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Analysis and High Heat Flux Test with the Preliminary First Wall Qualification Mock-ups for the ITER Blanket First Wall

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1. Introduction

Korea has responsibility for the procurement of the International Thermonuclear Experimental Reactor (ITER) blanket modules 1, 2 and 6 as a ITER participant. Each blanket module is composed of first wall (FW) panel and shield block. 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. The FW is an important component which faces the plasma directly and it is subjected to high heat and neutron loads. Therefore, a qualification program is introduced to guarantee acceptable quality of the total FW panel procured by six different domestic agencies including Korea. Korea submitted two First Wall Qualificaiton Mock-ups(FWQMs) to ITER Organization(IO) and they were successfully tested in the US (EB-1200 in SNL) and in the Germany (JUDITH in FZK). In the fabrication process, we made another mock-ups and they were tested with the Korea Heat Load Test Facility (KoHLT) before submission. The present paper shows the results of those mock-ups's testing.

2. Preparation of the mock-ups

The optimum joining condition of a HIP for the ITER FW has been developed with the conditions of 550 ^{O}C, 100 MPa, and 2 hour for Be/CuCrZr and of 1050 ^{O}C, 100 MPa, and 2 hours for CuCrZr/SS316L [1-4]. The prelimianry FWQMs were fabricated in the same conditions and ultrasonic test to find defect in the interfaces were performed but there is no defect. Finally, manifolds were welded to be installed at KoHLT-1 as shown in figure 1. He leak test were performed to find a leakage and then some of them were rewelded when there is a leakage.

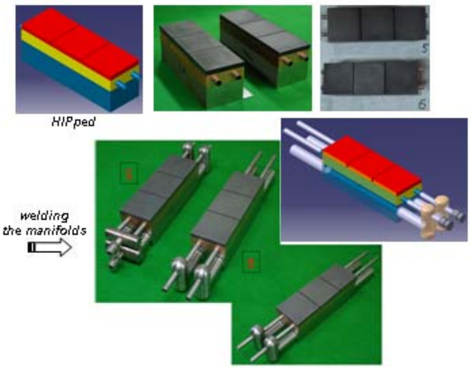

Figure 1 Fabricated preliminary FWQMs

3. Preliminary analysis for the HHF test

In order to determine the High Heat Flux(HHF) test condition, preliminary analysis with ANSYS were performed as shown in Fig. 2; the heat flux is assumed to be 0.625 and 0.725 MW/m^2 so as not to exceed the Be temperature limitation; water cooling conditions are determined from the KoHLT-1 facility conditions (25 ^{o}C and 0.1 MPa). For enough cooling, water speed is assumed to be 1.34 m/sec in SS tubes. By considering the steady condition, heating and cooling time were determined. More detailed simulation consitions were summnarized in Table 1. Figure 2 shows the temperature distribution when heating (1310 sec) for 0.625 and 0.725 MW/m^2. Maximum temperatures at Be surface reaches 236.1 ^{o}C and 273.4 ^{o}C at each heat flux.

Table 1 Simulation and test conditions

Items	FWQM #2	FWQM #5
Surface heat flux	0.625 [MW/m^2] 12,690 shots	0.700 [MW/m^2] 12,020 shots
Water flow	8.2 [kg/min] 1.34 [m/sec] at tube 0.335 [m/sec] at hole	
Water conditions	0.1 MPa, 25 ^{o}C	
Duration time	30 sec up 160 sec holding 30 sec down 60sec off	

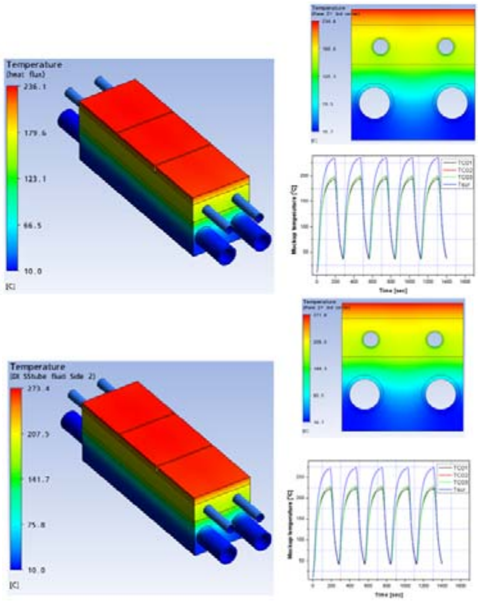

Figure 2 Temperature distribution at heating time (1310 sec, 5th cycle) and evolution for five cycles under 0.625 & 0.725 MW/m^2

4. HHF test of the fabricated mock-ups

The KoHLT-1 consists of a graphite heating panel, a box-type test chamber with water-cooling jackets, an electrical DC power supply, two water-cooling systems, an evacuation system, an He gas system, and some diagnostics, as shown in Fig. 4. The graphite heater is placed between two mockups, and the gap distance between the heater and the mockup is adjusted to 2-3 mm. We designed and fabricated a graphite heating panel to have an effective heating area of 244×80 mm^2 which is identical to the surface area of the KO FWQM, and to have an electrical resistance of 0.25 ohms during a high temperature operation.

We carried out HHF tests of the preliminary FWQMs from September 2008 to April 2009 with some breaks for the tests of other mockups. Prior to the main test, we performed a pre-test to adjust the required heat flux by changing the electrical current shot by shot. Nominal heat flux of the main test was 0.625 MW/m^2, for which the graphite heater current was set to 350-370 A. The flow rate of cooling water was 8.2 kg/min per each mockup, and its inlet temperature was 25°C, as summarized in Table 1. Preliminary FWQM no. 2 and no. 5 were tested 12,690 and 12,020 cycles, respectively. Figure 5 shows the measured temperature for last 100 cycles and photos after evacuation of mock-ups from test chamber. Over 12,000 cycles, the mock-ups shows no sudden temperature increase and no delamination or failure was found in visual observation after test. Figure 6 shows the comparison between measured temperature and analysis ones. It shows a good agreement at given heat fluxes.

5. Conclusions

HHF test of HIP bonded preliminary FWQMs have been performed at the KoHLT-1 facility over 12,000 cycles. No failure and delamination was found in the test. 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.

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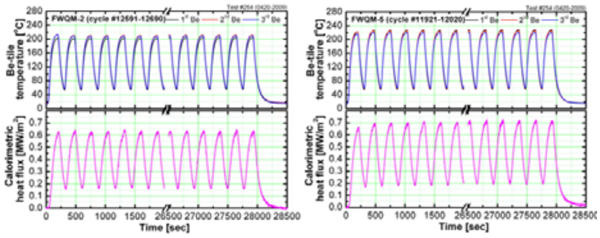
Figure 3 Test facility (KoHLT-1, graphite heater, mock-up installation)



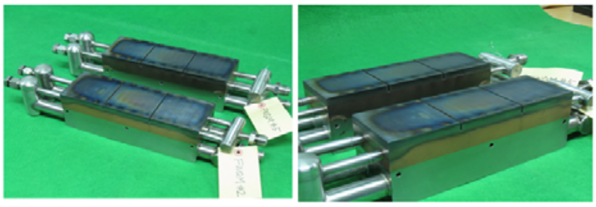


Figure 4 Tested mock-ups at JUDITH-1

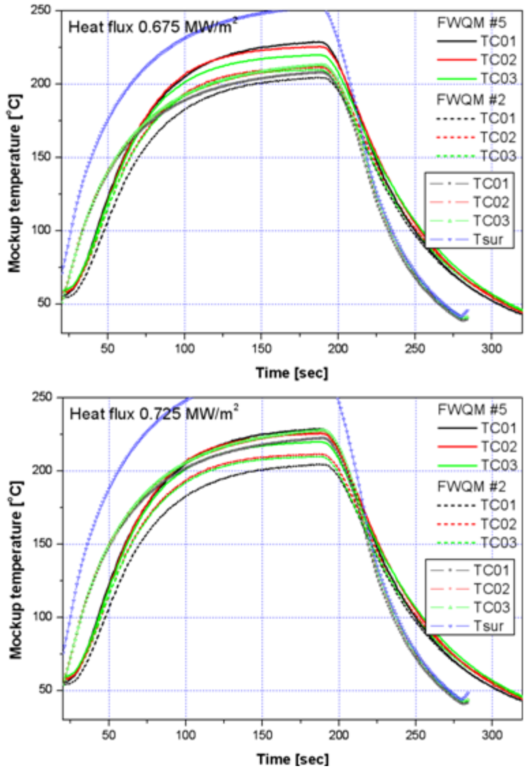


Figure 5 Comparison with temperature evolutions