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Fabrication and High Heat Flux Test Preparation of a Half-scale Sub-module Mock-up for the TBM First Wall

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1. Introduction

Korea (KO) has developed and participated in the Test Blanket Module (TBM) program in the ITER, in which Ferritic martensitic (FM) steel was used as the structural material for the TBM first wall (FW). To develop the fabrication method for the TBM FW and verify its integrity, a half-scale sub-module mock-up was fabricated and integrity test has been prepared. Two manifolds for connecting with the water supplying system in high heat flux (HHF) test were fabricated and welded with the mock-up. Pressure and He leak tests were successfully performed without any leak and failure. The flow rates in each channel were measured with the conventional ultrasonic sensor but it shows non-uniform flow distribution at each channel differently from the estimation by ANSYS-CFX. HHF test conditions were evaluated through the ANSYS-CFX analysis considering the above measured flow rates in each channel and it shows non-uniform temperature distribution of the FW surface. Now a new manifold design or modification of the fabricated one is being considered for a uniform flow distribution at each channel of the mock-up.

2. Fabrication of a half-scale sub-module mock-up

In the previous study, the parts of the mock-up were fabricated and prepared just before the Hot Isostatic Pressing (HIP) [1,2]. In this year, the mock-up was finally fabricated; HIPping of the welded plate and back plates, then machining the canned plate and inner block part. The helium leak tests were performed after fabricating each part of the mock-up and it is important procedure to check the leakage before HIP. The height of the mock-up is 444 mm, and its width and length are 260 mm and 435 mm, respectively. A photograph of the manufacturing process of the mock-up is shown in Fig. 1. A pair of manifolds were designed and fabricated to distribute coolant uniformly to 10 channels in the half-scale sub-module mock-up. In its design, an ANSYS-CFX analysis was used in the previous study [3]. The fabricated manifolds were welded to the mock-up, and a pressure and a helium leak test were performed.

3. Preparation of integrity test

For confirming the joint integrity of the fabricated mock-up, high heat flux (HHF) test with electron-beam facility has been prepared; (1) neutron radiography was performed for observing the internal channels. Then, (2) flow distribution at each channel of the mock-ups was measured using the ultrasonic sensors. (3) HHF test conditions were evaluated with the CFD code (ANSYS-CFX) with the measured flow rates.

Fig. 1. Manufacturing process for a half-scale sub-module mock-up.

3.1. Neutron radiography test

To investigate the deformation of the cooling channels after the fabrication of the mock-up, neutron radiography was carried using HANARO neutron radiography facility (NRF), which is research reactor at KAERI. Thermal flux of neutron is up to 10^7 n/cm^{2}sec and its maximum detectable size of defect is about 250 μm for hole and 16 μm for gap. Figure 2 shows one of the photos and it shows the internal channel of the mock-up clearly and even the internal structure of the manifolds. From the neutron radiography, we cannot find any severe deformations in all channels and defect in the mock-up.

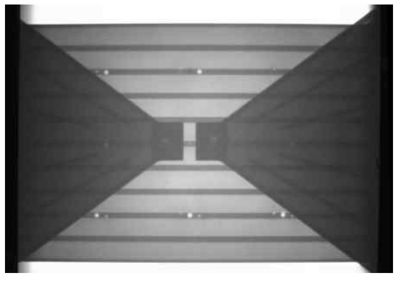

Fig. 2. Photograph of neutron radiography of the half-scale sub-module mock-up.

3.2. Flow distribution test

A flow distribution test was performed using an ultrasonic flow meter and total mass flow rate was measured with the conventional flow meter. The experimental loop for the flow distribution test consists of a pressurized water tank, pump, and valve systems. The water in the pressurized water tank passed the valve system, and then flowed to the mock-up and returned to the water tank as shown in Fig. 3. The used ultrasonic sensor is a conventional one, FUP1010. It measures averaged line velocity in the channel with the time difference according to the flows.

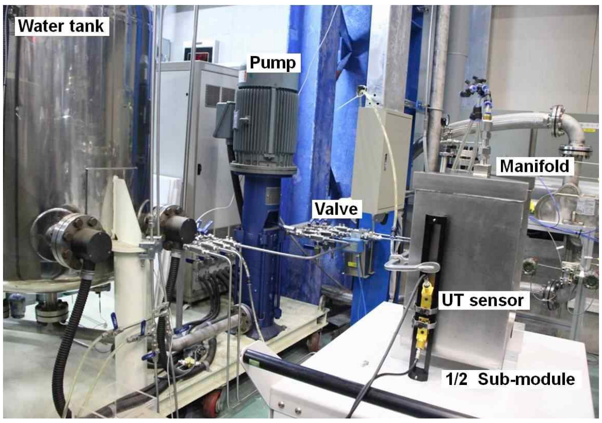

Fig. 3. An experimental loop for the flow distribution test of the half-scale sub-module mock-up.

Using the calibrated sensors, flow distribution test was performed; to keep the overall flow rate uniformly, flow velocities at each channel was measured one by one with a pair of ultrasonic sensors. The flow rates were changed from 0.1 kg/s to 0.6 kg/s. The measured and estimated velocities by ANSYS-CFX in case of 0.5 kg/s flow rate were compared as shown in Fig. 4. The reason of a discrepancy between experiment and analysis will be found but the previous HHF test simulation should be evaluated again since the current manifold cannot give a uniform flow rate at each channel. In the previous HHF test simulation, it was assumed that the flow rate at each channels are the same.

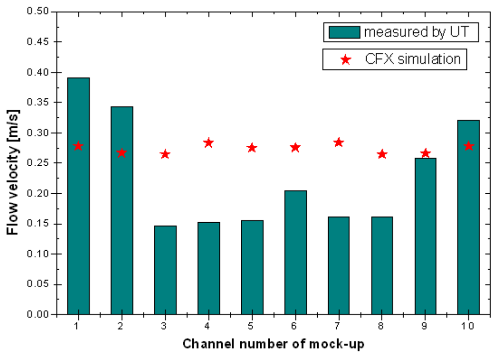

Fig. 4. Velocities in the cooling channels of the half-scale sub-module mock-up at a flow rate of 0.5 kg/s and the expected flow rate from a CFX analysis.

3.3. HHF simulation

Preliminary analyses were carried out again to check the effect of the flow rate difference. In the same way to the previous study, only the surface heat flux was considered up to 0.5 MW/m^2 and the water condition was reflected considering the water supply system (0.3 MPa, 25 ^{o}C) of the HHF test facility. And flow rate at each channels were used from the measured one. Figures 8 and 9 shows a 3-dimensional analysis results performed with ANSYS-CFX; they show a temperature distributions at 2nd heating (270 sec) and a temperature evolution for 2 cycles, respectively. The results show that the non-uniform flow rate caused the temperature difference in mock-up and it can affect the integrity test. Therefore, the manifolds will be fabricated again or modified before performing the HHF test.

4. Conclusions

A half-scale sub-module mock-up was successfully fabricated; HIPping of the welded plate and back plates, then machining the canned plate and inner block part. The height of the mock-up is 444 mm, and its width and length are 260 mm and 435 mm, respectively. For confirming the joint integrity of the fabricated mock-up, HHF test with E-beam facility has been prepared. The prepared manifolds were welded to the mock-up, and pressure and helium leak test were performed. Then, neutron radiography was performed for observing the internal channels of the mock-up. A flow distribution at each channel of the mock-ups was measured using the ultrasonic sensors. The measured and estimated velocities by ANSYS-CFX in the case of 0.5 kg/s flow rate were compared. Preliminary analyses for determining the HHF test conditions were carried out again to check the effect of the flow rate difference. The results show that the non-uniform flow rate caused the temperature difference at mock-up and it can affect the integrity test. Therefore, the manifolds will be fabricated again or modified before performing the HHF test.

References

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