Transactions of the Korean Nuclear Society Autumn Meeting
Jeju, Korea, October 21-22, 2010

Progress on the Fabrication Methods Development for the Korean Test Blanket Module First Wall in the ITER

[1]Dong Won Lee, [1]Suk Kwon Kim, [1]Young Dug Bae, [1]Jae Sung Yoon, [2]Seungyon Cho*
[1]Korea Atomic Energy Research Institute
Deokjindaero 1045, Yuseong-gu, Daejeon, 305-600, Republic of Korea
E-mail: dwlee@kaeri.re.kr
[1]National Fusion Research Institute
Gwahangno 113, Yuseong-gu, Daejeon, 305-333, Republic of Korea

1. Introduction

A Korean helium cooled molten lithium (HCML) test blanket module (TBM) has been designed to be tested in the International Thermonuclear Experimental Reactor (ITER) TBM [1-4] and related fabrication methods have been developed especially for the purpose of joining. Since the first wall (FW) of the HCML TBM is composed of a beryllium (Be) as an armor material and a FMS as a structural one, joining with Be to FMS and FMS to FMS should be developed in order to fabricate it.

2. Joining of FMS to FMS

The joining of FMS to FMS was developed using a Hot Isostatic Pressing (HIP, 1050 ^{o}C, 100 MPa, 2 hours) including the post HIP heat treatment (PHHT, normalizing at 950 ^{o}C for 2 hours and tempering at 750 ^{o}C for 2 hours). In the previous work, smaller mock-ups were fabricated with 100 mm length and tested under 0.5 to 1.5 MW/m^2 heat fluxes for 20 cycles at each heat flux to investigate the joint integrity and a Critical Heat Flux (CHF) [5]. And then, in order to confirm the joining integrity between FMS and FMS with HIP, new mock-ups were fabricated. Six single channels were fabricated with a wire cutting for making a rectangular channel, which will be replaced by a cold rolling in the future in order to make longer channel and for mass production. The fabricated single channels and a back plate for each mock-up were joined by the HIP to be as one-, two-, and three-channel mock-ups. After HIP, the developed PHHT was performed with all mock-ups to recover the strength. To be installed in test facility, dummy channels and flanges were welded for one- and three-channel mock-ups, as shown in Fig. 1, in which only the three-channel mock-up was tested in the present study.

In order to install KoHLT-2, connecting flanges were welded to this mock-up and it was installed with a Cu dummy for calorimetric measurement and a graphite heater. During the test, by a using a calorimeter, Cu dummy mock-up, the total power was measured and the absorbed power at the tested mock-ups was measured with a coolant temperature difference by thermocouples located at the inlet and outlet regions. Two thermocouples for the wall temperature measurement were inserted from the backside with a different depth. The mock-up was tested according to the test conditions and they survived for 1,000 cycles for a 1.0 MW/m^2 heat flux. After evacuation of the tested mock-up, pressure test up to 3.0 MPa was performed and there was no leakage. Figure 2 shows the measured temperature and calculated heat fluxes during the last 30 cycles and there were no sudden increases of the measured temperature or more heat flux. The inlet water temperature increased due to the closed water supply system. The measured temperatures showed a good agreement with the analysis ones by ANSYS-11, which were used for determining the test conditions, as shown in Fig. 3.

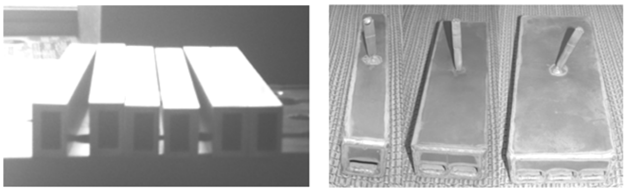

Fig. 1 Photograph of the fabricated FMS/FMs mock-ups.

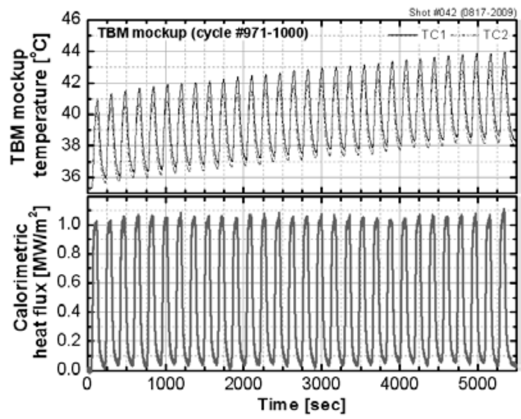

Fig. 2 Measured temperatures and heat flux of FMS/FMS mock-up.

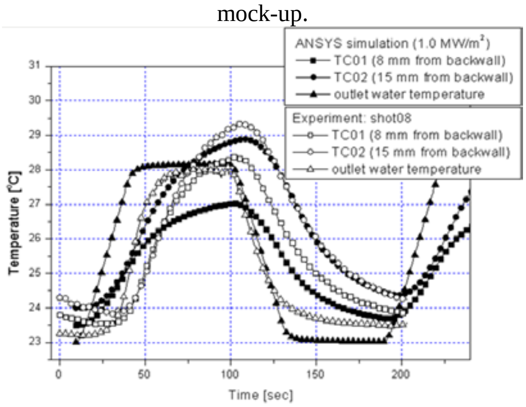

Fig. 3 Comparison with the measured and predicted temperatures for FMS/FMS mock-ups.

3. Joining of Be to FMS

The joining of Be to FMS were developed using the same method, HIP but the temperature and pressure conditions were different from that of FMS to FMS joining (580 ^{o}C, 100 MPa, 2 hours) and more, interlayer was used in Be tile side for diffusion bonding. So far, several interlayers have been tried and the following two conditions were used for fabricating the mock-ups; 1μm-Ti/0.5μm-Cr/5μm-Cu (#56) and 1μm-Cr/5μm-Cu (#57), as shown in Fig. 4. In order for KoHLT-1 to be installed, the connecting tubes were welded to this mock-up and it was installed with a Cu dummy for calorimetric measurement and a graphite heater. Differently from the previous test, no Cu dummy mock-up was used and only the coolant temperature difference by thermocouples located at the inlet and outlet regions was recorded. A thermocouple for the Be tile temperature measurement (8 mm from heated surface) was inserted.

The mock-up was tested according to the test conditions and they survived for 1,000 cycles over 0.5 MW/m^2 heat flux. The measured temperatures showed a good agreement with the analysis ones by ANSYS-11, which were used for determining the test conditions, as shown in Figures 5 and 6. After evacuation of the tested mock-up, ultrasonic and destructive tests (UT and DT) were performed to find the delamination in joint interfaces. During the test there was no sudden increase of temperature but there is delamination in mock-up #56. Because the thermocouple to measure the temperature was located in the sound joining region, it could not detect the delamination in the Be/FMS joint.

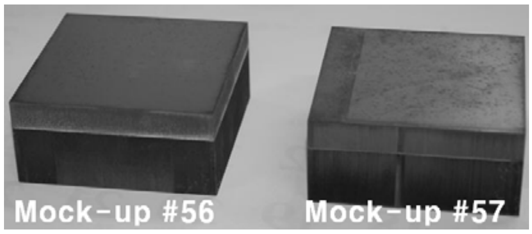

Fig. 4 Photograph of the fabricated Be/FMS mock-ups.

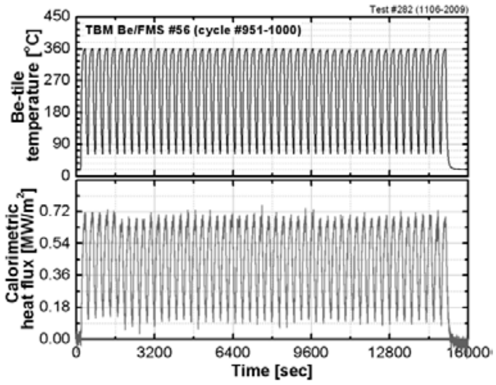

Fig. 5 Measured temperatures and heat flux for Be/FMS mock-up #56.

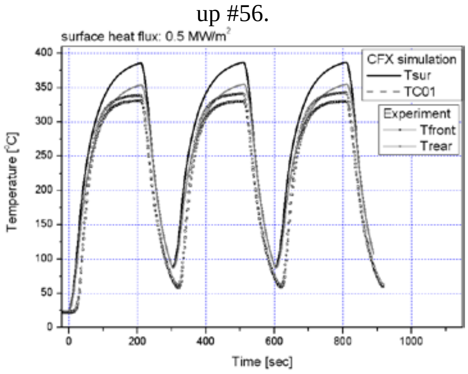

Fig. 6 Comparison the measured and predicted temperatures for Be/FMS mock-up #56.

4. Conclusion

Korea has proposed and designed the HCML TBM to be tested in the ITER and the fabrication methods such as HIP for TBM FW has been developed. For FMS to FMS joining, mock-ups were successfully fabricated with a HIP (1050 ^{o}C, 100 MPa, 2 hours) and the following PHHT (normalizing at 950 ^{o}C for 2 hours and tempering at 750 ^{o}C for 2 hours). HHF tests with a KoHLT-2 were successfully performed with the mock-up of up to 1,000 cycles under 1.0 MW/m^2 heat flux without any delamination or failure. For Be to FMS joining, mock-ups were successfully fabricated with a HIP (580 ^{o}C, 100 MPa, 2 hours) by trying the different interlyers (1μm-Ti/0.5μm-Cr/5μm-Cu and 1μm-Cr/5μm-Cu). In the same way, HHF tests with a KoHLT-1 were performed with 1,000 cycles under 1.0 MW/m^2 heat flux. During the test, there was no sudden increase of temperature but UT and DT results after the test showed a delamination in the case of using Ti/Cr/Cu interlayer. But the mock-up with the Cr/Cu interlayer showed a sound joining even after HHF test. Now, a prototype mock-up for the FW has been designed and started to fabrication. It will be also tested in the HHF test facility.

REFERENCES

[1] D.W. Lee, et al, Current status and R&D plan on ITER TBMs of Korea, J. of Korean Phys. Soc. 49, (2006) S340-S344.
[2] D.W. Lee, et al, Preliminary design of a helium cooled molten lithium test blanket module for the ITER test in Korea, Fusion Eng. Des. 82 (2007) 381-388.
[3] D.W. Lee, et al, Helium cooled molten lithium TBM for the ITER in Korea, Fusion Sci. and Tech. 52 (2007) 844-848.
[4] D.W. Lee, et al, Design and preliminary safety analysis of a helium cooled molten lithium test blanket module for the ITER in Korea, Fusion Eng. Des. 83 (2008) 1217-1221.
[5] D.W. Lee, et al, Fabrication and high heat flux test of the first wall mock-ups for the Korean He Cooled Test Blanket (KO HCML TBM), Fusion Eng. Des. 84 (2009) 1164-1169.
[6] A. Cardella, et al, Technical Basis for the ITER EDA plasma facing components, Fusion Eng. Des. 39-40 (1998) 377-384.
[7] ITER Material Properties Handbook, File code: ITER-AA02-2402.
[8] Klueh, R. L. and Harries, D. L., High Chromium Ferritic and Martensitic Steels for Nuclear Applications, West Conshohocken, PA: American Society for Testing and Materials, 2001. (ISBN: 0-8031-2090-7)