

Fabrication and Qualification Testing of Plasma Facing Components for the Nuclear Fusion Research

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1. Introduction

ITER divertor should remove the extreme heat flux up to 10 MW/m^2 (and 20 MW/m^2 in the transient condition) and various type of divertor have been developed for enhancing the heat transfer. For the limitation of mechanical machining, 3D metal printing technology is selected to fabricate the multi-layer cooling devices for the development of fusion divertor research. Thermo-hydraulic testing was performed in Korean heat load test facility using an electron beam (KoHLT-EB). For the high heat flux testing, various mockups were fabricated by many bonding technique, such as HIP (Hot Isostatic Pressing), VPS (Vacuum Plasma Spray) coating, and 3D metal printing method. Tungsten-armored mockups were fabricated by the HIP between W and FMS (Ferritic-Martensitic Steel), W coating in FMS. 3D printed mockup was designed and fabricated based on the optimization of the 3D cooling structure. KoHLT-EB was used to evaluate the thermos-hydraulic enhancement. Present results will contribute to the development of a Korean fusion research and DEMO reactor.

2. Methods and Results

2.1 High Heat Flux Testing Facility, KoHLT-EB

Korea heat load test facility by using electron beam (KoHLT-EB) [1] is operated in KAERI with an electron gun from Von Ardenne, Germany. In addition, several facilities with an electron beam gun were operated in the EU, Russia, US, and India [2-8]. KoHLT-EB 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. 1. Also, the beam scanning system was installed for the homogeneous beam deposition to the target mockups. KoHLT-EB is connected to the water cooling system for the test of high temperature targets. Also helium cooling system of a high temperature and high pressure is connected to this facility. The temperature of this system is measured by calorimetry for the coolant temperature and heat flux. Also, the thermocouples for the target, and pyrometers for the measurement of mock-up surface temperature were equipped in the diagnostic system.

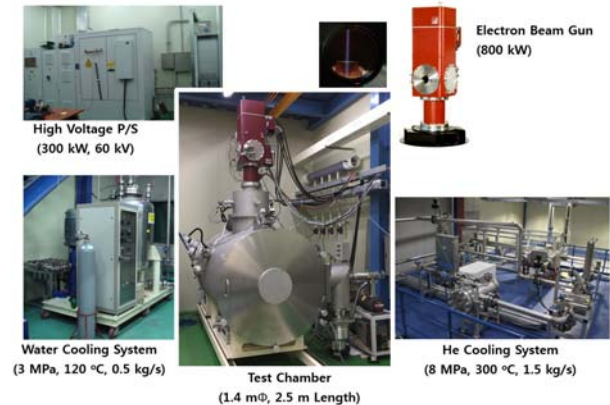


Fig. 1. High heat flux testing facility, KoHLT-EB

2.2 Mockup fabrication

The ferritic-martensitic steel (FMS) was developed as the structural materials for the fusion reactor, also ARAA materials was procured to fabricate the ITER TBM and DEMO materials in Korea [9]. FMS grade-91 (ASTM A387) and ARAA were used to fabricate the test mockups [10,11]. W/FMS bonding mockups were fabricated by using HIP (Hot Isostatic Pressings) technology and VPS (Vacuum Plasma Spray) coating method, in Fig. 2. For the fabrication of HIP mockups, the dimension of tungsten tiles is $50 \text{ mm} \times 50 \text{ mm} \times 2 \text{ mm}$ (thickness) and grade-91 FMS substrate is $50 \text{ mm} \times 50 \text{ mm} \times 30 \text{ mm}$ (thickness). And the dimension of the VPS substrate is $50 \text{ mm} \times 50 \text{ mm} \times 30 \text{ mm}$ (thickness). The thickness of tungsten coating layer by using the VPS process was 3.65 and 3.7 mm.



Fig. 2. W/FMS HIP bonding mockups (top) and coated mockups (bottom).

2.3 Fabrication of 3D metal Printing Mockups

ITER divertor was designed to remove the plasma heat load up to 10 MW/m² (steady) and 20 MW/m² (transient) and two concept have been developed for enhancing the heat transfer performance such as hypervapotron and twisted tape insertion. 3D metal printing technology was used to fabricate the multi-layer cooling devices [12-14]. An optimized cooling design mockups were fabricated with metal powder by using 3D printing technology. Three type mockup were fabricated, one mockup was machined from Al-bronze block, and the enhanced/optimized mockups were fabricated by using 3D metal printing technology for the industrial application, shown in Fig. 3 and 4. The enhanced mockup was fabricated with the 3D printed tube, and the optimized mockup was equipped with 3D printed swirl tapes (bottom right of Fig. 4).

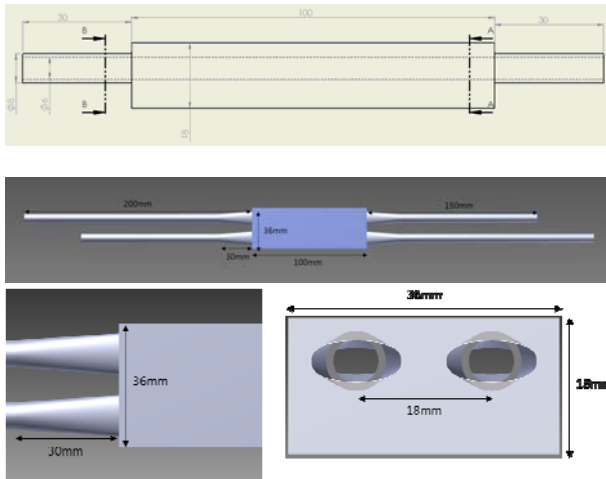


Fig. 3. Conceptual design of 3D metal printing mockups. (Top) reference mockup, (bottom) enhanced/optimized mockup.

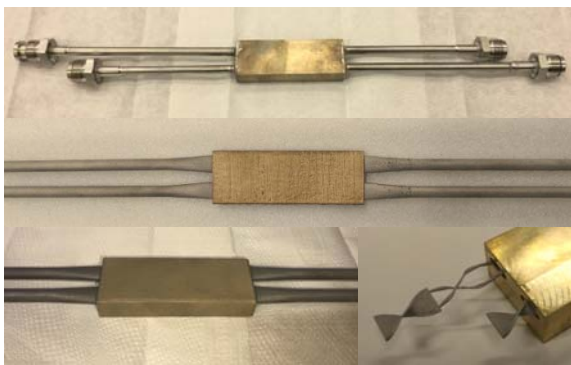


Fig. 4. 3D metal printing mockups with Al-bronze powder. (Top) reference mockup, (middle) enhanced mockup, and (bottom) optimized mockup.

2.4 Thermo-hydraulic performance testing

3D mockups were installed and tested to evaluate the thermo-hydraulic performance. Fig. 5 shows the

enhancement of heat removal performance of enhanced mockup at 1 MW/m². The test conditions are described in the Table 1.

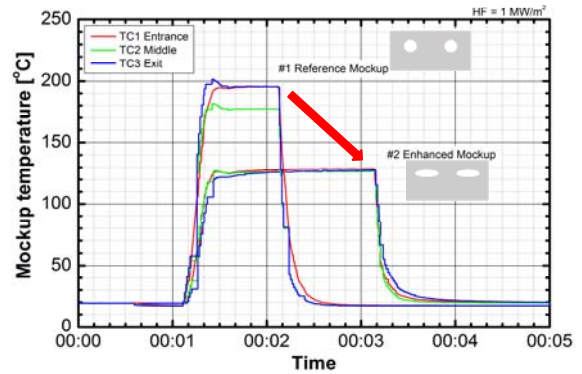


Fig. 5. Temperature response of reference mockup.

Table 1. Test conditions for the thermo-hydraulic performance testing.

Heat Flux		Water Coolant	
Incident Power [kW]	42	Pressure [bar]	8.5
Absorbed Power [kW]	23	Pressure Difference [bar]	3.6
Target Area [mm ²]	98x35	Flow Rate [kg/sec]	0.22
Heat Flux [MW/m ²]	6.5		

Fig. 6 shows the temperature response of enhanced/optimized 3D printing mockups in the test condition of heat load from 1 up to 6.5 MW/m².

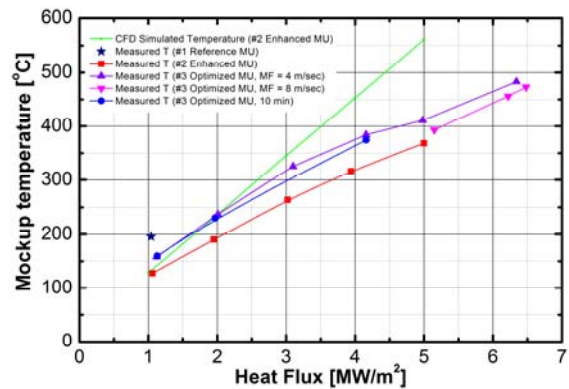


Fig. 6. Temperature response of testing mockups up to 6.5 MW/m² heat load

3. Conclusions

Plasma facing components for the high heat flux testing were fabricated and thermo-hydraulic and life-time testing was performed as selected for the development of fusion divertor and blanket first wall in KoHLT-EB high heat flux test facility. The various

cooling mockups for ITER, DEMO, and fusion research have been fabricated, such as HIP bonding, VPS coating, and 3D metal printing. 3D printed mockups were fabricated based on the optimization of cooling structure. Thermo-hydraulic testing for the fabricated mockups was performed in KoHLT-EB. These results will contribute the development of fusion research and DEMO concept.

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