§68. Evaluation of Thermal and Mechanical Properties of Joining Materials between Carbon Materials and Oxygen-Free Copper for a Divertor Plate of the LHD

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Divertor model specimens with a cooling tube were metallurgically joined a C/C composite with oxygen-free copper by only Ti foil, which are expected to be applied to a divertor plate of the LHD. Cyclic heat load tests were carried out on the divertor model specimens by a deflection-type electron beam heating apparatus. The thermal and mechanical properties of the joining parts were evaluated, and the integrity of the divertor model specimens was confirmed.

Fig.1 shows the divertor model specimen. A felt-type C/C composite (CX-2002U made by Toyo Tanso Co.) was joined metallurgically with oxygen-free copper having a cooling tube by using only Ti foil. The thickness of the CX-2002U composite was 10 mm or 20mm. In the joint, the model specimens were held for 10 minutes at 1000 ℃ in vacuum of $1x10^{-5}$ Torr.

In the cyclic and short pulse heating tests, a constant heat flux of electron beam was given for 10 sec and was stopped for 15 sec. The heat flux was a range up to 15 MW/m^2. The surface temperature of the C/C composite and the temperatures of upper and lower parts of the joining boundary were measured by a radiation pyrometer and thermocouples, respectively. The flow rate and inlet temperature of water coolant were a range from 15.2 to 30 l/min and 15 ℃, respectively. After the heat load tests, test pieces were cut out from the divertor model specimens and 4-point bending strength, continuous indentation, thermal conductivity by laser flush method and the microstructure by SEM were measured at the joining parts.

Fig.2 shows the surface temperature and the temperatures of upper and lower parts of the joining boundary as a function of heat flux. The sputtering of graphite materials is known to increase abruptly over 1200 ℃ due to the radiation-enhanced sublimation. The heat flux reached to 1200 ℃ was 8.5 MW/m^2 in the case of 20 mm in thickness and the flow rate of 20-30 l/min, 11 MW/m^2 in the case of 10 mm in thickness. The surface temperature in the case of 20 mm in thickness was higher than that of 10 mm in thickness.

In the 1000 cyclic heat load tests, surface erosion in the case of 20 mm in thickness of the CX-2002U composite was observed over 12 MW/m^2. The surface temperature of the CX-2002U composite was about 1600 ℃ at the heat flux of 12 MW/m^2. Therefore this divertor model specimen can endure till the surface temperature of 1600 ℃ or the heat flux of 12 MW/m^2.

Fig.3 shows the thermal conductivity of the joining parts by a laser flush method. These disks (ϕ 10x2t) including the joining boundary were cut out from the divertor model specimens. Before the heat load tests, the thermal conductivity increased with elevating temperature until the maximum value at about 600 ℃, and decreased over 600 ℃. On the other hand, the thermal conductivity after the heat load tests became very small and decreased with elevating temperature.

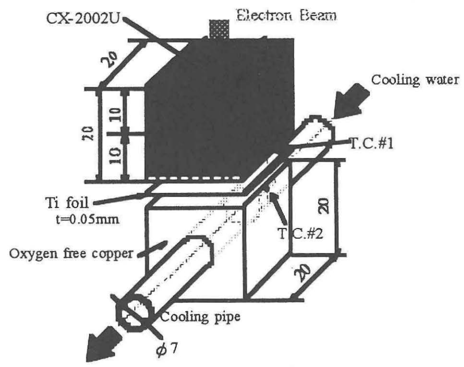

Fig.1 Divertor model specimen

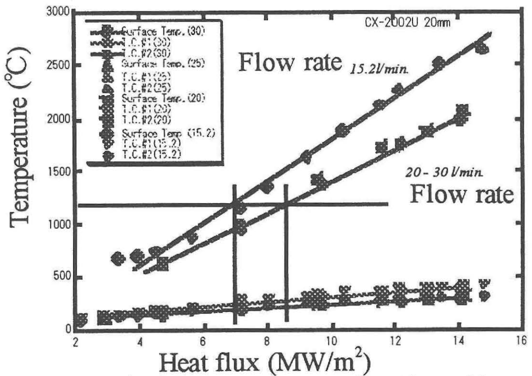

Fig.2 Changes in temperatures as a function of heat flux. (CX-2002U composite of 20 mm in thickness)

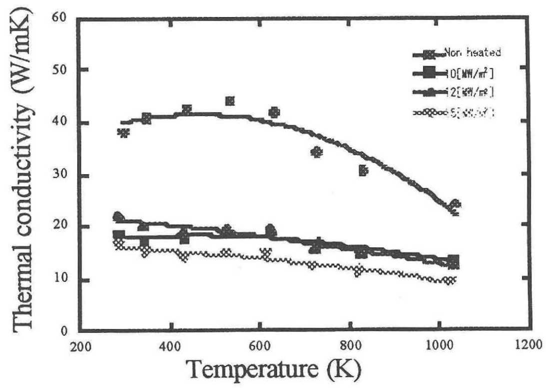

Fig.3 Thermal conductivity of the joining parts before and after cyclic heat load rest.