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Design and Analysis of HIP joined W and Ferritic-Martensitic Steel Mockup for Fusion Reactor Divertor Development

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1. Introduction

Korea has developed a Helium Cooled Ceramic Reflector (HCCR) based Test Blanket System (TBS) for an ITER [1-5], which consists of the First Wall (FW), Breeding Zone (BZ), Side Wall (SW), and BZ box. Among them, the FW is an important component which faces the plasma directly and, therefore, it is subjected to high heat and neutron loads. The FW of the TBM is considered to be composed of (1) a beryllium (Be) armor as a plasma-facing material and Ferritic-Martensitic (FM) steel as a structure material, or (2) a tungsten (W) armor and FM steel, or (3) bare FM steel. Since Be/FMS and bare FMS were developed and proved by high heat flux (HHF) test, W armor and FM steel joining, fabricated mock-ups, and preparation of the high heat flux (HHF) test for integrity investigation are introduced in the present study.

2. Fabrication of the W/FMS mockup

The joining of W to FMS was developed using hot isostatic pressing (HIP, 950 ^{o}C, 100 MPa, 1.5 hours) with following post heat treatment (tempering, 750 ^{o}C, 70 MPa, 2 hours). Further, an interlayer was used in the W tile side for diffusion bonding. Thus far, several interlayers have been attempted, and the following condition was used for fabricating the mockups: 32μm-Ti, as shown in Fig. 1. For proper installation in the test facility, Korea Heat Load Test (KoHLT-2), the connecting tubes and thermocouple installation were reflected in the design, as shown in Fig. 2, in which a thermocouple for the W tile temperature measurement (1.5 mm from the heated surface) will be inserted through holes drilled with a 1.2 mm diameter in each mockup.

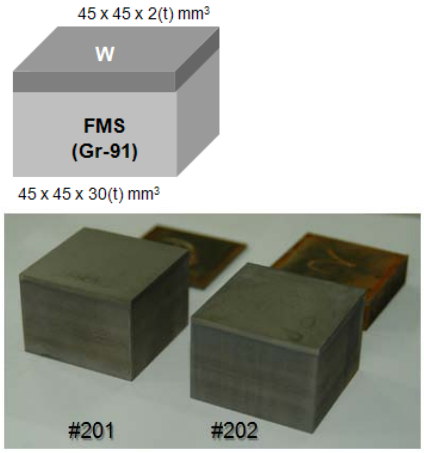


Fig. 1 Photograph of the fabricated W/FMS mockups

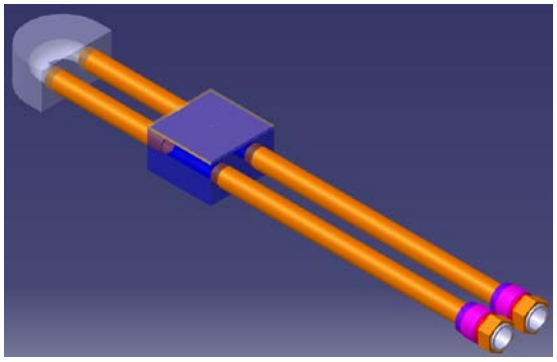


Fig. 2 Design of the W/FMS mockup for installation to KoHLT-2

3. Test conditions by preliminary analysis

The Preliminary analyses were carried out to specify the appropriate testing conditions of the mockups. In this test, only the surface heat flux was considered, and the water condition was reflected considering the KoHLT-EB water supply system (0.3 MPa, 25 ^{o}C). To reduce the length of the test time, an accelerated test was performed by increasing the heat flux to 0.5 and 1.0 MW/m^2. The heat flux amounts were determined to avoid the evaporation temperature of W. A 3-dimensional analysis was performed using ANSYS-13.

When a steady heating condition, the centered temperature of the W armor was about 285.3 ^{o}C. For 30 sec, it increased up to 257.3 ^{o}C which was 90% of the steady temperature. When cooling the mockup during 30 sec, it became 49.8 ^{o}C and it did not increase for 5 repeated cycles, as shown in Fig. 3. The temperature distributions of the 5th cycle of mockups under a 0.5 MW/m^2 heat flux are shown in Fig. 4. The same simulation was performed with the 1.0 MW/m^2 heat flux, as shown in Fig. 5. The simulation and test conditions are summarized in Table 1.

Table 1 Simulation conditions for W mock-up

Items	Conditions	Remark
Surface heat flux [MW/m^2]	0.5 / 1.0	5 cycles per each heat flux
Total water flow	0.15 kg/sec	
Inlet water conditions	0.3 MPa, 25 ^{o}C	Test conditions
Duration time	30 sec heating 30 sec cooling	60 sec duration time

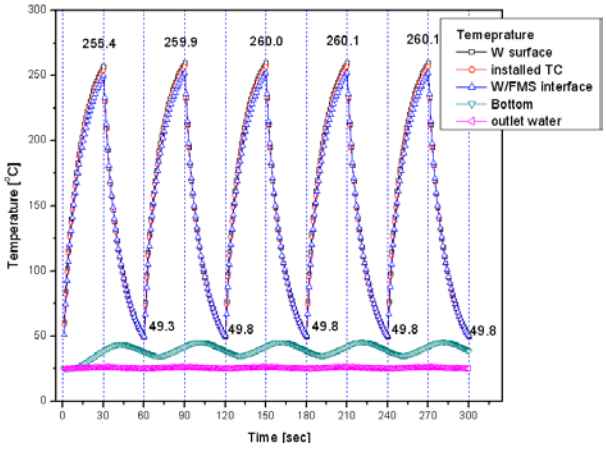
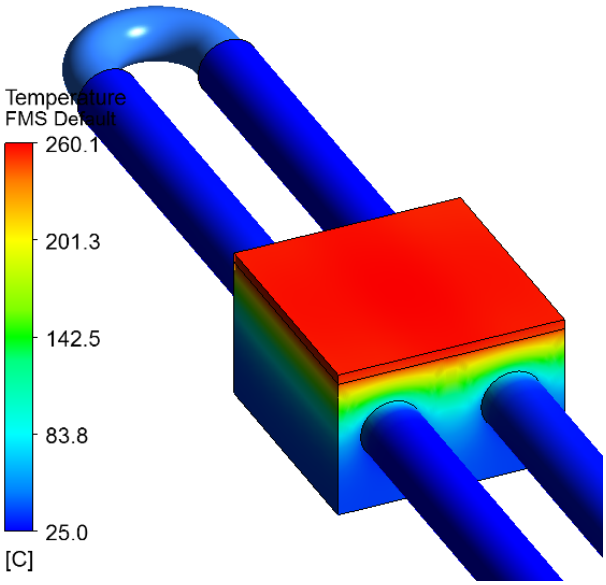


Fig. 3 Temperature evolution during 3 cycles with 0.5 MW/m^2 heat flux



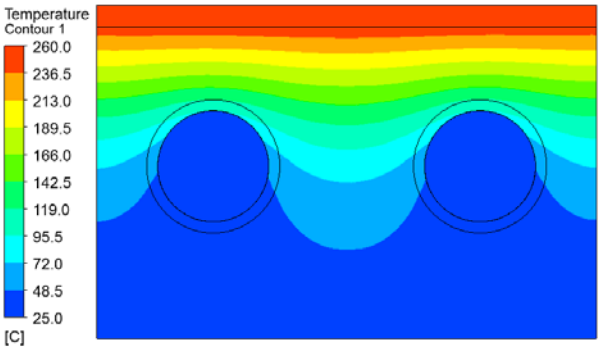


Fig. 4 Temperature distribution at heating time (270 sec, 5th heating)

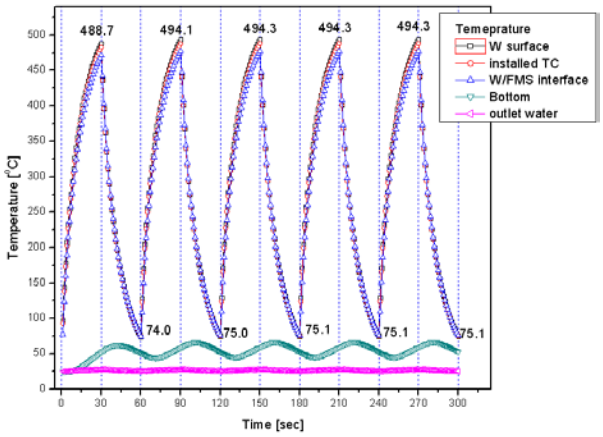


Fig. 5 Temperature evolution during 3 cycles with 1.0 MW/m^2 heat flux

4. Conclusion

For the application to fusion reactor, joining methods with W to FMS has been developed. The W mock-up was fabricated with HIP considering Ti interlayer and PHHT condition. And the HHF test was prepared by performing the preliminary analysis to determine the test conditions. From the analysis heating and cooling conditions were determined for 0.5 and 1.0 MW/m2 heat fluxes.

In the near future, the thermal life-time will be evaluated to determine the test period of the mockups by the mechanical analysis with ANSYS.

Acknowledgement

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