§19. Joining of C/C Composite with Copper Using Titanium and Evaluation of Thermal and Mechanical Properties for Joining Materials

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Joining specimens of a C/C composite and copper block with a cooling tube were manufactured for a model of LHD divertor plate. Integrity and thermal and mechanical properties of the joining parts were evaluated by electron beam heating, three-point bending, continuous indentation and microstructure examination tests.

Fig.1 shows geometry of a divertor model specimen that is composed of a felt-type C/C composite (CX-2002U made by Toyo Tanso Co.) joined with oxygen-free copper block including a cooling tube by using only titanium foil.

Electron beam heating tests were performed by ACT in NIFS. The energy of electron beam was 30keV, the heat flux was 8-15MW/m^2 and the irradiation period was 20 seconds. The pressure, the speed and the temperature of cooling water at the inlet were 0.5MPa, 14.7m/s and 10-40℃, respectively. A surface temperature of the C/C composite and the temperatures for upper and lower points of the joining part were measured by a radiation pyrometer and thermocouples. After heating tests, the divertor model specimens were cut out and bending, continuous indentation and microstructure examination tests were performed.

Fig.2 shows a surface temperature of the C/C composite, upper and lower temperatures near the joining part shown in figure 1 for 10 heating cycles as a function of heat flux. Those temperatures increased with increasing heat flux.

Fig.3 shows changes in temperatures for 100 heating cycles at 10 MW/m^2. Integrity of the joining parts has been preserved because those temperatures were lower than the joining temperature (1000℃) during heating cycles. On the other hand, a surface temperature of a specimen which was heated for 4 heating cycles at 15MW/m^2 increased rapidly because there were some unusual conditions in the joining part.

Fig.4 shows bending strengths of the joining parts after heating tests at various heat fluxes. In this figure, a solid and dotted lines indicate the average and the standard deviation values for bending strength of the CX-2002U composite. Clearly, the bending strengths of specimens heated at 15MW/m^2 decreased and cracks by delamination were observed at the joining parts by SEM.

In conclusion, integrity of this divertor model specimen was confirmed when the heat flux was lower than 12.5MW/m^2 and the temperature of the joining part was lower than 800℃.

These results were presented at PSI meetings, International Symposium on Carbon Science and Technology for New Carbon (8-12/9/98, Tokyo) and JSME Ibaraki lecture meeting (25/9/98, Ibaraki).

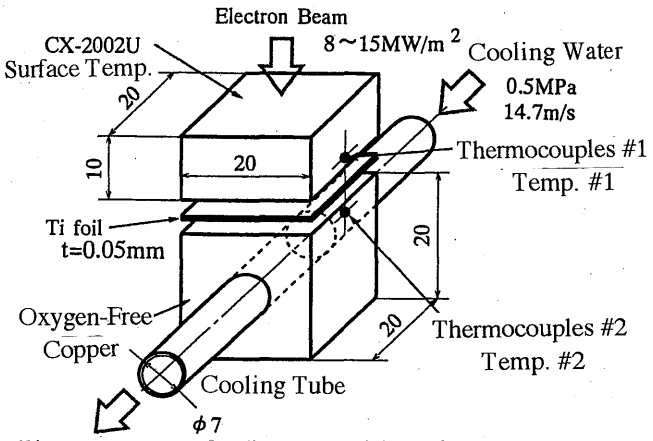

Fig.1 Geometry of a divertor model specimen.

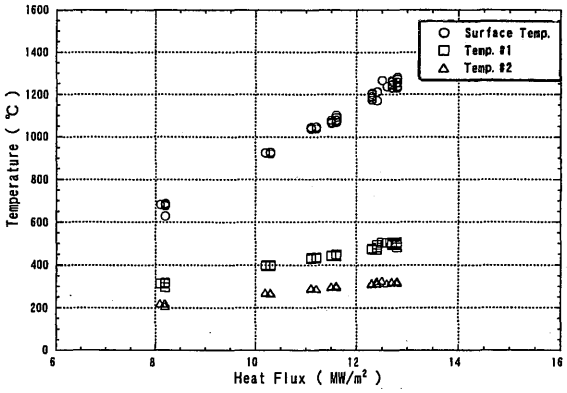

Fig.2 Changes in temperatures as a function of heat flux.

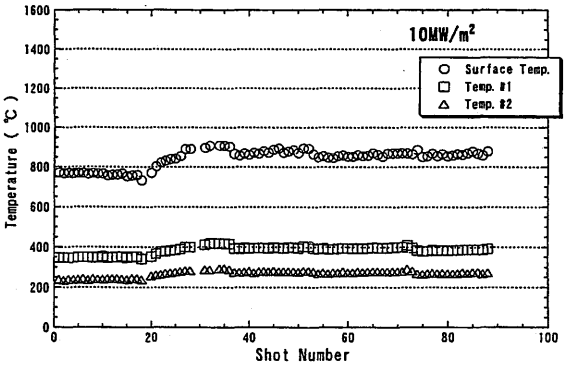

Fig.3 Changes in temperatures during heating cycles.

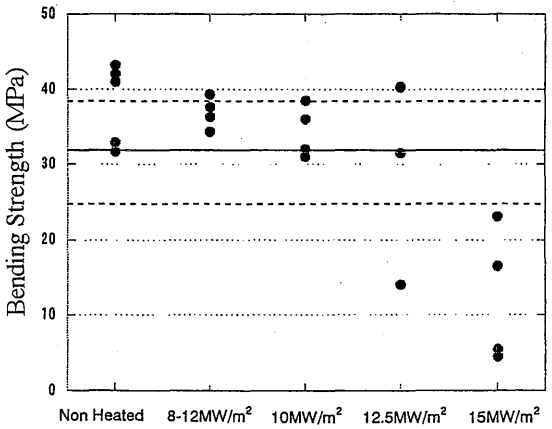

Fig.4 Bending strengths of the joining parts after heating tests.