§5. Development of High Z Coated Material and Thermal Process under Actively Cooled Condition

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Divertor plate of LHD will be subjected to high heat and plasma particles with a low energy and a high flux. Tungsten seems a promising candidate material for surface material of the divertor plate because of its low sputtering yield and good thermal properties. In the present work, thick tungsten coated carbon tile and molybdenum alloy have been jointed by brazing on the OFHC with a cooling tube. Thermal response and thermal fatigue lifetime tests using an electron beam facilitie have been carried out on the tungsten coated mock-ups under the actively cooling condition.

Tungsten were coated by vacuum plasma spraying technique (VPS) on tiles, 20 mm x 20 mm x 10 mm. The substrate materials were carbon/carbon composite CX-2002U, isotropic fine grained graphite IG-430U made by Toyo Tanso and TZM(Ti-Zr Mo alloy). 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 carbon tiles were jointed by Ti brazing and silver brazing on the OFHC surface with a cooling tube. In addition, the tungsten-coated TZM were jointed by Ti brazing. The thickness of Ti foil and silver alloy used was 0.05 mm. The brazing temperature of Ti brazing and silver brazing were 745 °C and 1000 °C, respectively. The mock-ups are denoted here as W/CX2002U/OFHC, W/IG-430U/OFHC and W/TZM/OFHC.

Heat flux experiments have been 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 22 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 have been carried out under the condition that the water flow velocity, pressure and temperature were 15 m/s, 0.5 MPa and 20°C, respectively. Thermal fatigue tests were also carried out up to 100 cycles at a heat flux of 10 MW/m^2. After the heat flux experiments, surface modification was examined with a scanning electron microscope.

In case of W/IG-430U/OFHC by Ti brazing, micro cracks were formed at corners of the IG-430U part during the brazing process, but not in W/IG-430U/OFHC by sliver brazing. This means that the cracks were formed by restrain force of VPS-coating layer during and after the brazing because the brazing temperature of Ti brazing was higher than that of the silver brazing. On the other hand, no damage were observed in the W/CX-2002U/OFHC and W/TZM/OFHC mock-ups by both Ti and silver brazing. It is considered that excellent mechanical strength of CX-2002U suppress crack formation.

Figure 1 shows the heat flux dependence of plateau temperatures measured at the surface and T2 for W/TZM/OFHC with Ti brazing and the W coating thickness of 0.5 mm. It can be seen that the temperature increases monotonically with the increasing heat flux. No cracks and no exfoliation were formed in W-coating and at braze interface by heat loads of up to 10 MW/m^2.

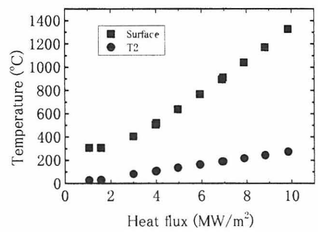

Fig. 1 Plot of steady state temperature of the surface and the lower(T2) side of the brazed area of the VPS-W/TZM/OFHC as a function of heat flux.

Figure 2 shows thermal fatigue test up to 100cycles (10MW/m^2, 16s ON/ 16s OFF) for W/TZM/OFHC with Ti brazing. It can be seen that temperatures at surface and T2 did not change much. These results indicate that no failure occurred at the braze interface or in the W coating during cyclic heat load.

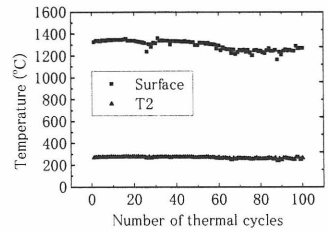

Fig. 2 Change of temperature at the surface, the lower(T2) side of the brazed area versus cycle number.

On the other hand, in the case of W/CX-2002U/OFHC, surface temperature increased even if at low high flux but temperature of T1 and T2 did not increased much. This indicates that joint between W and CX-2002U was not good enough. However, after the improvement of the fabrication process for W coated CX-2002U, such kind of temperature increase was not observed and W/CX-2002U/OFHC successfully withstood at least 100 cycles of heat loads at 10 MW/m^2 for 16s.