§3. High Heat Flux Tests for Closed Divertor Mockup

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The active particle control using helical divertor (HD) system has become necessary for farther improvement of the LHD plasma performance. On the basis of the experimental and simulation results, design of the closed HD (CHD) has been progressed. To evaluate the thermal performance of the CHD mockup-tile, a test facility ACT (Active cooling test-stand) was used.

Fig. 1 shows experimental setup of the CHD mockup-tile consisted by a couple of graphite armor tiles and were tightly fixed by two Mo-bolts (M6) to SUS cooling pipe of 27.2 mm in diameter. To improve thermal contact between the armor tiles and cooling pipe, super graphite sheet with 0.2 mm thick was inserted into the boundary. Since each tile piece was almost thermally insulated, the parallelogram shape electron beam which was defined by beam limiter was injected into only one half of the tile surface. The four thermocouples were embedded just beneath the tile surface as shown in Fig. 1.

In the case of steady state LHD plasma discharges with 3 MW input power, heat flux to the CHD is estimated to be ~1.5 MW/m^2. During discharges, temperature rise due to the high heat influx to the divertor tiles needs to be reached to a steady state condition (saturated) at least. Therefore, stepwise heat loading with steady state up to the 1.5 MW/m^2 every 0.1 MW/m^2 steps was performed. Consequently, the temperature rises at all thermocouple positions were reached to the saturation level at less than ~5 min durations times. It indicates that the CHD mockup-tile shown in Fig. 1 could withstand at least the expected heat load in LHD. However, the highest temperature point (TC3) was reached to over 1200 °C. In order to achieve the safe plasma operations, it should be suppressed further low temperature.

In this study, we have performed more detailed analysis from comparison of a heat load experimental data and a heat transfer analysis of ANSYS program. Fig. 2 shows experimental results of the temperature evolution of CHD mockup-tile during the heat load up to the ~1.1 MW/m^2 (symbols). The plotted temperature corresponds to the saturation temperature of each heat load. In all positions, the temperature was gradually increased with increasing the heat load, and TC3 position was highest and finally reached to near 1200 °C. In contrast, the temperature of the TC5 position which located closest to the cooling pipe was sufficiently lower than that of TC3. Numerical simulation results of heat transfer analysis were also plotted together (solid lines), and these results have shown good agreement with experimental data. From these results, it could be considered that if the efficiency of heat transfers from the position of the TC3 to the TC5 were improved, the temperature rise of TC3 must be more suppressed. From such a speculation, improved shape of CHD mockup-tile as shown in Fig. 3 was proposed and then, numerical simulation of the heat transfer analysis by ANSYS had been performed. The key point of an improvement of Fig. 3 was that the pass of the heat transfer to the cooling pipe will become effectively due to changing the shape of the back of a tile from a step shape to the slope shape. From the simulation results, the temperature of TC3 position during the heat load at around 1.0 MW/m^2 was decreased over 100 °C than that of Fig. 2. These results indicate that improvement shapes seem to be good performance for CHD in LHD, and systematic heat loading test in ACT will need to assessment for it.

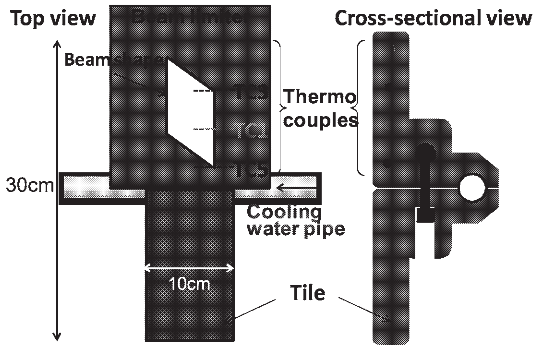

Fig. 1. Top and cross-sectional view of the experimental set up of the CHD mockup-tile.

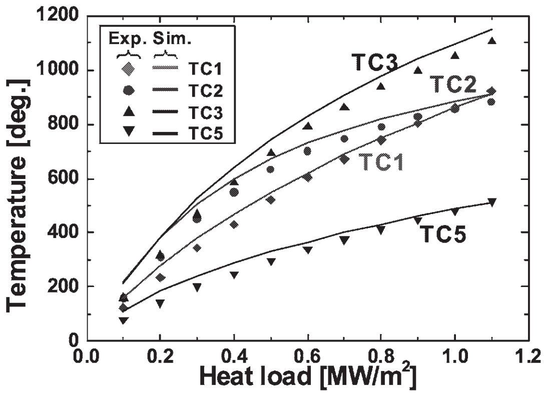

Fig. 2. Temperature evolution of CHD mockup-tile during heat loading. Symbols corresponds to the experimental data, and solid lines are the numerical simulation results of heat transfer analysis by using ANSYS program.

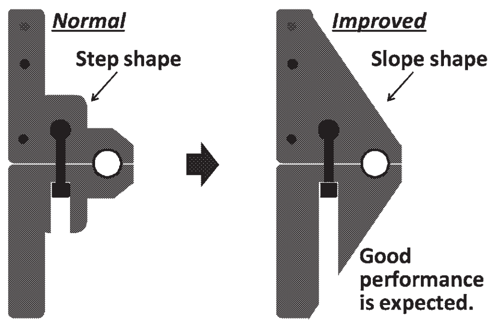

Fig. 3. Improved shape of CHD mockup-tile.