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Performance Qualification for High Heat Load Components of Fusion Reactor in KAERI

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1. Introduction

Korea heat load test facility (KoHLT-EB) [1] was constructed for the developments of plasma facing components (PFCs) to elucidate the ITER and DEMO technology [2]. The tokamak PFCs are the first wall, divertor, heating ports, and diagnostics ports, etc. Each PFC is comprised of an armour materials, a heat sink for the cooling, and the structural materials. Be, W, C-composites, and advanced materials were selected for these armour. For the effective cooling performance, each armour was bonded to heat sink or structural materials. In this study, we used four types of bonding technologies, such as HIP (Hot Isostatic Pressing), coating, brazing and 3D printing methods, and performed by using KoHLT-EB for high heat flux testing to evaluate a thermal life-time.

2. Methods and Results

2.1 W/FMS HIP bonding

The ferritic–martensitic steel (FMS) was developed as the structural materials for the fusion reactor [2], also ARAA materials was procured to fabricate the ITER TBM and DEMO materials in Korea. [3,4]. In this work, FMS grade-91 (ASTM A387, American Alloy Steel, USA) was used to fabricate the test mockups [5]. W/FMS mockups were fabricated by using HIP (Hot Isostatic Pressings; ASTM A989/A989M) technology. We used the titanium thin foil as an interlayer material. The dimension of tungsten tiles is 50 mm × 50 mm × 2 mm (Thickness) and grade-91 FMS substrate is 50 mm × 50 mm × 30 mm (Thickness). The coolant manifolds were designed and fabricated to join into test mockups (FMS part) to install into KoHLT-EB, shown in the Figure 1. Two mockups were installed into the target assembly with Cu heat dump.

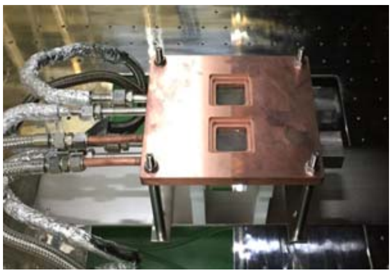

Fig. 1. Target assembly of W/FMS (Grade.91) bonding mockups by using HIP technology

2.2 W coating

The other fabrication technology for W/FMS mockups is the coating procedure by using the vacuum plasma spray system (VPS) [6]. The thickness of tungsten coating layer was 3.65 and 3.7 mm on the FMS (ARAA [3,4]) substrate in the Figure 2. The dimension of the substrate is 50 mm × 50 mm × 30 mm (Thickness).

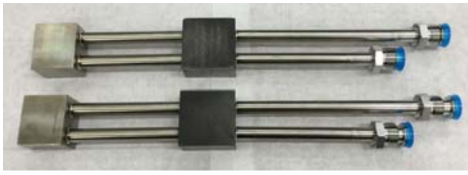

Fig. 2. Fabrication of W coated mockups

2.3 W/Cu bonding

Divertor technologies as PFCs of KSTAR was developed by using brazing and HIP technology. [7] This study was performed by KSTAR team in Korea. Now we are testing the KSTAR mockups and prepared the 10 MW/m^2 heat load testing in figure 3.

Fig. 3. Target assembly of W/Cu bonding mockups for KSTAR

2.4 3D Printing

The divertor should remove the extreme heat flux up to 10 MW/m^2 and the various type of divertor have been developed for enhancing the heat transfer such as hypervapotron, twisted tape insertion, etc. for the limitation of complexity to mechanical machining, now 3D printing method is used to fabrication of multi-layer cooling devices. [8] In this study, an optimized cooling structure was fabricated with metal powder by using 3D printing technology in figure 4. Preliminary thermal-hydraulic analysis was performed to confirm the effects of the inner cooling geometry with a conventional CFD code, ANSYS-CFX. [9].

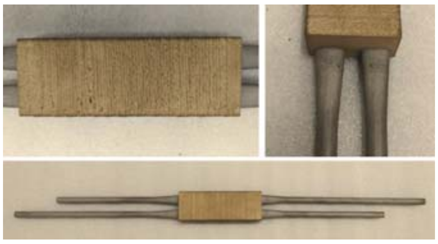

Fig. 4. 3D printing mockup

2.5 Heat Load Test Facility

Korea heat load test facility by using electron beam (KoHLT-EB) [1] was constructed in November 2012 with an electron gun from Von Ardenne, Germany. This electron beam facility with an 800 kW electron gun for a high heat flux with a maximum beam power of 300 kW is now in operation to conduct high heat flux tests for the plasma facing components, as shown in Fig. 5. Also, the beam scanning system was installed for the homogeneous beam deposition to the target mockups. The allowable target dimension is 70 cm × 50 cm in a vacuum chamber (about 140 cm diameter, 250 cm length).

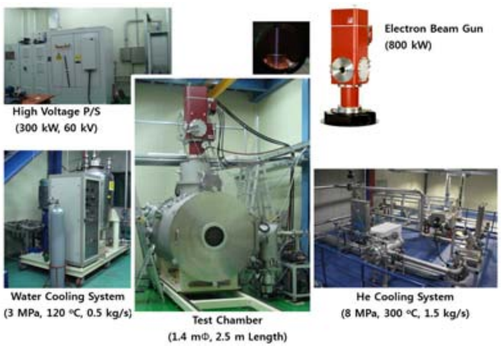

Fig. 5. High heat flux test facility, KoHLT-EB

This facility is connected to the water cooling system for the test of high temperature targets. Also a high temperature and high pressure (300 °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.

2.6 Heat load test

Before the thermal life-time testing, we performed the screening test for the safety and optimized beam power for the testing heat load. Figure 6 shows the elevated heat load up to 1.5 MW/m^2.

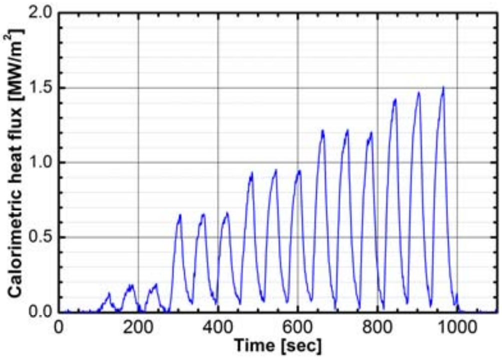

Fig. 6. Screening test and heat load for W/FMS HIP mockups

The temperature distribution is shown in the Figure 7 in the test condition of heat load 1.5 MW/m^2, also, electron beam of KoHLT-EB was tuned as a thermal cycles of 30 sec beam ON and 30 sec beam OFF. The cooling conditions were 0.35 kg/sec of flow rate, 0.3 MPa pressure, and room temperature of inlet water coolant. In this cyclic testing, the base temperature was 90 °C, and peak temperature was 570 °C.

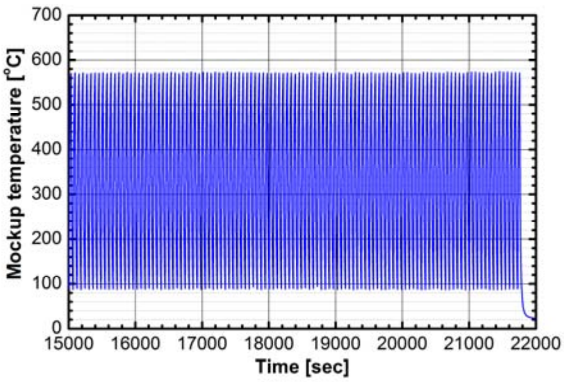

Fig. 7. Temperature distributions for W/FMS HIP mockups at 1.5 MW/m^2 heat load

3. Conclusions

For the development of PFCs, various small mockups were fabricated by using four types of bonding techniques and tested in a high heat flux test facility to evaluate the cyclic life-times. The high heat flux facility KoHLT-EB has been operated for the high heat load test of PFCs. Tungsten armour mockups were, such as W and FMS HIP bonding, W coating in FMS structural materials up to 3 mm, W and Cu bonding, and 3D metal printing cooling structure. And thermo-hydraulic tests and thermal fatigue tests were performed to qualify the mockups specification and bonding techniques. W/FMS HIP mockups were passed the thermal fatigue test successfully up to 1,000 cycles. And the screening test was performed for the W coated mockups as elevating heat load conditions. W/Cu bonding mockups for KSTAR tokamak now under the test in Korea. Also we selected the 3D printing technology for the complex cooling channel for next tokamak concepts.

Acknowledgment

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