Development and Qualification Test for ITER Plasma Facing Components in Korea

Suk-Kwon Kim*, Seong Dae Park, Hyung Gon Jin, Eo Hwak Lee, Jae-Sung Yoon, Dong Won Lee

Korea Atomic Energy Research Institute, Daejeon, Republic of Korea
**Corresponding author: skkim93@kaeri.re.kr*

1. Introduction

Korea heat load test facility by using electron beam (KoHLT-EB) [1] 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 in the high heat flux test facilities of the world [2-4]. 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. After the fabrication of small mock-ups and prototypes, 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 performance test with the small-scale and large-scale mockups, and prototype.

2. Methods and Results

2.1 W/FMS HIP joining mockup

As the structural materials for the ITER TBM and future fusion reactor, the ferritic–martensitic steel (FMS) was used to fabricate the test mockups [5], 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. 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.

The coolant manifolds were designed and fabricated to join into test mockups (FMS part) for the high heat flux test. 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

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 [6]. The optimized coating processes were developed to maintain the coating layer.

Final tungsten coating layer was 3.65 (#1) and 3.7 mm (#2) thickness on the FMS substrate by using this VPS. Also, the dimension of FMS substrate is 50 mm (W) × 50 mm (L) × 30 mm (T).

2.3 Heat Load Test Facility

Korea heat load test facility by using electron beam (KoHLT-EB) was constructed in November 2012 with an electron gun capacity of 800 kW (from Von Ardenne, Germany), as shown in Figure 1 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 TBM and so on.

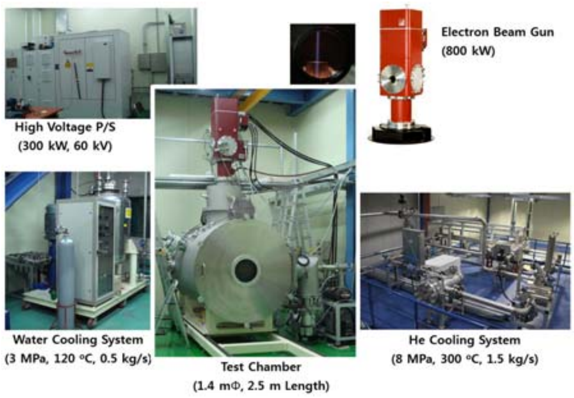

Fig. 1. High heat flux test facility KoHLT-EB

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). 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. For the performance test, high temperature and high pressure (350 °C, 8 MPa) helium cooling facility was constructed, this Helium Supply System (HeSS) will be connected to the KoHLT-EB for verification of design and manufacturing techniques.

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, which was constructed in the next room of the KoHLT-EB facility.

2.4 Heat load 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. 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.

Near future, KoHLT-EB will be connected to the full scale high temperature and pressure helium loop and it will be used for the thermo-hydraulic performance test, 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

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, and the applied heat load was 1 ~ 5 MW/m^2. 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 next fusion reactor materials.

Acknowledgment

This work was supported by a National Research Foundation of Korea (NRF) grant funded by the Ministry of Science, ICT and Future Planning of the Republic of Korea (NRF-2015M1A7A1A01002474).

REFERENCES

[1] Suk-Kwon Kim, Eo Hwak Lee, Jae-Sung Yoon, Dong Won Lee, Duck-Hoi Kim, and Seungyon Cho, “Commissioning of the Korean High Heat Flux Test Facility by Using Electron Beam System for Plasma Facing Components,” Fusion Science and Technology, vol.64, pp.288-292, 2013.
[2] Patrick Majerus, Rainer Duwe, Takeshi Hirai, Winfried Kuehnlein, Jochen Linke, Manfred Roedig, “The new electron beam test facility JUDITH II for high heat flux experiments on plasma facing components,” Fusion Engineering and Design, vol.75–79, pp.365-369, 2005.
[3] J.M. McDonald, T.J. Lutz, D.L. Youchison, F.J. Bauer, K.P. Troncosa, R.E. Nygren, “The Sandia plasma materials test facility in 2007,” Fusion Engineering and Design, vol.83, pp.1087-1901, 2008.
[4] G.M. Kalinin, V.Ya. Abramov, A.A. Gervash, V.B. Zolotarev, N.S. Krestnikov, I.V. Mazul, Yu.S. Strebkov, S.A. Fabritsiev, “Development of fabrication technology and investigation of properties of steel-to-bronze joints suggested for ITER HHF components,” Journal of Nuclear Materials, vol.386–388, pp.927-930, 2009.
[5] Yang-Il Jung, Jeong-Yong Park, Byoung-Kwon Choi, Dong-Won Lee, Seungyon Cho, “Fabrication of W/FMS joint mock-ups using a hot isostatic pressing,” Fusion Engineering and Design, vol.89, pp.1029–1032, 2014.
[6] Se-Yeon Moon, Bong Guen Hong, “Thick tungsten coating for fusion plasma-facing materials applied with a vacuum plasma spray coating method,” Surface and Coatings Technology, vol.280, pp.225-231, 2015.