Qualification Program of Korea Heat Load Test Facility KoHLT-EB for ITER Plasma Facing Components

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1. Introduction

Korea heat load test facility by using electron beam (KoHLT-EB) [1,2] for the plasma facing components was constructed to evaluate the fabrication technologies and performance for the fusion reactor materials in Korea. Preliminary thermo-hydraulic and performance tests were conducted using various test mockups [3-5] for the plasma facing components in the high heat flux test facilities of the world [6-8]. The previous heat flux tests were performed by using the graphite heater facilities [9-11] in Korea. Several facilities which equipped with an electron beam as the uniform heat source were fabricated for the tokamak PFCs in the EU, Russia and US. These heat flux test facilities are utilized for a cyclic heat flux test of the PFCs. Each facility working for their own purpose in EU FZJ [6], US SNL [7], and Russia Efremov institute [8].

After the fabrication of ITER HCCR (Helium Cooled Ceramic Reflector) TBM (Test Blanket Module) small mock-ups, prototypes and TBM itself, the integrity and cooling performance should be tested under the similar operation condition of ITER. For this purpose, KoHLT-EB was constructed and this facility will be used for ITER TBM performance test with the small-scale and large-scale mockups, and prototype. Also, it has been used for other fusion application for developing plasma facing component (PFC) for ITER FW, tungsten divertor, and heat transfer experiment and so on under the domestic R&D program.

2. Methods and Results

2.1 W/FMS joining mockup fabrication

As the structural materials for the ITER HCCR TBM and future fusion reactor, the ferritic–martensitic steel (FMS) was used to fabricate the test mockups [12,13], and the FMS was grade-91 (ASTM A387, American Alloy Steel, USA). W/FMS joining mockups were fabricated by HIP (Hot Isostatic Pressings) technology. As an interlayer material, a titanium foil was used. The HIP process was conducted at 900 °C, 100 MPa for 1.5 hours to form a diffusion bonding in the interlayer. The tempering process was performed at 750 °C, 70 MPa for 2 hours for FMS [12]. The dimension of W tiles is 50 mm (Width) × 50 mm (Length) × 2 mm (Thickness) and grade-91 FMS substrate is 50 mm(W) × 50 mm (L) × 30 mm (T). Each component was prepared using an electro-discharge machining.

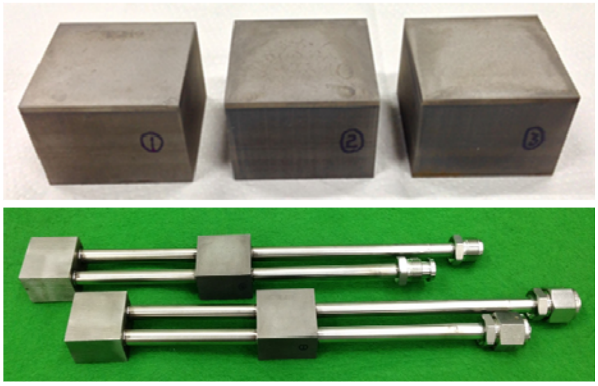

Fig. 1. W/FMS HIP joining mockups

The coolant manifolds were designed and fabricated to join into test mockups (FMS part) for the high heat flux test, shown in the Figure 1. Also the thermocouple hole (1.2 mm-Φ) was machined from the FMS back side into below the surface of tungsten side by 1 mm. one K-type thermocouple (1 mm-Φ) was installed in this hole to monitor the mockup temperature.

2.2 W/FMS coating mockup fabrication

Recently, W/FMS mockups by coating procedure were fabricated to evaluate the tungsten thin layer, and the vacuum plasma spray system (VPS) were used in this process [14]. The optimized coating processes were developed to maintain the coating layer.

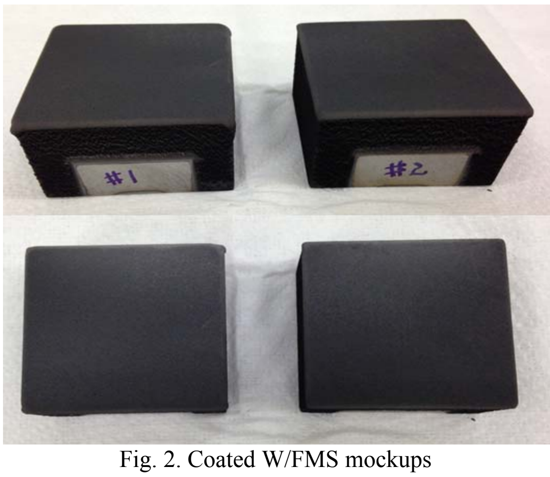

Fig. 2. Coated W/FMS mockups

Final tungsten coating layer was 3.65 (#1) and 3.7 mm (#2) thickness on the FMS substrate by using this VPS in the Figure 2. Also, the dimension of FMS substrate is 50 mm (W) × 50 mm (L) × 30 mm (T). Black color in the figure was a coated-tungsten layer, caused by VPS coating in vacuum.

2.3 Heat Load Test Facility

Korea heat load test facility by using electron beam (KoHLT-EB) [1,2] was constructed in November 2012 with an electron gun capacity of 800 kW (from Von Ardenne, Germany), as shown in Figure 3 and the facility is, at present, in operation to conduct the high heat flux tests for the plasma facing components development such as ITER blanket first wall, tungsten PFCs, ITER neutral beam duct liner, ITER HCCR TBM and so on.

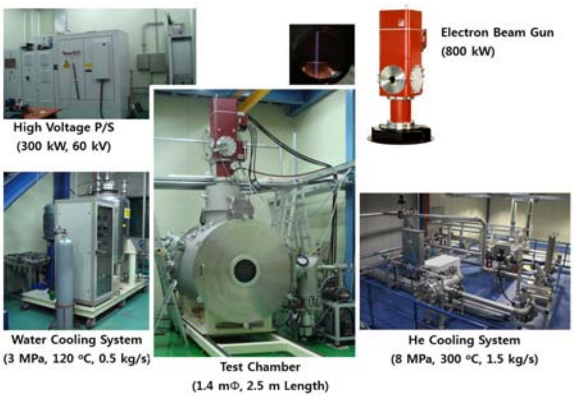

Fig. 3. High heat flux test facility KoHLT-EB

KoHLT-EB is capable of continuous operation, and also the pulsed operation of a cyclic heat load and controllable heat load, where the maximum allowable target dimension is 70 cm × 50 cm inside a vacuum chamber (about 140 cm diameter, 250 cm length). Table 1 and Table 2 show the specifications and operational parameters of this high heat flux test facility KoHLT-EB.

The electron beam gun equipped in KoHLT-EB has the beam performance, such as; maximum accelerating voltage, 60 kV, maximum beam power, 300 kW, focused beam spot below 10 mm in diameter, beam power bandwidth, 2 kHz and beam signal bandwidth, 20 kHz. Also, the beam scanning (deflection by pattern) system was installed in the exit port of electron beam gun; this beam control system has the beam parameter of the scanning frequency 10 kHz, dynamic beam deflection ±15° and static beam deflection ±22°. And the applied heat loads are 2.5 MW/m^2 (specific target area, 400 mm x 150 mm) and 20 MW/m^2 (150 mm x 50 mm).

This facility is connected to 3 MPa water cooling system for the test of high-temperature targets and decontamination system for beryllium filtration as shown in Figure 4. And for the performance test of ITER HCCR TBM, high temperature and high pressure (350 °C, 8 MPa) helium cooling facility was constructed, this Helium Supply System (HeSS) [15] will be connected to the KoHLT-EB for verification of design and manufacturing techniques of the HCCR TBM.

Table I: The Specifications for High Heat Flux Test Facility

Facility	KoHLT-EB
Major Target	PFCs development
Heat Flux	5 MW/m^2 (300×200 mm^2)
Heat Source	Electron Beam (MAX 60 keV)
Power Supply	300 kW (DC 60 kV)
Test Chamber	Cylindrical chamber (Φ1.4m×D2.5m)
Filling Gas	Vacuum condition
Vacuum System	1,900 lps TMP (base pressure < 10^{-6} mbar)
Coolant supplying System	Water: ~ 120 °C, 3 MPa, He gas: ~ 350 °C, 8 MPa

Table II: The Operational Parameters for the Electron Beam System

Beam power	150 kW (300 kW max.)
Acceleration voltage	0-60 kV
Mid-frequency high voltage power supply	300 kW max.
Beam diameter	< 10 mm (focused)
Pulse length	1 msec
Scanning area	700 mm x 500 mm
Scanning frequency	20 kHz

The temperature of this system is measured by calorimetry for the coolant temperature and heat flux, the thermocouples for the bulk temperature of the target, and IR camera and pyrometers for the mock-up surface temperature to the normal directions. Usually, before the high heat flux test for integrity test of fabricated mockup, NDT is performed using ultrasonic test (UT) facility [16], which was constructed in the next room of the KoHLT-EB facility.

2.4 Preliminary test

A thermal fatigue test shall be performed on the fabricated mockups to validate manufacturing technology, thermo-hydraulic performance and design validation using high heat load testing. The test parameters are defined along with numerically simulated conditions. In order to be implemented on the test mockups for the heat flux test, it shall have first successfully passed the formal manufacturing acceptance requirements, such as pressure test, leak test, and ultrasonic test for the interlayer. In this work, KoHLT-EB facility was used to evaluate thermal life cycle for the testing mockups.

The test conditions for high heat flux testing were evaluated thermo-hydraulic and thermo-mechanical analysis by using ANSYS CFD numerical code [13]. In the case for beam irradiation of 1.0 MW/m^2 heat load, and thermal cycles of 30 sec beam ON and 30 sec beam OFF. These results were optimized for applied heat load with the 0.15 kg/sec, 0.3 MPa, and room temperature water coolant. By this analysis, the maximum surface temperature of tungsten is below 457.3 °C, the temperature in the cooling pipe is below 150 °C.

Before the main fatigue test, the screening tests for thermo-hydraulics were performed to validate the bonding of interlayer. In the Figure 5, the heat load of 0.3-1 MW/m^2 were applied into the mockups, and each step was 5 cycles.

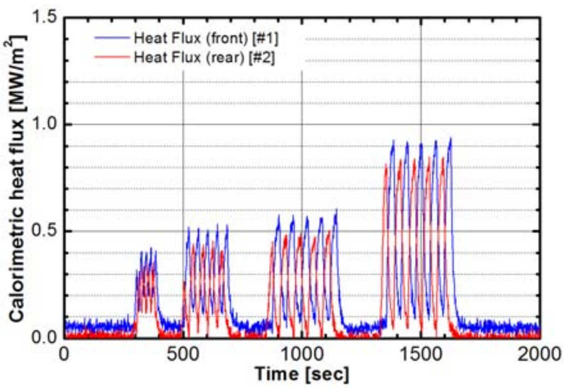

Fig. 5. Screening test for W/FMS HIP mockups

Near future, KoHLT-EB will be connected to the full scale high temperature and pressure helium loop HeSS [15] and it will be used for the thermo-hydraulic performance test of ITER HCCR TBM, which should provide the qualified data under the sound facility operation. The following qualification tests will be performed to evaluate the high heat flux test facility for the plasma facing components and fusion reactor materials.

3. Conclusions

Korea heat load test facility by using electron beam KoHLT-EB was constructed for the high heat flux test to verify the plasma facing components, including ITER TBM first wall. The qualification tests were performed to evaluate the high heat flux test facility for the PFCs and fusion reactor materials. For the thermal fatigue test, two types of tungsten mock-ups were fabricated. The cooling performance was tested under the similar operation condition of ITER and fusion reactor. After the completion of the preliminary mock-up test and facility qualification, the high heat flux test facility will assess the performance test for the various plasma facing components in fusion reactor materials.

Acknowledgment

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