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High Heat Flux Test Simulation of Tungsten Macro-brush Mock-ups for the KSTAR Divertor

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1. Introduction

The divertor has been an important part of PFC because of its intrinsic function achieving effective particle control to keep high quality plasma with enough shaping flexibility. The divertor will be exposed to heat loads during operation of KSTAR-like plasma fusion device [1]. Therefore, it is important to withstand high heat loads. In this paper, the hydraulic thermo-mechanical analysis was performed by ANSYS WORKBENCH 15.0 in order to predict the fatigue lifetime of the mock-ups for the high heat flux (HHF) test under the KSTAR base mode operating conditions.

2. Analysis setup

2.1 Test mock-up description

The mock-ups for the divertor were designed in flat tile and macro-brush type. It consisted of four parts; the plasma facing tile using pure tungsten (W), the interlayer using oxygen-free high conductive copper (OFHC-Cu), the block and tube using CuCrZr alloy. As shown in Fig. 1, the eight W tiles were used and their dimensions were 12.25-mm long, 13.75-mm wide, and 5-mm thick. The OFHC-Cu as an interlayer was brazed in between W tile and CuCrZr block, and its dimensions were 50.5-mm long, 28-mm wide, and 2-mm thick. The dimensions of the CuCrZr block as a heat sink were 50.5-mm long, 28-mm wide, and 33-mm thick. The inner CuCrZr tube diameter was 12 mm with the external tube diameter of 15 mm.

2.2 HHF test conditions

In aspect of the heat flux, the maximum KSTAR base mode operating condition is 5.0 MW/m^2 on the surface of the divertor for 20 sec. Therefore, a uniform heat flux of 5.0 MW/m^2 was applied to the W tile during the heating phase with the water as a coolant flowing continuously during the heating and cooling phases [2]. The simulation conditions are summarized in Table I.

Table I: Simulation conditions

Parameters	Test conditions
Coolant conditions	0.5 MPa, 20 $^{\circ}$C, 1 kg/s
Incident heat flux	5.0 MW/m^2
Duration time	20 sec heat-on / 20 sec heat-off

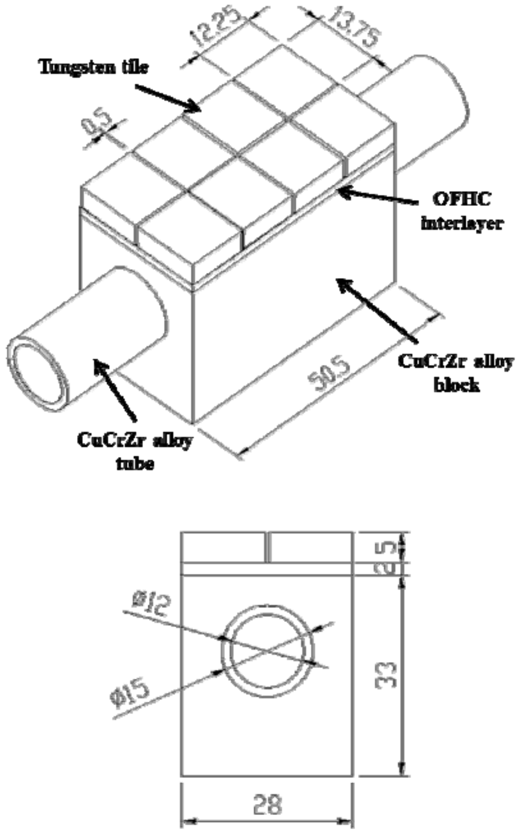

Fig. 1. Schematic of the mock-ups for the HHF test

3. Finite element analysis

The analysis was performed using Pro-E for 3-dimensional modeling, ANSYS-CFX for thermo-hydraulic analysis and ANSYS-mechanical for the thermo-mechanical analysis.

3.1 Thermo-hydraulic analysis

The transient analysis was performed, neglecting the subcooled boiling effect. Fig. 2 shows the temperature profiles on the mock-ups at the 20 sec heating operation. The maximum temperature of the W tile, OFHC-Cu interlayer, CuCrZr block and CuCrZr tube were 628.24 $^{\circ}$C, 419.42 $^{\circ}$C, 392.90 $^{\circ}$C, and 244.37 $^{\circ}$C, respectively. These values for the W and CuCrZr were within the recommended operational range [3]. The outlet coolant temperature was 36.92 $^{\circ}$C. Five cycles were simulated using following conditions; 20 sec heating phase and 20 sec cooling phase per each

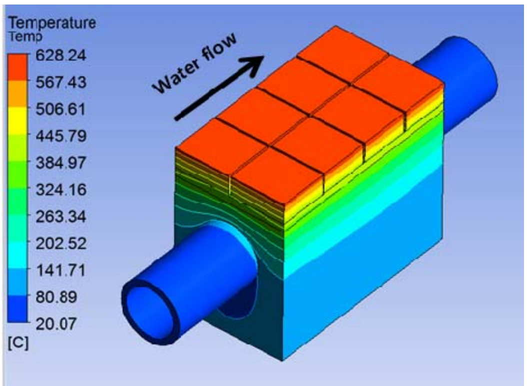

Fig. 2. Temperature distributions for the mock-ups.

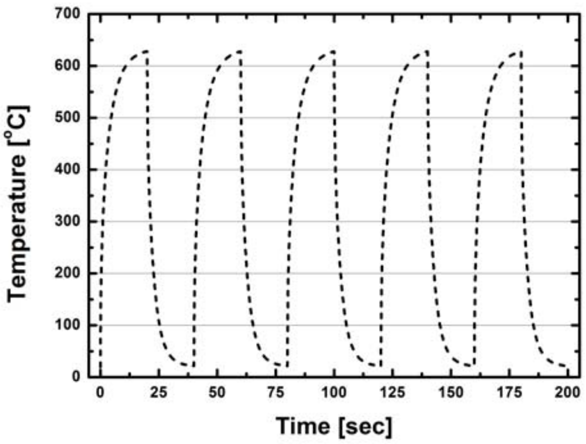

Fig. 3. Maximum surface temperature evolution of the W tile for 5 cycles under the 5.0 MW/m^2 heat flux.

cycle. Fig. 3 shows the maximum surface temperature evolution of the W tile for 5 cycles. This result confirmed that there were no temperature increases as cycles continued.

3.2 Thermo-mechanical analysis

The thermo-mechanical analysis was carried out using the calculated temperature distributions as loads from the thermo-hydraulic analysis results at the end of the heating operation time, 20 sec. The steady state analysis was performed, neglecting the OFHC-Cu interlayer effect because it was a functional material for the brazed mock-ups. Fig. 4 shows the total strains for the mock-ups. The maximum total strain of the mock-ups was located under the edge of the W tile. The maximum total strain of the W tile was 0.8309%, that of the CuCrZr block was 0.5477%, and that of the CuCrZr tube was 0.1923%.

To predict the fatigue lifetime of the mock-ups, the calculated equivalent total strains were applied to the experimental fatigue curves [4]. As shown in Fig. 5, the each fatigue lifetime of the W tile, the CuCrZr block and the CuCrZr tube was 1,513, 20,675 and more than 1,000,000 cycles, respectively. Therefore, the minimum requirement to be tested in these mock-ups was determined to be 1,513 cycles.

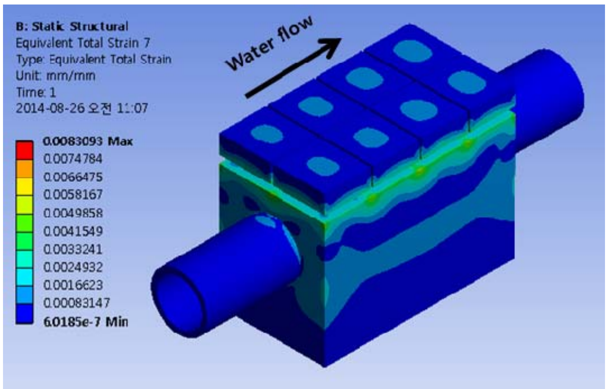

Fig. 4. Total strains for the mock-ups.

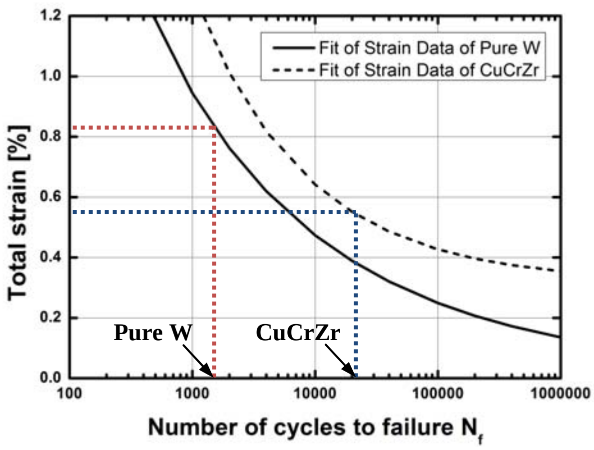

Fig. 5. The number of cycles of pure W and CuCrZr using the experimental fatigue curves.

4. Conclusions

Under KSTAR base mode operating conditions, the finite element analysis was performed to predict the fatigue lifetime of the mock-ups for the HHF test. The results of analyses showed that the mock-up's temperatures were within the recommended operational range, and its fatigue lifetime was about 1,513 cycles.

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