Status on the Development of the Fabrication Technology and the Mock-up Qualification Tests for the ITER Blanket First Wall

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Abstract. ITER blanket modules are composed of first walls (FW) and shield blocks (SB). FWs are one of the most thermally loaded components in ITER, since they will receive the severe localized and cyclic heat loads during the operation. Therefore, the qualification program was agreed to be performed in order to guarantee the acceptable quality of the FWs procured by six different domestic agencies including Korea. The manufacturing specification of first wall mock-up including design and the high heat flux testing plan were made by the discussion between IO and domestic agencies. Each first wall mock-up consists of three beryllium armor tiles attached to a Cu alloy (CuCrZr) heat sink plate internally cooled by SS cooling tube. Two mock-ups were delivered by Korea domestic agency to the test facilities (US and EU). Both of them successfully passed the qualification tests and their test results were approved by ITER Organization. In this paper, the status of the development of the fabrication technology and the results of the qualification tests for KO mock-ups are presented.

1. Introduction

Korea was responsible for the procurement of the ITER blanket modules 1, 2 and 6 in the original procurement allocation. According to the procurement reallocation of blanket system, Korea will procure the blanket shield block in place of the blanket first wall. Nevertheless, several R&D activities in Korea have been performed including fabricability study and mock-up qualification. The ITER blanket module is composed of a first wall (FW) panel and a shield block. The FW panel consists of beryllium armor in the form of tiles attached to a Cu alloy (CuCrZr) heat sink plate internally cooled by SS cooling tube [1~2]. Currently, hot isostatic pressing (HIP) is chosen as a candidate manufacturing process of FW panel. The FW panel is one of the most thermally loaded components in ITER, since they will receive severe localized and cyclic heat loads during the future fusion operation of ITER tokamak. Therefore, a qualification program has been performed to guarantee acceptable quality of the total FW panel procured by six different domestic agencies including Korea.

Several R&D activities have been carried out in Korea domestic agency, as follows. The various joining methods were investigated for the improvement of the bonding performances between Be and Cu alloy, and Cu alloy and SS, respectively. The various mock-ups with different dimensions and coating layers were fabricated to find an optimized bonding condition. Also, cyclic high heat flux tests were performed for the validation of mock-ups with the various test facilities. As a result, two sets of qualification mock-ups were manufactured and delivered to Sandia National Laboratory (US) and Nuclear Research Institute (Czech) for the ITER qualification test, respectively. In order to validate high heat flux capability, Korea heat load test facility (KoHLT-1) was installed in KAERI and is being successfully operated up to several thousand cycles with spare mock-ups.

2. Development of bonding technologies

2.1. Cu alloy/SS joining

The optimal HIP joining condition was investigated for the improvement of bonding performance between Cu alloy and SS. From the various studies, the Cu alloy/SS joining was successfully found, which were HIP joining at 1050 ℃ and 100 MPa for 2 hours, including a post heat treatment [1,2].
High heat flux (HHF) tests are essential for investigation of the thermo-mechanical performance of the FW, since the ITER FW receives severe localized and cyclic heat loads during fusion operation. Therefore, two types of Cu/SS mock-up were fabricated using the optimized processing conditions, as pictured in **FIG. 1**. They were tested in the e-beam facility, JEBIS, with 5.0 and 3.2 MW/m^2 of heat flux. Both mock-ups survived for up to 1130th and 1530th cycles, respectively, which were higher numbers of cycles to failure than expected [3].

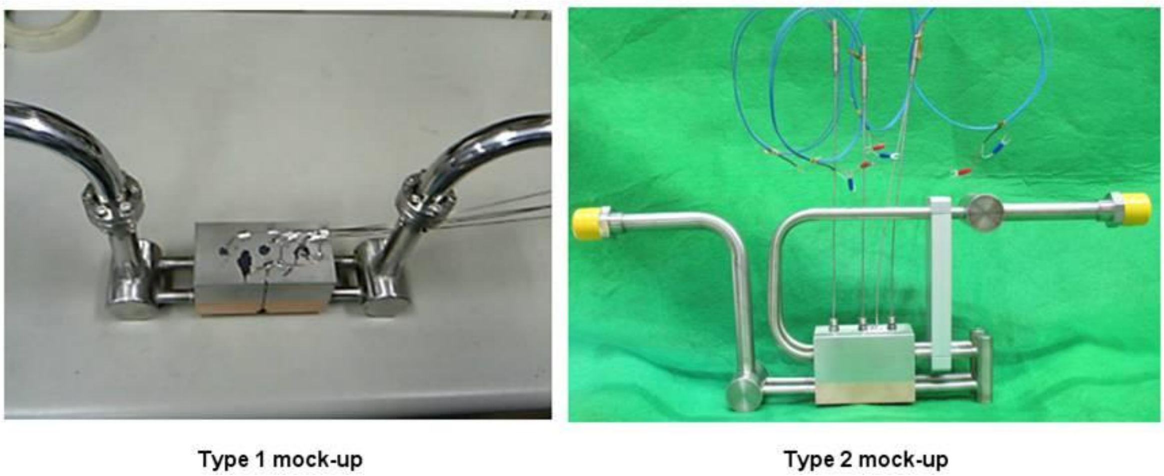

FIG. 1. Cu/SS mock-ups for the HHF test at JEBIS.

2.2. Be/Cu alloy joining

The optimal HIP joining condition has been investigated to improve the bonding strength between Be and Cu alloys, which was a HIP at 580 ℃, 100 MPa for 2 hours using a 1μm Cr / 10μm Cu interlayer including a post-heat treatment after the HIP of the Cu and SS tube with 1050 ℃ and 100 MPa for 2 hours [4]. For the high heat flux tests, two Be/Cu/SS mock-ups were fabricated with a 1μm Cr / 10μm Cu interlayer by HIP including a post-heat treatment, as shown in **FIG. 2**. They were tested in an e-beam facility, TSEFEY with the heat flux of 1.5 and 2.0 MW/m^2. Both mock-ups survived up to 1000 cycles at 1.5 MW/m^2 and 268 cycles at 2.0 MW/m^2, respectively [5].

FIG. 2. Be/Cu/SS mock-ups for the HHF test in TESFEY.

3. Fabrication of the qualification mock-ups

According to the investigated results for the HIP joining conditions, two mock-ups were manufactured in Korea for the participation in the ITER qualification test, as shown in **FIG. 3**. Even though the details of the manufacturing method was described in the manufacturing reports which were submitted to ITER organization, the brief summary of the manufacturing procedure is described in **FIG. 4** [6-7].

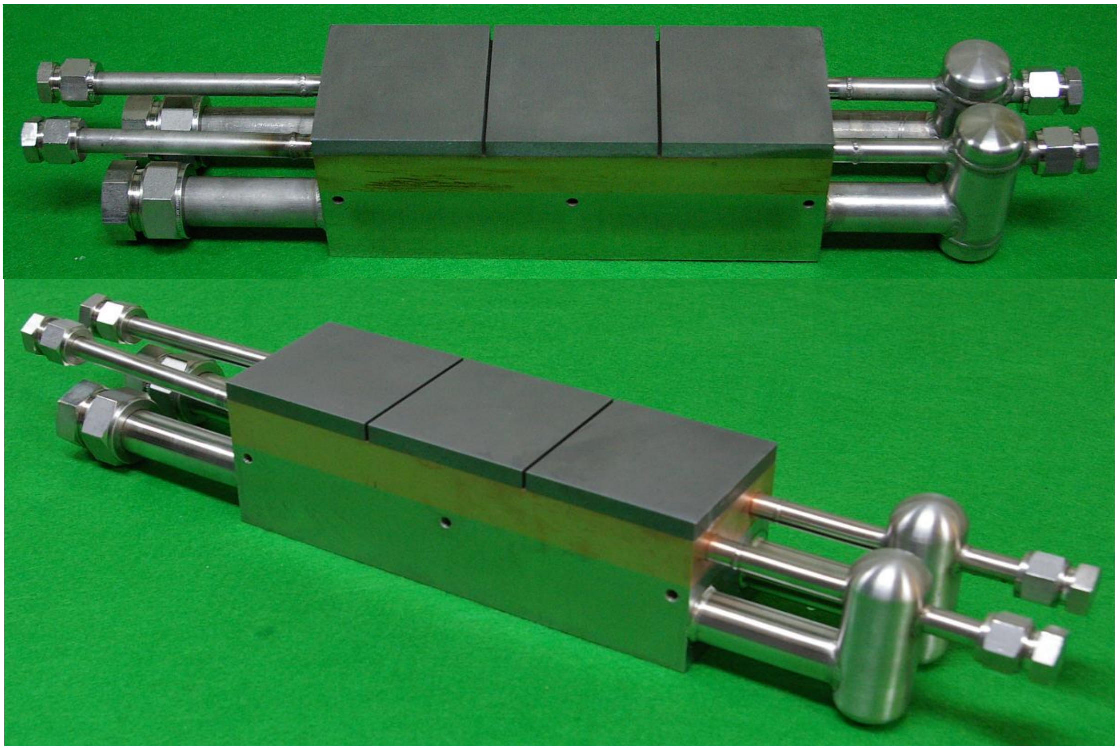

FIG. 3. A Be/Cu/SS mock-up for the ITER qualification program.

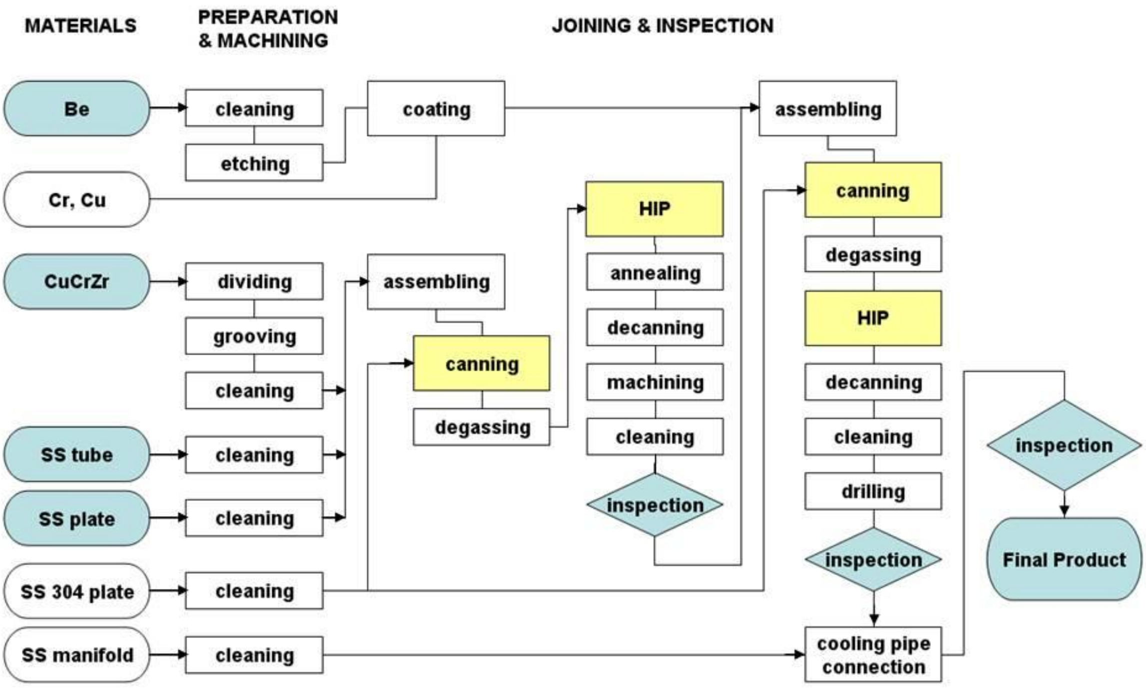

FIG. 4. Fabrication process of the Be/Cu/SS mock-up.

For the fabrication of KO mock-ups, two stages of HIP joining process were conducted for the SS/CuCrZr joint and the Be/CuCrZr joint, respectively. The HIP condition of SS/CuCrZr joint were used with the same condition optimized with previous studies (Cu alloy/SS: 1050 ℃, 100 ㎫ for 2 hours, Be/Cu alloy: 580 ℃, 100 ㎫ for 2 hours). Ultrasonic examinations were carried out Be/CuCrZr interface and SS/CuCrZr interface after HIP bonding process, as shown in **FIG. 5**. The obtained C-scan image maps of UT result have proven no defects at the interfaces of Be/CuCrZr. The mechanical properties of CuCrZr alloy were examined following thermal and mechanical treatment. The tensile strength of the material at two temperatures has satisfied the ITER requirement. The grain size was less than 200 ㎛ as ITER specification is less than 500 ㎛. The low fatigue tests were performed under conditions of constant total strain amplitude in fully reversed strain control cycle. From the impact test of the SS/Cu alloy specimen, the fracture occurred in the side of CuCrZr alloy joint. As a result, SS/CuCrZr joint was likely to be well bonded. In the specimen of Be/CuCrZr joint, the fracture occurred along the Be side. Successful helium leak test and pressure test were performed for both mock-ups. Two mock-ups were delivered to SNL (Sandia National Laboratories) in US and NRI (Nuclear Research Institute) in Czech for the participation in the ITER qualification program. Both of them successfully passed the qualification tests and their test results were approved by the ITER Organization.

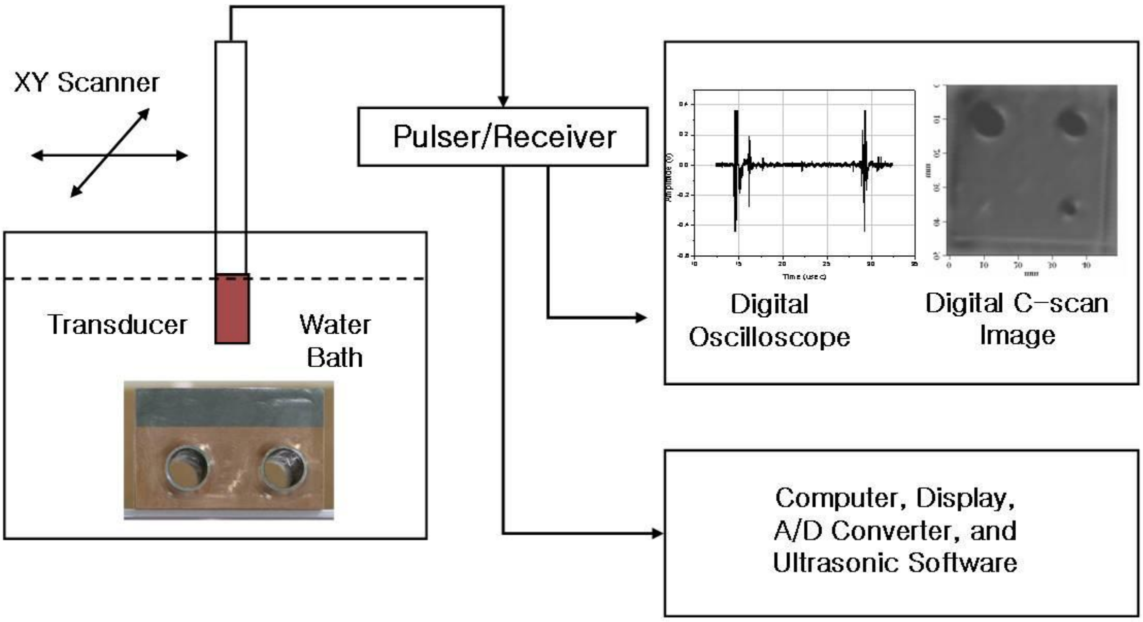

FIG. 5. Block diagram of ultrasonic test system.

4. Korea Heat Load Test facility (KoHLT-1)

Korea Heat Load Test facilities (KoHLT-1 and KoHLT-2) were constructed and operated using a graphite heating panel. One of the major purposes of this facility is to carry out a thermal cycle test for the validation of bonding performance of the ITER first wall. KoHLT-1 and KoHLT-2 were equipped with a graphite heating element, a water cooled box-type vacuum chamber, and a diagnostic systems, as shown in **FIG. 6**. The electrical power of the graphite heating element is provided by a 40 kW DC power supply for KoHLT-1 and a 80 kW DC power supply for KoHLT-2. The diagnostic system consists of two independent calorimetric power measuring systems, thermocouples, a vacuum gauge, and a CCD camera. Water cooling, Be treatment, and vacuum pumping systems are also equipped. The maximum mock-up sizes of KoHLT-1 and KoHLT-2 are 80 mm x 80 mm and 700 mm x 70 mm, respectively. The details of the specification of KoHLT-1 are described in **TABLE 1** [8].

(a) (b)

FIG. 6. Korea heat load test facilities: (a) KoHLT-1 and (b) KoHLT-2.

TABLE 1. Specifications of KoHLT-1, KoHLT-2 and BESTH (Czech, NRI).

Facility	KoHLT-2 (Korea Heat Load Test Facility-2)	KoHLT-1 (Korea Heat Load Test Facility-1)	BESTH (Beryllium Sample Thermal Test Device)
Country (Institute)	Korea (KAERI)	Korea (KAERI)	Czech Republic (NRI)
Major Target	Large PFC	PFC development inc. ITER blanket FW	ITER Blanket FW Qualification Mockup
Heat Flux (Target Area)	0.46 MW/m² (700×100mm²)	0.7 MW/m² (244×80mm²) 1.5 MW/m² (80×80mm²)	0.625 MW/m² (244×80mm²)
Heating Element	Graphite Panel (0.5 Ω)	Graphite Panel (0.25 Ω)	Graphite Panel (1 Ω)
Power Supply	80 kW (DC 200V, 400 A)	40 kW (DC 100V, 400 A)	40 kW (DC 200 V, 200 A)
Test Chamber	Box-type chamber with a large movable platform (1.2×1.2×2.4 m³)	Box-type chamber (0.3×0.3×1.2 m³)	Two cylinder type chambers (<0.3mD×1mL)
Filling Gas	He	He	He
Cooling Water	25-100 °C, 3 MPa	25 °C, 0.1 Mpa, 1 m/sec	100 °C, 0.5 Mpa, 1.3 m/sec
Target No.	2	2	2+2
Be Compatible	No	Yes	Yes

5. Summary

In this report, the current R&D activities for ITER first wall have been presented. The various joining methods were investigated for the interfaces between Be and CuCuZr, and CuCrZr and SS, respectively. The various mock-ups with different dimensions and coating layers were used to find the optimum bonding conditions. From this investigation, the optimal HIP bonding conditions were found as 1050 ℃, 100 ㎫, 2 hours for Cu alloy/SS and 580 ℃, 100 ㎫, 2 hours for Be/Cu alloy, respectively. To participate in the qualification program, two sets of qualification mock-ups were manufactured using the optimized processing conditions. They were delivered to test facilities in US and Czech for ITER qualification testing. In order to validate the high heat flux capability, the domestic heat flux test facility Korea heat load test facilities (KoHLT-1 and KoHLT-2) were installed and operated sucessfully.

Acknowledgement

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