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Experiment and analysis of hypervapotron mock-ups for preparing the 2nd qualification of the ITER blanket first wall

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ABSTRACT

According to the increased heat flux condition up to 5 MW/m^2 in the International Thermonuclear Experimental Reactor (ITER), new design of the blanket first wall (FW) has been considered and the analysis was performed with ANSYS-CFX for checking its temperature with the ITER operation conditions. And a semi-prototype of the FW was proposed to be tested with the similar heat flux conditions under the second qualification for the FW procurement. In order to investigate the fabrication procedure and analysis capability of the code, two types of mock-up were fabricated according to the current semi-prototype design except for bending shape; one with hypervapotron and another without it. They were tested with KoHLT-2 (Korea Heat Load Test) facility and the results were compared with the ones by CFX code. The mass flow rate of inlet coolant was the same as the ITER condition and heat flux was loaded up to 0.48 MW/m^2 heat flux. The results show that the temperature of the mock-up can be predicted using the CFX code even with the complex geometry and the hypervapotron shows its function to increase the cooling.

1. Introduction

Since the blanket first wall (FW) of the International Thermonuclear Experimental Reactor (ITER) is subjected to a high heat and high neutron loads, it 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. Moreover, since the peak heat load to be endured was assumed to be 5.0 MW/m^2, a device to enhance the cooling such as hypervapotron should be adopted in the FW design. Due to the above constraints, joining methods of the three different metals and application of the hypervapotron in terms of fabrication and analysis are the key issues.

For the development and verification of the fabrication methods, two-step qualification program has been progressed by ITER organization and participants who will procure the blanket FW. In Korea, the joining method has developed using the hot isostatic pressing (HIP) and it was proved through the several mock-up fabrication and high heat flux tests for confirming the joining integrity. Some of them were tested in foreign facilities such as JEBIS at JAEA in Japan, TSEFEY at Efremov in Russia, and JUDITH at FZJ in Germany, and others were tested in our own facilities such as KoHLT-1 and -2 (Korea Heat Load Test facility). And finally, the 1st qualification was passed, in which two 80 × 80 × 3 Be/Cu/SS mock-ups were tested under 0.625 and 0.875 MW/m^2 heat fluxes for 12,000 cycles and then tested under 1.75 and 1.40 MW/m^2 heat fluxes for 1000 cycles at FZJ and SNL, respectively [1–7]. Currently, the 2nd qualification program was started and the semi-prototype (SP) should be fabricated by the end of 2011 for testing under 5.0 MW/m^2 heat flux for certain number of cycles.

In order to prepare the second qualification, we have analyzed the current semi-prototype design using the commercial code, ANSYS-CFX and investigated on the fabrication methods including joining of the different metals, making the hypervapotron, and bending of the block. As the first step of the preparation, two mock-ups with and without hypervapotron were fabricated with the same dimension to the current semi-prototype design and they were tested in the KoHLT-2 (Korea Heat Load Test) facility with 0.48 MW/m^2 heat flux. The results were compared with the analysis ones by ANSYS-CFX to verify the semi-prototype design and performance analysis results [8].

2. Mock-up fabrication and thermal-hydraulic experiment

Fig. 1 shows the current semi-prototype design and it is composed of three FW fingers and central beam. Three same fingers were composed of Be armor, Cu alloy heat sink, and SS structure, and the hypervapotron was adopted in the Cu block for enhancing

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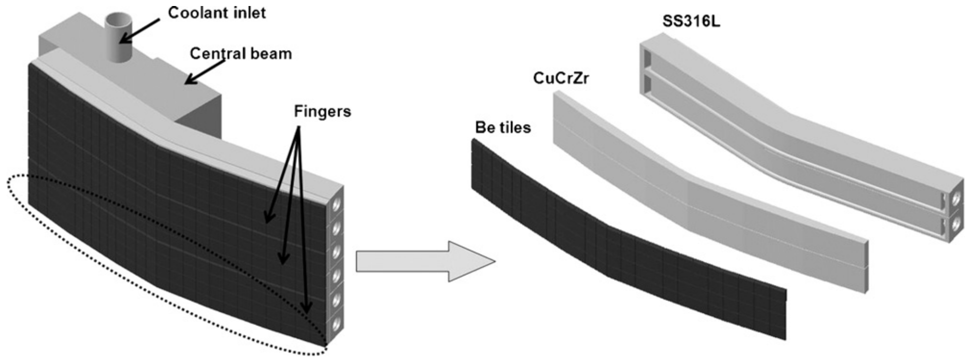

Fig. 1. Current design of the semi-prototype and its components.

the cooling in order to endure the high heat flux from the plasma. Since the fabrication of the hypervapotron in the Cu side and evaluate its capability experimentally in the present study, the simple mock-ups were designed preserving the 700 mm length, 101 mm width, and other dimensions except for the bending. Two mock-ups were fabricated; one with hypervapotron called enhanced SP mock-up and the other without it called normal SP mock-up, as shown in Fig. 2. Fig. 3 shows the detailed dimension of the mock-ups. For the hypervapotron, the height and width of the teeth were 5 mm and 3 mm respectively, and the pitch was 3 mm. The Cu and SS block were joined not with HIP but with brazing since the main objective of this mock-up was the thermal-hydraulic testing and fabrication of the hypervapotron with milling.

The test was performed with KoHLT-2 (Fig. 4) which was developed by KAERI with the following operation parameters; the maximum power is 80 kW and surface heat flux can be up to 0.65 MW/m^2 for the used heater. Its water supply system has capability to supply water of 25–120 °C temperature and 3 MPa pressure, as shown in Fig. 5. A graphite heater (100 mm × 300 mm) was fabricated to heat the mock-up and the two mock-ups were installed between the heater with 2 mm gaps, as shown in Fig. 5. During the test, the total power in the power supply was measured and the absorbed powers at the tested mock-ups were measured with a coolant temperature differences by thermocouples located at the inlet and outlet regions of the coolant. Three thermocouples for the wall temperature measurement were inserted from a back-side of the mock-ups, which were located 5 mm from the heated surface, as shown in Fig. 3. The mock-up was tested with two inlet coolant flow rates; 0.324 kg/s and 0.584 kg/s, in which the later one was for the ITER operation condition. Heat fluxes were loaded up to 0.65 MW/m^2, as shown in Table 1. However, since the loading heat flux became unstable in the case of over 0.48 MW/m^2 heat flux, the results with 0.48 MW/m^2 heat flux were used for the compar-

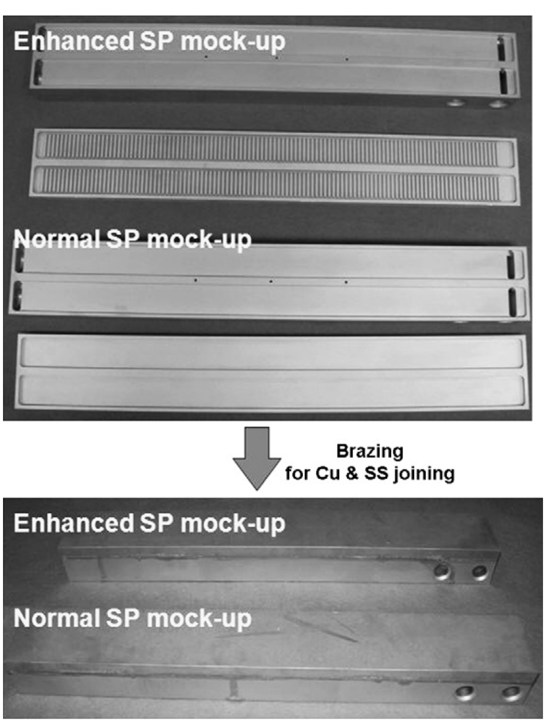

Fig. 2. Photos of the fabricated SP mock-ups.

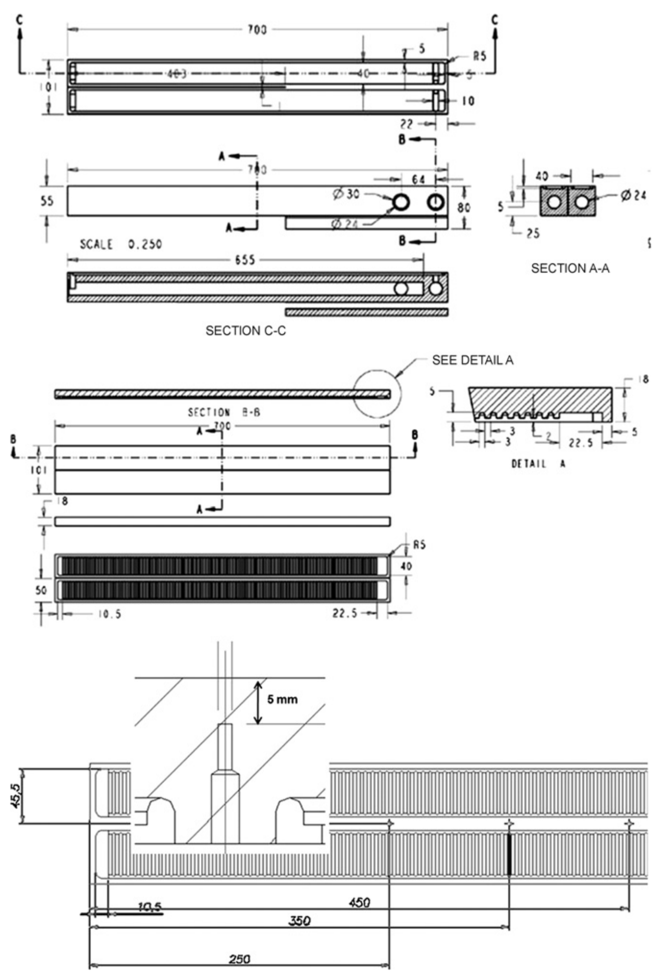

Fig. 3. Detailed drawings of the fabricated SP mock-ups.