§4. Evaluation of Tungsten Coated Carbon as LHD Divertor Plate

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Tungsten seems a promising candidate material for the armor of the plasma facing materials such as the divertor plate in fusion devices because of its low sputtering yield and good thermal properties. The disadvantages of tungsten as the armor of the plasma facing components such as the divertor plate are its heavy weight and the brittleness below DBTT. For the near term application for LHD, tungsten coated carbon tiles could be convenient because the tiles could be easily replaced without big change in heat transfer properties to cooling channels.

Tungsten coatings on graphite by plasma spray (PS) or physical vapor deposition (PVD) were produced and their performance under high heat flux loading has been examined. Tungsten coatings on CFC (CX-2002U) and isotropic fine grain graphite (IG-430U) have been successfully produced by vacuum plasma spray (VPS) technique and their good thermal and adhesion properties have been confirmed by high heat flux tests. In addition, surface modifications such as blistering and hydrogen isotope/helium retention of VPS-W irradiated by a low energy and high flux hydrogen isotope/helium have been also investigated.

CX-2002U and IG-430U received PVD multilayer diffusion barrier layers of rhenium and tungsten prior to the VPS tungsten coating in order to inhibit uncontrolled brittle carbide formation. In the present work, test samples have been fabricated and pulse high heat flux experiments have been performed to optimize thickness and number of the multilayer diffusion barrier of rhenium and tungsten.

Tungsten has been coated on tiles, 12 mm x 12 mm x 4.5 mm, by the vacuum plasma spraying technique (VPS). The substrate materials were CX-2002U and IG-430U made by Toyo Tanso. The thickness of the tungsten coating layer was 0.5 mm. In addition, thickness and number of the multilayer diffusion barrier of rhenium and tungsten has been changed. In the present experiments, the following samples have been used.

(a)VPS-W/Re(5μm)/W(5μm)/Re(5μm)/W(5μm)/Re(12μm)/IG-430U

(b)VPS-W/Re(12μm)/W(12μm)/Re(12μm)/W(12μm)/Re(12μm)/IG-430U

(c)VPS-W/Re(5μm)/W(5μm)/Re(5μm)/W(5μm)/Re(12μm)/CX-2002U.

Heat flux and beam duration used were 0.8, 1.5 and 4 GW/m^2, 5 and 20 ms using an electron beam irradiation. Irradiation area was 2 mm x 2mm. The sample temperature was measured using an optical pyrometer. The electrical current was also measured to evaluate emission of the secondary and the thermal electron, ion. In addition, cross sectional view of the sample is monitored using a CCD camera. After the heat load experiments, surface and structure of cross section of the samples were observed using an optical microscope and SEM.

In the case of 1.5 GW/m^2 and 5ms, the order of maximum peak temperature are (b), (a) and (c). The surface temperature increased with the thickness of interlayer. In addition, in the case of CX-2002U, the surface temperature was lower than that of the others. Cracks were formed in the part of VPS-W of the samples of (a) and (b). In addition, in the case of (a), the cracks propagated to the multilayer of Re/W. On the other hand, in the case of (b), the cracks propagate to the part of VPS-W and do not to the the multilayer of Re/W. In the case of (c), no cracks were formed. These results indicate that the sample(c) has best performance for the behavior under pulse high heat flux irradiation.

In the case of 4.0 GW/m^2 and 5ms, molten and resolidification occurred near the surface about 0.1 to 0.2 mm depth and the cracks propagate to the carbon materials through the interlayer. In addition, the electric current change during the irradiation indicated that emission of thermal electron and ionized particle occurred. In the case of a heat flux of 0.8 GW/m^2, 1.5 GW/m^2 and a duration of 5ms, the direction in which a electric current flow is that of electron beam flow. On the other hand, in the case of 4 GW/m^2 and 5 ms, electric current flows opposite direction of the electron beam in the middle of the irradiation. This is considered to be emission of the thermal electron from heated sample surface. The observation using the CCD camera showed that particles were emitted during the irradiation and the electric current oscillated. This is considered to be due to the electric charged particles emission. Investigation of fundamental process of the particle emission and dependence of tungsten material will be required.

In addition, surface analyses of VPS-W coated CX-2002U and IG-430U, which were exposed to LHD diverter plasma, have been carried out. Hydrogen retention and surface composition have been examined RBS, ERD and XPS.