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Performance Test of High Heat Flux Test Facility for the Calorimetry and Beam Control

Suk-Kwon Kim[a*], Ara Jo[a], Hyung Gon Jin[a], Eo Hwak Lee[a], Jae-Sung Yoon[a], Dong Won Lee[a], Seungyon Cho[b]
[a]*Korea Atomic Energy Research Institute, Daejeon, Republic of Korea*
[b]*ITER Korea, National Fusion Research Institute, Daejeon, Republic of Korea*
[*]*Corresponding author: skkim93@kaeri.re.kr*

1. Introduction

The Korea Heat Load Test facility, KoHLT-EB (Electron Beam) has been operating for the plasma facing components to develop fusion engineering in Korea. The ITER Neutral Beam Duct Liner (NBDL) was fabricated and tested to qualify the thermocouple fixation method for the temperature measurement during a direct collision of the high-power neutral beam during ITER operation. The NBDL is CuCrZr panels, which are actively water cooled using deep drilled channels. To perform the profile test, the assessment for the possibility of an electron beam Gaussian power density profile and the result of absorbed power for that profile before the test start is needed. To assess the possibility of Gaussian profile, for the qualification test of a Gaussian heat load profile, small calorimetry was manufactured to simulate a real heat profile in the neutral beam duct liner, and this calorimetry has two cooling channel with five thermocouples, which is the same as NBDL. Preliminary analyses with ANSYS-CFX using a 3D model were performed with the calorimetry model. The heating area was modeled to be 60 mm x 250 mm. The simulated heat flux is 0.5 - 1.2 MW/m^2 at 0.75 kg/sec of the water flow rate. A steady heat flux test was performed to measure the surface heat flux, surface temperature profile. With a thermo-hydraulic analysis and heat load test, the Gaussian heat profile will be confirmed for this calorimetry and NBDL mockup. The Korean heat load test facility will be used to qualify the specifications of various plasma facing components in fusion devices.

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 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 conducted 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 the plasma facing components. Each facility working toward unique targets of their own purpose 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 [19-23] 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 a high heat flux test of 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 conduct 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 the ITER blanket FW mockups.

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 using 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 conduct the profile test, an assessment of the possibility of the electron beam Gaussian power density profile and the results of the absorbed power for this profile before the test starts are need.

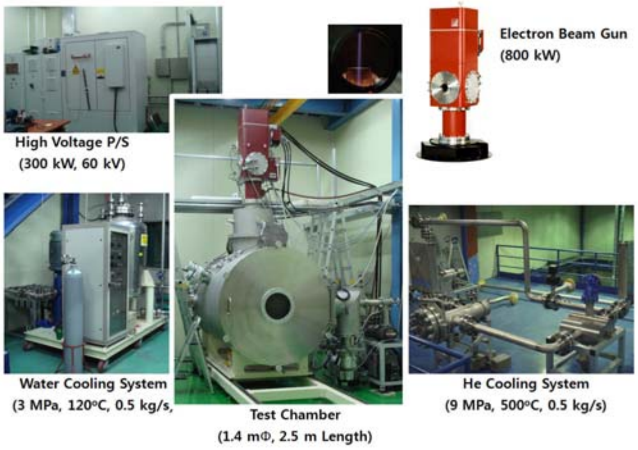

Fig. 1. High heat flux test facility using an electron gun and helium cooling system.

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.

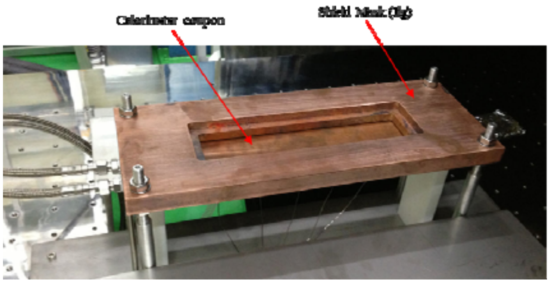

Fig. 2. Calorimeter mockup with shield mask block

The high heat flux tests (HHFT) were conducted during a 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 were recorded during HHFT. In addition, the calorimeter coupon temperature from each thermocouple was compared between the thermocouple locations. As a result, an HHFT test on the calorimetric mockup with uniform profile was successfully conducted. Gaussian shaped beam patterning was successfully developed to simulate the requirement for the Gaussian profile. The results of the calorimetric coupon test can be summarized as below.

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

To conduct a profile test for a large Cu module, a test module with a 220 x 240 mm^2 irradiated area was fabricated, which has 6 cooling channels with 20 thermocouples, as shown in Fig. 4.

The main objective of a uniform profile test is to determine the response time and measurement accuracy of the thermocouples. The uniform heat load 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. The absorbed heat flux was calculated as a coolant temperature difference between the inlet and outlet of the test mock-up.

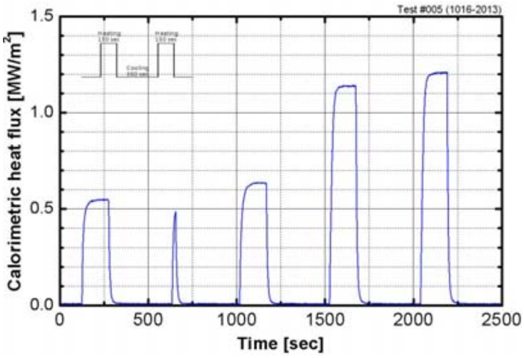

Fig. 3. Heat flux-Time behavior of uniform profile

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

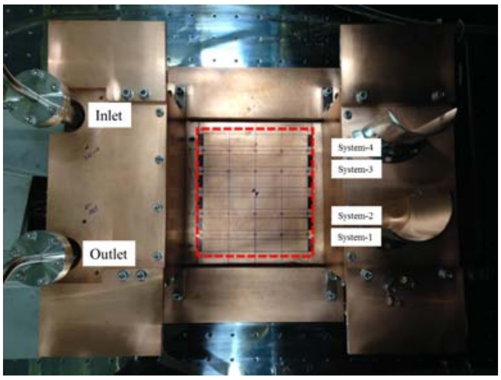

Fig. 4. Large Cu module and shield mask block.

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

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 the thermocouple fixation system-1, 2 and 4 were 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 systems-3 and 4 is less than that of systems-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 was 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 the test mockups with a Gaussian peak profile.

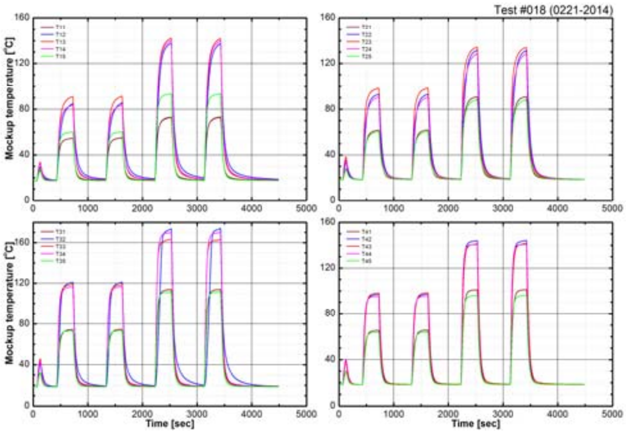

Fig. 8. Temperature distribution of test mockups.
(flat beam profile)

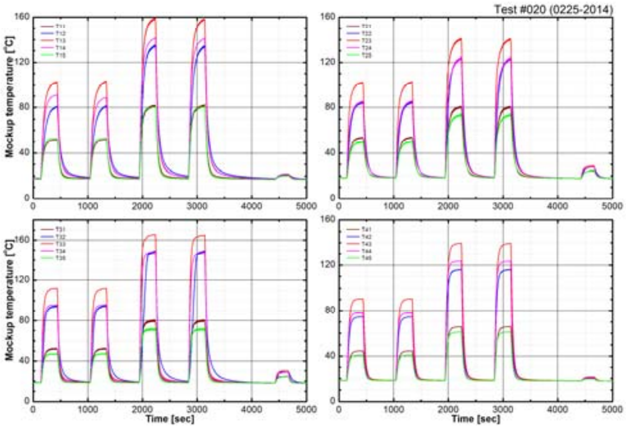

Fig. 9. Temperature distribution of test mockups.
(Gaussian peak profile)

3. Conclusions

To conduct 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

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