§16. Evaluation of High Z Divertor Plate Module of LHD

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LID divertor plate of LHD will be subjected to high heat flux of about 10 MW/m^2 and armor brazed with OFHC is going to be used as LID divertor plate. In this study, thick tungsten coatings on carbon carbon composite and other carbon materials for surface materials of the divertor was newly successfully demonstrated. High heat flux experiments have been performed on the coated tiles in order to prove the suitability and load limit of such coating materials.

Disadvantages of tungsten as a plasma facing material are its heavy weight and poor workability. One of the possibilities to overcome them is to coat tungsten on light carbon materials, which have shown good heat load resistance in the present plasma confinement devices. In the present work, thick tungsten coated carbon/carbon fiber composite (CFC) tile as well as isotropic fine grained graphite tile were jointed by brazing on the OFHC with a cooling tube. Thermal response and thermal fatigue lifetime tests using electron beam facilities were carried out on the tungsten coated mock-ups under the actively cooling condition.

Tiles, 20 mm x 20 mm x 10 mm, were coated by vacuum plasma spraying technique (VPS). The substrate materials were carbon/carbon composite CX-2002U and isotropic fine grained graphite IG-430U made by Toyo Tanso. The CX-2002U and IG-430U received PVD W/Re multilayer diffusion barrier layers prior to the VPS tungsten coating in order to inhibit uncontrolled brittle carbide formation. Thickness of the tungsten-coating layer was 0.5 mm and 1.0 mm. The tungsten-coated tiles were jointed by Ti brazing and silver brazing on the OFHC surface with a cooling tube. The mock-ups are denoted here as W/CX2002U/OFHC and W/IG-430U/OFHC. Mock-ups of CX-2002U/OFHC and IG-430U/OFHC without W coating were also prepared to compare with the W coated specimens. Heat flux experiments were carried out using the Active Cooling Teststand (ACT) of National Institute for Fusion Science (NIFS). The tile was irradiated by electron beam with 30 keV. Beam duration was 20 sec. Heat flux was changed from 2 to 10 MW/m^2. Surface temperature of the tile was measured with an optical pyrometer. Temperatures of upper side (T1) and down side (T2) of interface of brazed area were also measured with thermocouples. The heat flux experiments were carried out under the condition that the water flow velocity, pressure and temperature were 14.4 m/s, 0.5 MPa and 25°C, respectively. After the heat flux experiments, surface modification was examined with a scanning electron microscope. Ultrasonic testing was also performed to examine degradation of adhesion between the carbon and OFHC by thermal stress.

Fig. 1 shows the heat flux dependence of plateau temperatures measured at the surface, T1 and T2 for W/CX-2002U/OFHC and CX-2002U/OFHC with silver brazing and the W coating thickness of 0.5 mm. It can be seen that the temperature increases monotonically with the increasing heat flux. Surface temperature of the W/CX-2002U/OFHC was 35 °C higher than that of the non-coated CX-2002U/OFHC at the heat flux of about 10 MW/m^2. This is expected to be caused by the thickness of W of W/CX-2002U/OFHC. No cracks and no exfoliation were formed in W-coating and at braze interface by heat loads of up to 10 MW/m^2.

In the case of Ti brazing, surface temperature increased 250-300°C due to a VPS-W coating of 1 mm thickness. The reason for this may be probably related to the defects formed in the inside of the W/CX-2002U/OFHC and W/IG-430U during Ti brazing process. Detailed observation of cross section of the mock-ups insides structure will be required to confirm this.

Thermal fatigue test up to 160cycles (10MW/m^2, 20s ON/ 65s OFF) for W/CX-2002U/OFHC with Ti brazing showed that though surface temperature gradually increased from 1250°C to 1500°C during the cycle test, temperatures at T1 and T2 did not change much. The surface morphology observed by SEM also did not change. These results indicate that no failure occurred at the braze interface or in the W coating during cyclic heat load.

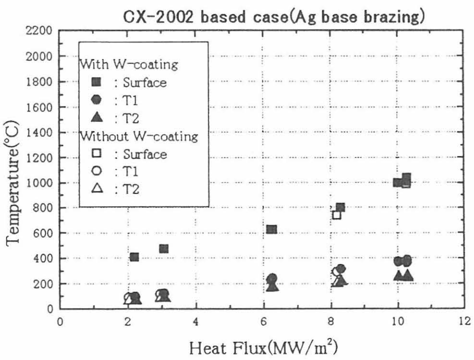

Fig. 1 Plateau temperatures at the surface, T1 and T2 for W/CX-2002U/OFHC and CX-2002U/OFHC (silver Brazing). The thickness of W-coating was 0.5 mm.