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Qualification Procedure of High Heat Flux Testing for the Plasma Facing Components of Fusion Research

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1. Introduction

The Korea heat load test facility using electron beam (KoHLT-EB) [1,2] was constructed to evaluate the fabrication technologies and performance for the fusion reactor materials and plasma facing components (PFCs), as shown in Figure 1 and the facility is, at present, in operation to conduct the high heat flux tests for the PFCs development such as ITER blanket first wall (FW), tungsten PFCs, ITER helium cooled ceramic reflector (HCCR) test blanket module (TBM) FW and so on. Preliminary thermo-hydraulic and performance tests were conducted using various test mockups for the plasma facing components in the high heat flux test facilities of the world [3-5]. Several facilities equipped with an electron beam as the uniform heat source were fabricated for a cyclic heat flux test of the PFCs. Each facility working for their own purpose in EU FZJ [3], US SNL [4], and Russia Efremov institute [5].

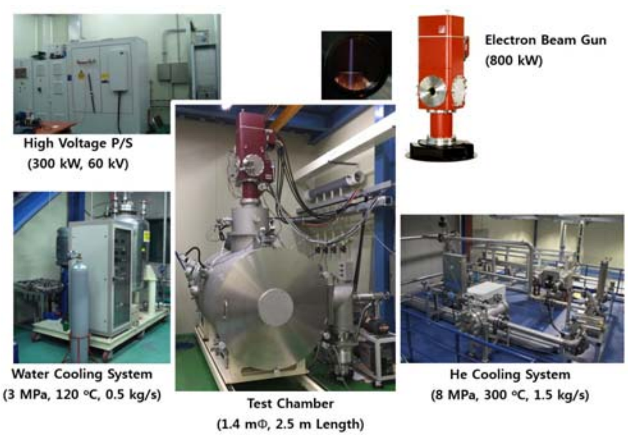

Fig. 1. Korea heat load test facility, KoHLT-EB

2. Methods and Results

2.1 High heat flux test facility

KoHLT-EB was constructed in November 2012 with an electron gun capacity of 800 kW (from Von Ardenne, Germany). KoHLT-EB is capable of a cyclic heat load, and the maximum allowable target dimension is 70 cm × 50 cm inside a vacuum chamber. Table 1 and Table 2 show the specifications of KoHLT-EB.

The electron beam gun of KoHLT-EB has the beam performance, such as; maximum accelerating voltage, 60 kV, maximum beam power, 300 kW, beam power bandwidth, 2 kHz and beam signal bandwidth, 20 kHz, and focused beam spot below 10 mm in diameter. Also, the beam scanning system was installed in the exit port of electron beam gun. The evaluated heat loads are 2.5 MW/m^2 (with the specific target area, 400 mm x 150 mm) or 20 MW/m^2 (150 mm x 50 mm).

Table 1. Specifications for high heat flux test facility

Facility	KoHLT-EB
Major Target	PFCs development
Heat Flux	5 MW/m^2 (300×200 mm^2)
Heat Source	Electron Beam (MAX 60 keV)
Power Supply	300 kW (DC 60 kV)
Test Chamber	Cylindrical chamber (Φ1.4m×D2.5m)
Filling Gas	Vacuum condition
Vacuum System	1,900 lps TMP (base pressure < 10^{-6} mbar)
Coolant supplying System	Water: ~ 120 °C, 3 MPa, He gas: ~ 350 °C, 8 MPa [6]

Table 2. Operational parameters for the electron beam system

Beam power	150 kW (300 kW max.)
Acceleration voltage	0-60 kV
Mid-frequency high voltage power supply	300 kW max.
Beam diameter	< 10 mm (focused)
Pulse length	1 msec
Scanning area	700 mm x 500 mm
Scanning frequency	20 kHz

The high temperature and high pressure helium cooling system was constructed, this helium supply system [6] will be connected to the KoHLT-EB for the qualification of design and manufacturing of HCCR TBM.

2.2 Qualification testing for plasma facing components

In the qualification testing of PFCs, such as an ITER blanket FW [7], a high heat flux test must be performed at up to 4.7 MW/m^2 in the operation conditions. The specified value for the heat flux will be intended as the target value for the absorbed heat flux with a flat profile. A heat flux profile is defined as flat when its variation is within ±5% of its average value when applied onto a flat surface. The tests shall utilize a mask over the required surfaces to ensure a flat beam profile. A 0.5 MW/m^2 heat flux will be applied to no less than 80% of the surface area of PFC as defined in table 1 for all thermal mapping cycles. Thermal fatigue cycling will be applied as described below and in accordance with table 3.

Table 3. Test procedure for ITER FW mockups [7].

FW mockup	Heat Flux and cycles	Cycle duration
Initial thermal mapping cycle	0.5 MW/m^2	Sufficient for steady state
Step1	7,500 cycles 4.7 MW/m^2	15 s/ 15 s on/off
Intermediate thermal mapping	0.5 MW/m^2	Sufficient for steady state
Step 2	1,500 cycles 5.9 MW/m^2	15 s/ 15 s on/off
Thermal mapping	0.5 MW/m^2	Sufficient for steady state

For the calibration test, 80% of the surface of the PFC should be irradiated by an electron beam, where the inlet temperature of the cooling water is about 70 °C(±5 °C), the inlet pressure is 2 MPa(±5%), and the water flow velocity is 2 m/s(±5%).

A thermal fatigue heat flux test shall be performed on the PFC mockups to validate the manufacturing performance and design validation using heat flux testing. The test parameters are defined below along with acceptance criteria.

1) No failure; any failure of any part of the PFC mockup will be classed as a failure.

2) No detachment of armour materials of PFC during steps 1 and 2.

3) No loss of armour materials when visually inspected, loss of tile edge, or particles when examined at macroscopic levels.

4) No variation of the maximum surface temperature exceeding 20% between the initial and the intermediate thermal mapping, and between the intermediate and final thermal mapping during phases 1 and 2

5) No appearance of any hot spots during fatigue cycling during phases 1 and 2. A hot spot is a specific location of the heated surface, generally extending on one or more armour tiles, where the temperature is higher than the other armour tiles, which are subject to the same heat flux and have no defects. This hotter region will be considered a hot spot if its maximum surface temperature is higher than 30% when compared to the other properly bonded tiles.

3. Conclusions

For the development of PFCs for the fusion research, various mockups were fabricated using a specific bonding process, and was equipped with an enhanced heat sink geometry and manufacturing processes. The qualification test, such as high heat flux testing was performed to evaluate the armour materials of PFCS at the heat load of the operation conditions For this high heat flux test, the Korean high heat flux test facility using an electron beam system (KoHLT-EB) was constructed to qualify the performance of PFCS fabrication. This facility will be used in the performance test for the various plasma facing components in fusion devices.

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