Manufacturing and High Heat Load Testing of 3D Printed Divertor Mockups for Nuclear Fusion Reactor

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1. Introduction

ITER divertor should remove the extreme heat flux up to 10 MW/m^2 and various type of divertor have been developed for enhancing the heat transfer such as hypervapotron, twisted tape insertion, etc. For the limitation for the complexity of mechanical machining, 3D metal printing technology by direct energy deposition is used to fabricate the multi-layer cooling devices for the development of fusion divertor research, and for the optimization of the thermo-hydraulic performance with water cooling in a Korean heat load test facility using an electron beam (KoHLT-EB). An optimized cooling structure was fabricated with Al-bronze commercial metal powder by using 3D printing. Preliminary thermal-hydraulic analysis was performed to confirm the effects of the inner cooling geometry with a conventional CFD code, ANSYS-CFX. 3D printed divertor mockup was designed and fabricated based on the optimization of the 3D cooling structure. KoHLT-EB was used to evaluate the enhancement of the cooling capacities. The present research results will contribute to the development of a Korean fusion reactor and DEMO research.

2. Methods and Results

2.1 Heat Load Test Facility

Korea heat load test facility by using electron beam (KoHLT-EB) [1] is operated in KAERI 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. 1. 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.

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.

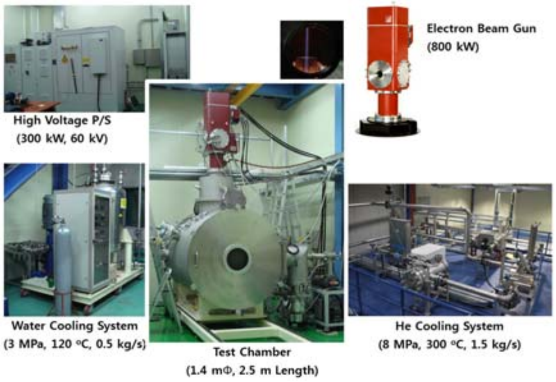

Fig. 1. High heat flux test facility, KoHLT-EB

2.2 3D Printing Mockups

ITER divertor was designed to remove the plasma heat load up to 10 MW/m^2 and two divertor concept have been developed for enhancing the heat transfer performance such as hypervapotron and twisted tape insertion. There is some limitation for the complexity of mechanical machining, so 3D metal printing technology was used to fabricate the multi-layer cooling devices. [2-4] In this study, an optimized cooling structure was fabricated with metal powder by using 3D printing technology. Preliminary thermal-hydraulic analysis was performed to confirm the effects of the inner cooling geometry with CFD code, ANSYS-CFX. [5]

Three mockups were fabricated; reference mockup, enhanced mockup, and optimized mockup.

Reference mockup was machined from Al-bronze block in Fig. 2, Enhanced and Optimized mockups were fabricated from Al-bronze powder by using 3D metal printing technology for the industrial application, shown in Fig. 3 and 4, respectively.

Fig. 2. Reference mockup by Al-bronze machining

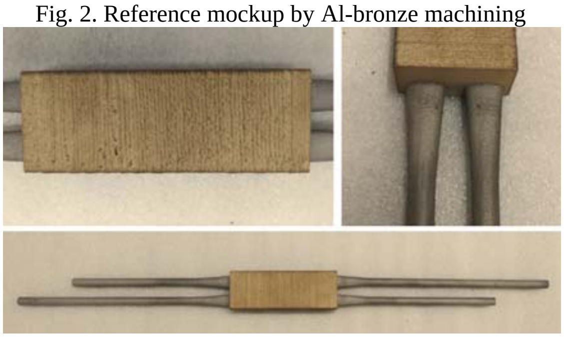

Fig. 3. Enhanced mockup by using 3D metal printing with Al-bronze powder

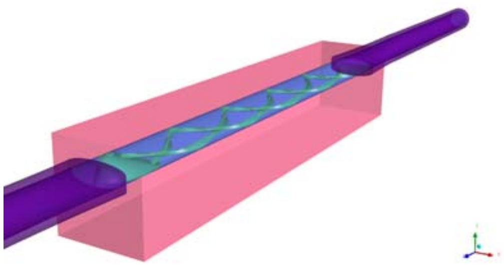

Fig. 4. Optimized mockup (Top) by using 3D metal printing with Al-bronze powder and swirl tube insert (Bottom).

2.3 Thermo-hydraulic performance

Firstly, the reference mockup was installed and tested to evaluate the thermos-hydraulic performance. Fig. 5 shows the heal flux and temperature response at 1 MW/m^2. Maximum temperature of mockup is 295 °C, by measuring the thermocouples positioned at 1 mm depth.

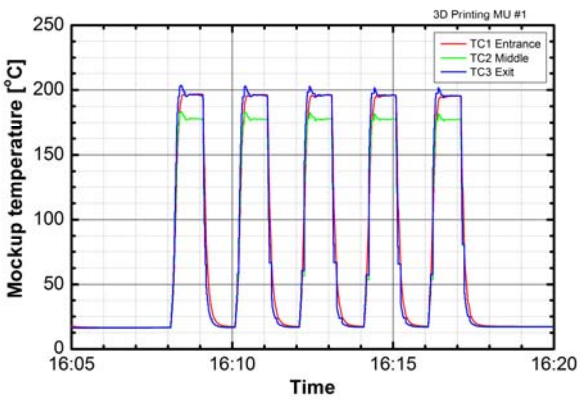

Fig. 5. Temperature response of reference mockup

Fig. 6 shows the temperature response of enhanced mockup in the test condition of heat load from 1 up to 5 MW/m^2. Maximum temperature is 485 °C in the middle of mockup at 5 MW/^{2}. We will compare the thermos-hydraulic analysis and the experimental results, so determine the enhanced and optimized cooling channel devices.

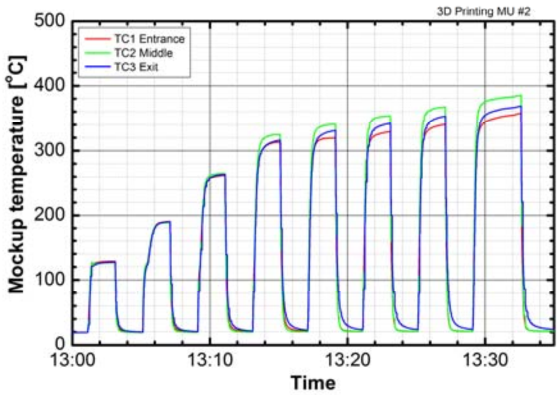

Fig. 6. Temperature response of enhanced mockup up to 5 MW/m^2 heat load

3. Conclusions

3D metal printing technology was selected for the development of fusion divertor research, and the optimization of thermo-hydraulic performance with a water cooling in KoHLT-EB facility. The various cooling design for ITER and DEMO divertor have been fabricated for the enhancement of cooling performance, such as swirl tube and hypervapotron. 3D printed divertor mockup was designed and fabricated based on the optimization of 3D cooling structure. These research results will contribute the development of Korean fusion reactor and DEMO research.

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