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Current Status of the High Heat Flux Test Facility for the Plasma Facing Components

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1. Introduction

Plasma facing components are the dominant topics in the development of fusion reactors. The main components of the tokamak PFCs are the blanket first wall, divertor, and various diagnostics ports, 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, KoHLT-EB (Electron Beam) has been operating for the plasma facing components to develop fusion engineering in Korea. This electron beam facility was constructed using a 300 kW electron gun, and the maximum target dimension is 70 cm × 50 cm in a cylindrical vacuum chamber of about 140 cm in diameter and 250 cm in length. The performance tests were carried out for the calorimetric calibrations with Cu dummy mockup and for the heat load test of tungsten first wall mockups. Also the thermo-hydraulic tests were performed to evaluate the high temperature gas-cooling devices. For the simulation of the heat load test of each mockup, preliminary thermal-hydraulic analyses with ANSYS-CFX were performed. For the development of the plasma facing components, test mockups were fabricated and tested in the high heat flux test facility and non-destructive method. These manufacturing technologies and test performances will be used for the development of a fusion reactor.

2. Methods and Results

2.1 Heat load test facility

Korean heat load test facility by 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. The first wall panels are one of the critical components in the ITER machine with a surface heat flux of 4.7 MW/m^2 or above. Thus, a qualification program needs to be performed with the goal of qualifying the joining technologies required for the ITER First Wall. For the non-destructive tests (NDT) of the fabricated small-scale mockups, visual and dimension inspections were performed whenever needed during the fabrication process, and ultrasonic tests (UT) were performed using ultrasonic probes.

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 by using a graphite heater) [12-15] consists of a target assembly (target mount, graphite heater), test chamber (1.2 m × 1.2 m × 2.4 m, vacuum system and chamber cooling jackets). But, this heat source with graphite heater has the disadvantage of the short life time and the non-homogeneous irradiation of high heat flux. So, there are several facilities using electron beam as the 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. After the commissioning in 2012, this facility is working in the high heat flux test of the ITER PFCs.

2.2 Test facility and evaluation

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, 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. This machine will be utilized for a cyclic heat flux test of the plasma facing components. In addition, a helium cooling system (high temperature 500 °C, high pressure 9 MPa) will be coupled with an electron beam system for high temperature cooling devices. 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.

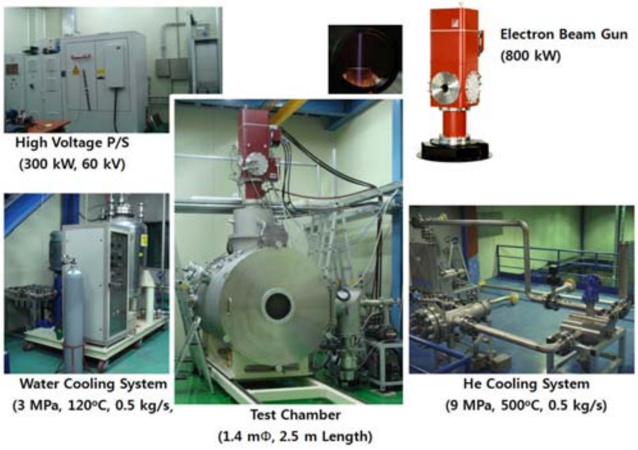

Fig. 1. High heat flux test facility by using an electron gun and helium cooling system.

In order 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 6 cooling channel with 20 thermocouples, as shown in Fig. 2.

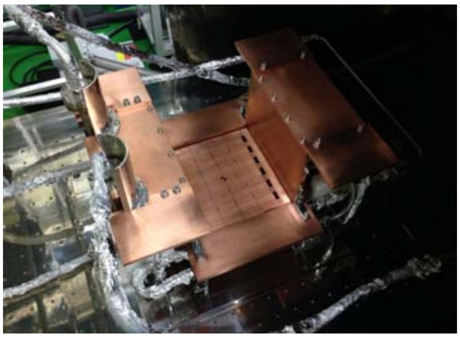

Fig. 2. Test mockup for the thermo-hydraulic calorimetry.

The main objective of uniform profile test is to determine the response time and measurement accuracy of the thermocouples. A uniform profile (Flat beam pattern) heat load of Fig. 3 is applied over the whole area covered by the thermocouples. The applied electron beam powers are 30 and 60 kW. 300 seconds of pulse lengths had been applied to this test.

- Beam power
  - Power = 30, 60 kW @ 40 kV
  - Absorbed heat flux = 0.43, 0.90 MW/m2
  - Heating time = 300 sec
  - Cooling time = 600 sec
- Electron beam irradiation area
  - 220 mm × 240 mm (W×H)

Absorbed heat flux is calculated as coolant temperature difference between the inlet and outlet of test mock-up.

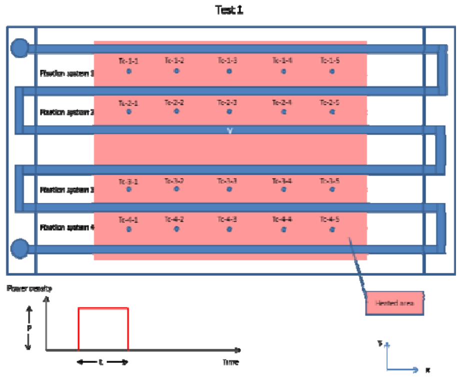

Fig. 3. Simulated beam deposition in the test mockup. (Flat beam profile)

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. 4 is applied over the whole area covered by the thermocouples. The applied maximum electron beam powers are 25 and 50 kW in the central area of test mock-up. 300 seconds of pulse lengths had been applied to this test.

- Beam power
  - Power = 25, 50 kW @ 40 kV
  - Absorbed heat flux = 0.45, 0.94 MW/m2
  - Heating time = 300 sec
  - Cooling time = 600 sec
- Electron beam irradiation area
  - 220 mm × 240 mm (W×H)

Absorbed heat flux is calculated as coolant temperature difference between the inlet and outlet of test mock-up.

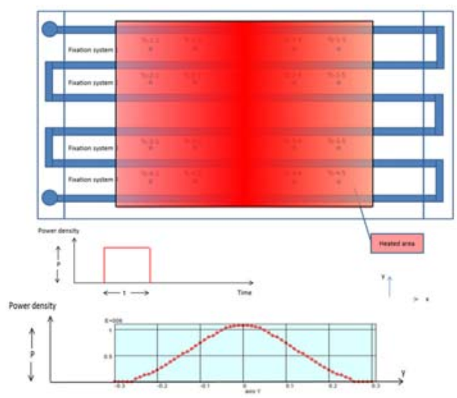

Fig. 4. Simulated beam deposition in the test mockup. (Gaussian peak profile)

2.3 Test Results

In case of uniform profile at whole area, the maximum temperature is measured from central thermocouple of test mock-up except the thermocouple fixation system-3 from the 0.43 and 0.9 MW/m^2 heat flux. In case of 0.43 MW/m^2 heat flux, the acquired temperatures of thermocouple fixation system-1, 2 and 4 are almost same. The temperature of thermocouple fixation system-3 had been measured highest temperature among the all of thermocouple fixation systems. As shown below Fig. 5, response time of thermocouple fixation system-3 and 4 is less than system-1 and 2.

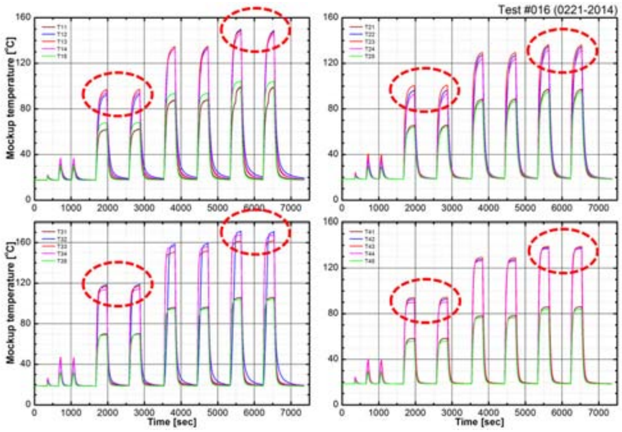

Fig. 5. Temperature distribution of test mockups. (Flat beam profile)

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

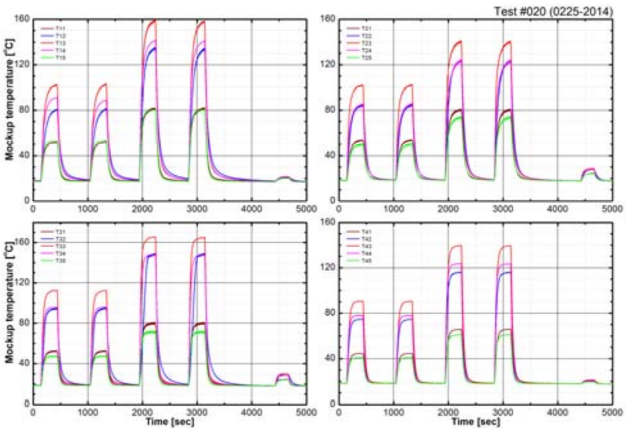

Fig. 6. Temperature distribution of test mockups. (Gaussian peak profile)

3. Conclusions

In order to perform the 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 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. For this high heat flux test, the Korean high heat flux test facility using an electron beam system (KoHLT-EB) was constructed to qualify the performance of small-scale mockup. In this facility, a cyclic heat flux test will be performed to measure the surface heat flux, surface temperature profile, and cooling capacity. The Korean heat load test facility will be used in the performance test for the various plasma facing components in fusion devices.

Acknowledgment

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