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High Heat Flux Testing of Tungsten PFCs for the Fusion Reactor Development

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1. Introduction

Tungsten divertor plasma facing components (PFCs) were fabricated by using hot isostatic-pressing (HIP) bonding and vacuum plasma spray method (VPS) for the fusion reactor development. Tungsten mockups were designed for the high heat flux test with the Korean high heat flux test facility - electron beam (KoHLT-EB), which was constructed for the performance qualification of various PFCs. KoHLT-EB was used to qualify the PFCs performances of each fusion research. The high heat load conditions were simulated by using a thermo-hydraulic analysis tool with the ANSYS-CFX code. A high heat flux testing was performed up to the thermal life-time of each mockup with the evaluated conditions in 1 ~ 5 MW/m^2. HIP-bonded testing mockups consisted of 2 mm pure tungsten PFCs and ferritic-martensitic steel (FMS) as structural materials, and VPS mockups are comprised with 1 ~ 2 mm coated tungsten layer and FMS. These tungsten mockups are the candidate for the blanket and divertor in DEMO or a fusion power reactor.

2. Methods and Results

2.1 W/FMS HIP joining mockup

As the structural materials for the ITER TBM and next fusion reactor, the ferritic-martensitic steel (FMS) was used to fabricate the test mockups [1], and the FMS was grade-91 (ASTM A387). W/FMS joining mockups were fabricated by HIP method. An interlayer material is thin titanium foil, the HIP process was conducted at 900 °C, 100 MPa to form a diffusion bonding. 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. Figure 1 shows the installation of W HIP mockups in the KoHLT-EB target assembly.

Fig. 1. Fabrication and installation of W HIP joining mockups

2.2 W/FMS coating mockup

Recently, W/FMS mockups by coating procedure were fabricated to evaluate the tungsten thin layer, and the VPS were used in this process [2]. The optimized coating processes were developed to maintain the coating layer.

Final tungsten coating layer was 3.65 and 3.7 mm 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), as shown Figure 2.

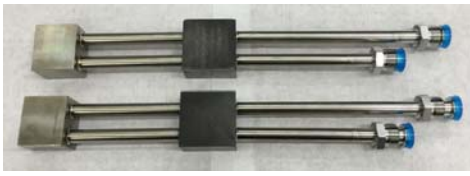

Fig. 2. Fabrication of W coated mockups

2.3 Heat Load Test Facility

Korea heat load test facility by using electron beam (KoHLT-EB) [3] was constructed with an electron gun capacity of 800 kW, as shown in Figure 3. This facility is in operation to conduct the high heat flux tests for the plasma facing components development such as ITER blanket first wall, tungsten PFCs, ITER TBM and so on. KoHLT-EB is capable of continuous operation, and also the pulsed operation of a cyclic heat load and controllable heat load. 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, and beam signal bandwidth, 20 kHz. The beam scanning system was installed in the exit port of electron beam gun, and the applied heat loads are 2.5 MW/m^2 (400 mm x 150 mm).

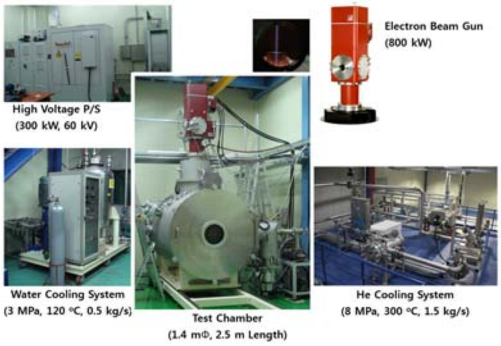

Fig. 3. High heat flux test facility, KoHLT-EB

This facility is connected to the water cooling system for the test of high temperature targets. Also a high temperature and high pressure (350 °C, 8 MPa) helium cooling facility is connected to the KoHLT-EB. 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 pyrometers for the mock-up surface temperature to the normal directions.

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 1.5 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 0.35 kg/sec, 0.3 MPa, and room temperature water coolant.

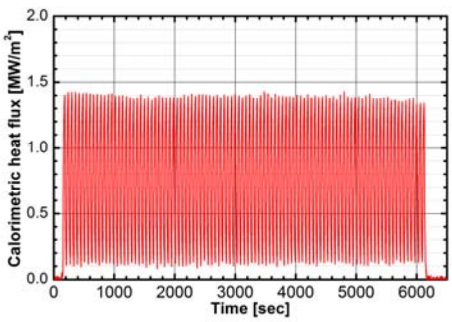

Fig. 4. Distribution of the high heat flux for the tungsten HIP joining mockups

Figure 4 shows the distribution of the high heat flux for the tungsten HIP joining mockups. First mockup was delaminated in the edge of tungsten tiles and second mockup up to 469 cycles is passed the high heat flux testing successfully up to 1,000 cycles (target value). Figure 5 shows the strain-failure formula curve, also the test position were checked inside the figure.

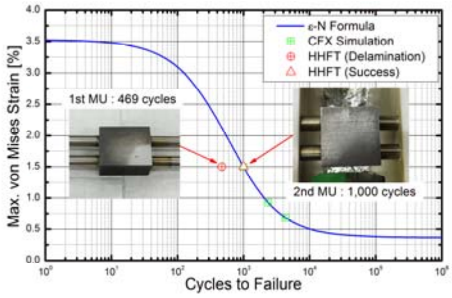

Fig. 5. Strain-'cycles to failure' formula and test results

3. Conclusions

For the thermal fatigue test, two types of tungsten mock-ups were fabricated by using HIP bonding and VPS method for the fusion reactor development. The verification of the cooling performance was tested under the 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 assess the performance test for two type of plasma facing components.

Acknowledgment

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