-up are 101 mm long, 50 mm wide and 52 mm thick with two circular cooling tubes (8mmID). Five thermocouples are installed to measure the temperature in the mock-up according to the distance from the heat source. Two manifolds and connected pipes were prepared for the coolant. For the HHF test in the TSEFEY-M facility, the Be/Cu mock-ups are fabricated as shown in Fig. 3. Dimensions of the mock-ups are 50 mm long, 50 mm wide, and 32 mm thick (10 mm of Be tile and 22 mm of Cu alloy). Two circular tubes (10mm ID) are inserted for cooling.

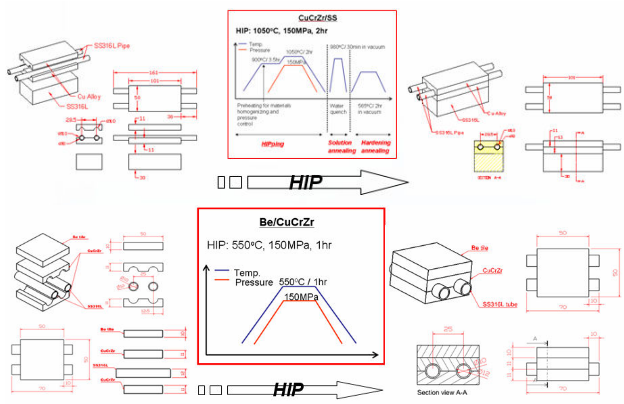

Figure 1. Schematic of the Cu/SS mock-up and TCs installation

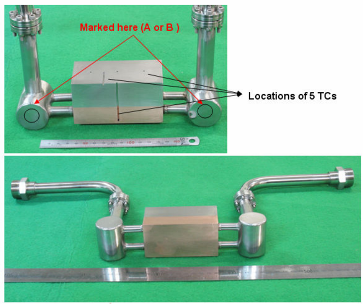

Figure 2. Fabricated Cu/SS mock-up with manifolds

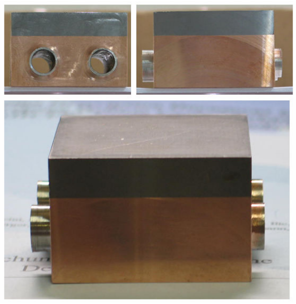

Figure 3. Fabricated Be/Cu mock-up

3. Heat flux test results of the Cu/SS mock-up

JEBIS was used as a high heat flux test facility for the Cu/SS mock-ups since there is no high heat flux test facility in Korea. From the preliminary analysis with ANSYS-10 for finding the test conditions according to the water cooling system and e-beam capacity in the JEBIS, the test was performed with 5 MW/m^2 of heat flux, 7 m/sec of cooling water speed (0.1 MPa, 25 ^{o}C), and 45 sec duration (15 sec heating and 30 sec cooling) [3]. Fig. 4 shows the temperature evolution measured during HHF test. Analysis results are also plotted in the figure. Temperature responses during the first and the 1000th cycle agreed very well and they also agreed well with analysis result. However, after 1000th cycle, the temperature goes higher than the expected and the test was stopped. The delaminations were found in the Cu/SS mock-up as shown in Fig. 5. From the constant strain fatigue curve for SS316L and CuCrZr, the expected life times are 2310 and 780 cycles, respectively as shown in Fig. 6.

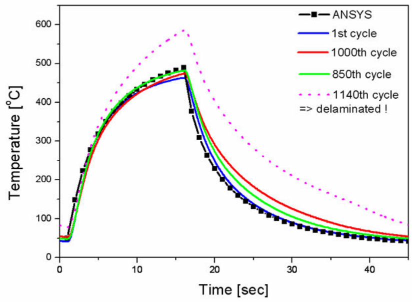

Figure 4. Temperature evolution during HHF test

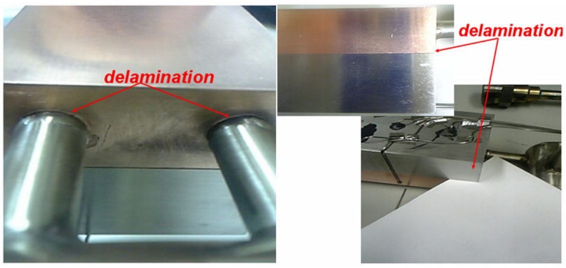

Figure 5. Cu/SS mock-up after HHF test

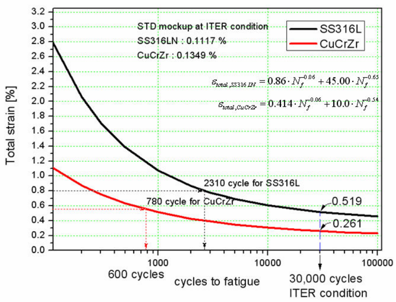

Figure 6. Constant strain fatigue curve for CuCrZr and SS316L

4. Preparation of HHF test for the Be/Cu mock-up

HHF test for the Be/Cu mock-up will be performed in the same way with that for the Cu/SS mock-up. The test conditions are found from the analysis with ANSYS-10 with 2D model as shown in Fig. 7; the heat flux is assumed to be 3.2 MW/m^2 not to exceed the Be temperature limitation (630 ^{o}C); water cooling conditions are decided from the TSEFEY-M facility conditions (25 ^{o}C and 2 MPa). For enough cooling, water speed is assumed to be 10 m/sec and then the heat transfer coefficient in the tube is 31625 W/m^{2}K. Fig. 8 shows the temperature and strain distribution by analysis when the duration is assumed to be 80 sec (40 sec heating and 40 sec cooling for saturated condition). The expected cycle for CuCrZr is 600 for these test conditions.

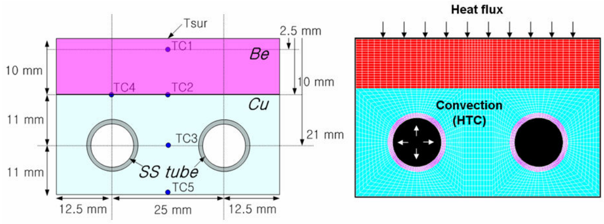

Figure 7. Analysis model of ANSYS 9.0

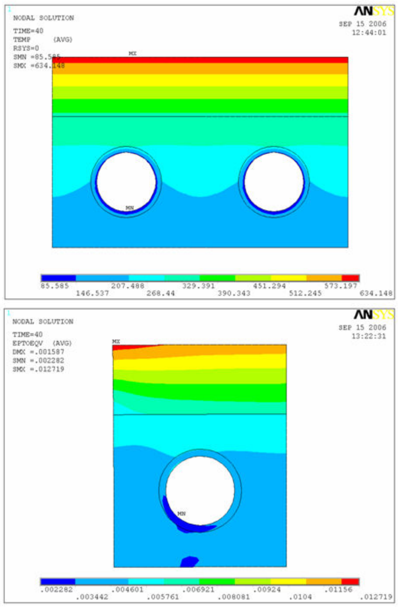

Figure 8. Results of thermal analysis under each heat flux

5. Conclusions

HHF test of the HIP bonded Cu/SS mock-up has been carried out under heat flux of 5.0 MW/m2 and 1000 cycles. Temperature responses during the test agreed well with the analysis results. After1000 cycle, the mock-up was delaminated but it is larger value than the cycle to failure of CuCrZr itself. The HIP bonded Be/Cu mock-up was prepared for the HHF test and the preliminary analysis was performed to find the test conditions and its value of cycle to failure.

REFERENCES

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

[2] J. Y. Park et. al., "Optimization of joining condition for ITER first wall fabrication," 5th Asia Plasma Fusion Association, Jeju, Korea, Aug. 2005,

[3] 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.

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