Transactions of the Korean Nuclear Society Autumn Meeting
Pyeongchang, Korea, October 30-31, 2014

Performance Test of Korea Heat Load Test Facility (KoHLT-EB) for the Plasma Facing Components of Fusion Reactor

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1. Introduction

The key technology for the development of plasma facing components (PFCs) is the dominant topic in the fusion reactors. The main components of the PFCs in the tokamak are the blanket first wall and divertor, which include the armour materials, the heat sink with the cooling mechanism, and the diagnostics devices for the temperature measurement. The Korea Heat Load Test facility by using electron beam (KoHLT-EB) has been operating for the plasma facing components to develop fusion engineering. This electron beam facility was constructed using a 300 kW electron gun and a cylindrical vacuum chamber. Performance tests were carried out for the calorimetric calibrations with Cu dummy mockup and for the heat load test of large Cu module. For the simulation of the heat load test of each mockup, the preliminary thermal-hydraulic analyses with ANSYS-CFX were performed. For the development of the plasma facing components in the fusion reactors, test mockups were fabricated and tested in the high heat flux test facility.

2. Methods and Results

2.1 High heat flux test

The Korean heat load test facility using an electron beam system (KoHLT-EB) [1-3] for the plasma facing components (PFC) was constructed to evaluate the fabrication technologies required for the ITER first wall (FW) and the tokamak materials. ITER blanket small-scale mockups were fabricated to evaluate the performance of the heat removal in the first wall. The concept of a hypervapotron in the tokamak first wall was selected to enhance the heat transfer of the first wall, and to remove the high heat load [4, 5]. The ITER FW includes beryllium armour tiles joined to a CuCrZr heat sink with stainless steel cooling tubes.

Preliminary thermo-hydraulic tests were performed using the Korea heat load test facility at the Korea Atomic Energy Research Institute (KAERI) [6-11] for the plasma facing components. The KoHLT-2 (Korea Heat Load Test facility using a graphite heater) [12-15] consists of a target mount, graphite heater and a test chamber with cooling jackets. However, this heat source with a graphite heater has the disadvantage of a short life and non-homogeneous irradiation of high heat flux. There are several facilities using an electron beam as the uniform heat source. These machines are utilized for a cyclic heat flux test of plasma facing components. Each facility is working to unique targets of their own purposes in EU FZJ [16], US SNL [17], and RF Efremov institute [18]. Recently, a new high heat flux test facility using an electron beam system was fabricated at KAERI [19] in Korea to qualify the performance for the ITER blanket FW mockups, hypervapotron cooling devices in the fusion devices, and other plasma facing components. KoHLT-EB is now operated for the high heat flux test of the ITER PFCs.

2.2 Test facility

An electron beam facility (KoHLT-EB) with an 800 kW electron gun (from Von Ardenne, Germany) for a high heat flux with a maximum beam power of 300 kW and maximum accelerating voltage of 60 kV, is now in operation to perform the high heat flux tests for the plasma facing components, as shown in Fig. 1. This electron beam facility using a 60 kV electron gun from Von Ardenne GmbH will be constructed using a power supply system of 300 kW, where the allowable target dimension is 70 cm × 50 cm in a vacuum chamber (about 140 cm diameter, 250 cm length). This facility needs a cooling system for a high-temperature target and beryllium filtration system for ITER blanket FW mockups.

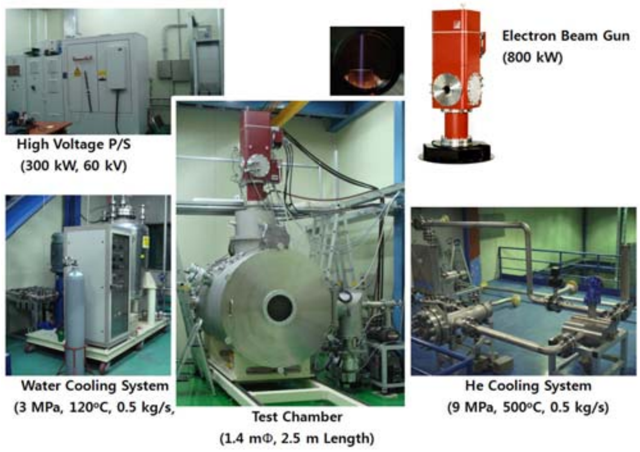

Fig. 1. High heat flux test facility using an electron gun and helium cooling system.

This machine will be utilized for a cyclic heat flux test of the plasma facing components. The methods to measure the temperature of this system will be selected with the calorimetry of the coolant, the thermocouples for the bulk temperature of the targets, and an IR camera and pyrometers for the target surface temperature.

To perform the profile test, an assessment of the possibility of electron beam Gaussian power density profile and the results of the absorbed power for that profile before the test starts are need. To assess the possibility of a Gaussian profile, for the qualification test of the Gaussian heat load profile, a calorimeter was manufactured to simulate real heat, and this calorimeter has 2 cooling channels with 5 thermocouples, as shown in Fig. 2.

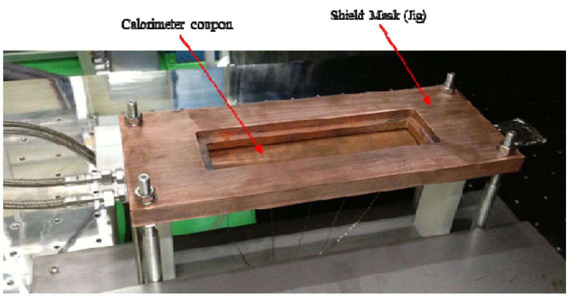

Fig. 2. Calorimeter mockup with shield mask block

The high heat flux tests (HHFT) were performed on the calorimetric mockup test for the beam deposition of the uniform, Gaussian profiles. The temperature behavior of each thermocouple, coolant temperature at the inlet/outlet and calculated heat flux had been recorded during HHFT. Also, the calorimeter coupon temperature from each thermocouple had been compared between the thermocouple locations. As a result, HHFT test on the calorimetric mockup with uniform profile has been performed successfully. Gaussian shaped beam patterning has been successfully developed to simulate the requirement for Gaussian profile in the Fig. 3. The results of calorimetric coupon test can be summarized as below.

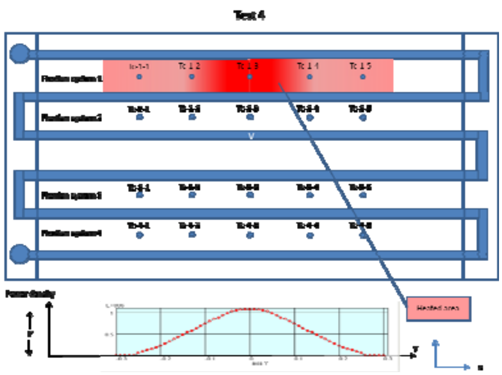

Fig. 3 the requirement for Gaussian profile

In case of uniform profile, the absorbed heat flux is calculated as 0.55 ~ 1.21 MW/m^2. Thermocouple response shows broad distribution of 3 thermocouples in the middle of calorimeter coupon. Fig. 4 shows the heat flux of the uniform profile. In case of Gaussian profile, the absorbed heat flux in the center area is calculated 0.41 ~ 0.74 MW/m^2. Thermocouple response shows half-moon shaped heat flux in the middle of calorimeter mock-up.

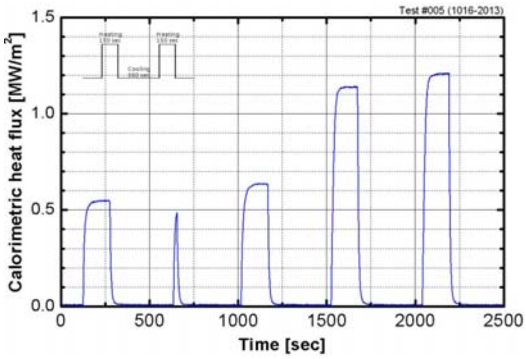

Fig. 4. Heat flux-Time behavior of uniform profile

To perform the profile test for large Cu module, test module of 220 x 240 mm^2 irradiated area was fabricated, and this Cu module has 6 cooling channels with 20 thermocouples, as shown in Fig. 5.

The main objective of a uniform profile test is to determine the response time and measurement accuracy of the thermocouples. The uniform heat load of Fig. 6 is applied over the whole area covered by the thermocouples. The applied electron beam powers are 30 and 60 kW. 300-second pulse lengths were applied to this test. Absorbed heat flux is calculated as a coolant temperature difference between the inlet and outlet of the test mock-up.

The Gaussian beam test will be to see if the power profile can be re-created afterwards from the discrete measurements. Gaussian shaped profile heat load of Fig. 7 is applied over the whole area covered by the thermocouples.

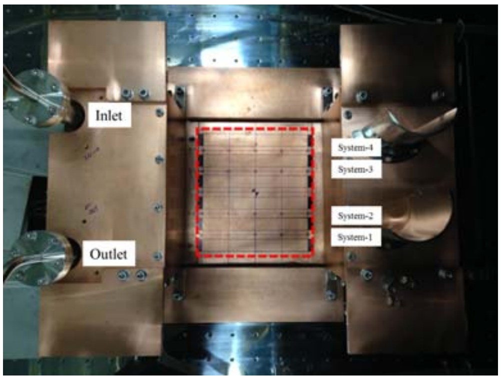

Fig. 5. Large Cu module and shield mask block.

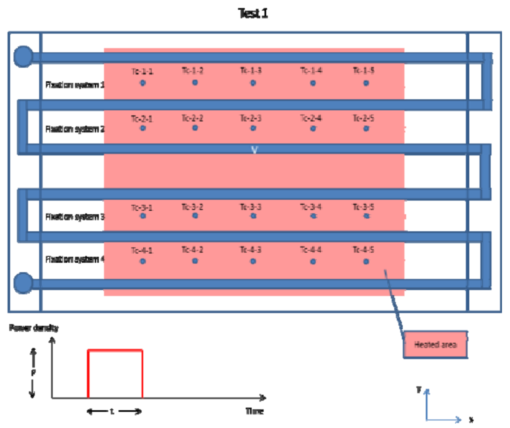

Fig. 6. Simulated beam deposition in the test mockup. (Flat beam profile)

The applied maximum electron beam powers are 25 and 50 kW in the central area of the test mock-up. 300-second pulse lengths had been applied to this test. Absorbed heat flux is calculated as the coolant temperature difference between the inlet and outlet of the test mock-up.

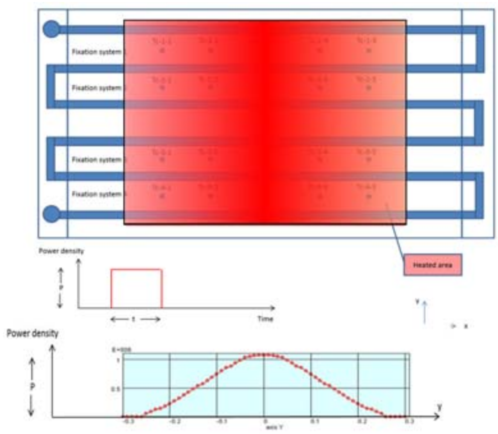

Fig. 7. Simulated beam deposition in the test mockup. (Gaussian peak profile)

2.3 Test Results

In the case of a uniform profile in the whole area, the maximum temperature is measured from the central thermocouple of the test mock-up except the thermocouple fixation system-3 from the 0.43 and 0.9 MW/m^2 heat flux. In the case of the 0.43 MW/m^2 heat flux, the acquired temperatures of thermocouple fixation system-1, 2 and 4 are almost the same. The temperature of thermocouple fixation system-3 was highest among all of the thermocouple fixation systems. As shown in Fig. 8, the response time of thermocouple fixation system-3 and 4 is less than that of system-1 and 2.

Because of the applied heat load as a Gaussian shaped profile to test the mock-up, the acquired temperature response from the central thermocouple is higher than that of the other thermocouples. Similar to the other uniform profile test, the thermocouple fixation system-3 showed the highest temperature response for a heat flux of 0.45 and 0.94 MW/m^2. Fig. 9 shows the temperature distribution of test mockups with Gaussian peak profile.

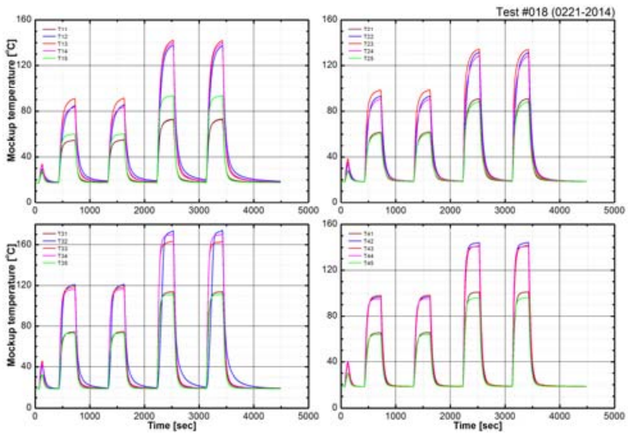

Fig. 8. Temperature distribution of test mockups. (flat beam profile)

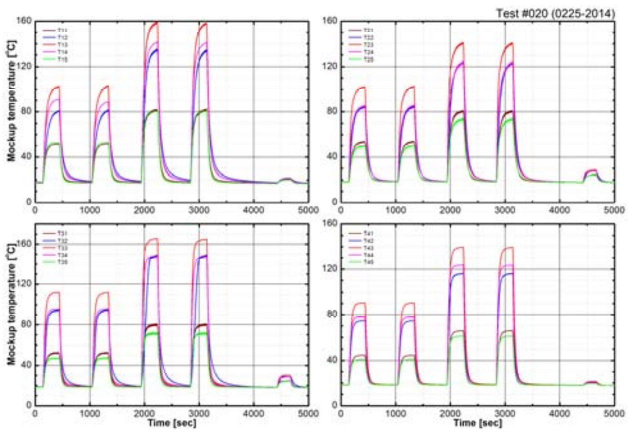

Fig. 9. Temperature distribution of test mockups. (Gaussian peak profile)

3. Conclusions

To perform a beam profile test, an assessment of the possibility of electron beam Gaussian power density profile and the results of the absorbed power for that profile before the test starts are needed. To assess the possibility of a Gaussian profile, for the qualification test of the Gaussian heat load profile, a calorimeter mockup and large Cu module were manufactured to simulate real heat. For this high-heat flux test, the Korean high-heat flux test facility using an electron beam system was constructed. In this facility, a cyclic heat flux test will be performed to measure the surface heat flux, surface temperature profile, and cooling capacity.

Acknowledgment

This work was supported by R&D Program through National Fusion Research Institute (NFRI) funded by the Ministry of Science, ICT and Future Planning of the

Republic of Korea (NFRI-IN1403)

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