§30. Thermal Property and Stress Analyses of Tungsten Coating/Joint Materials

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Tungsten is potential candidate for an armor of the first wall and the divertor plate of the fusion reactor because of its low erosion yield and good thermal properties. Joint material with tungsten and cooling channel will be used as the divertor plate. Cu is one of high thermal conductivity material for the cooling channels. In addition, in the case of the fusion demonstration reactor (DEMO), neutron damage will be a critical issue. Structure materials of the first wall/blanket and the cooling channels of the divertor of DEMO will be made by low activation materials. Tungsten coated reduced activation materials could be convenient for the first wall/blanket and divertor plate. In the present works, following three kinds of samples and mock-ups have been developed and fabricated.

(1) Tungsten coated reduced-activation ferritic/martensitic steel (RAF/M) F82H (Fe-8Cr-2W) by Vacuum Plasma Spraying (VPS) (VPS-W/F82H)

(2) Tungsten coated reduced-activation ferritic/martensitic steel (RAF/M) F82H (Fe-8Cr-2W) by Vacuum Plasma Spraying (VPS) and Atmospheric Plasma Spraying (APS) brazed on oxygen free high purity copper (OFHC) block with a cooling tube (VPS-W/F82H/OFHC and APS-W/F82H/OFHC)

(3)Four rods of fine-grained tungsten (ST-1) and coarse-grained tungsten (ST-2) jointed on oxygen-free high thermal conductivity Cu (OFHC) block with a cooling tube using Non Defective Bonding (NDB) by NIPPON TUNGSTEN CO.,LTD. They are simply denoted as W(ST-1)/OFHC and W(ST-2)/OFHC, respectively.

Thermal response and repeated heat loading experiments on the samples and the mock-ups using an Active Cooling Test Stand (ACT) in NIFS and an electron beam heat loading experiment setup in RIAM of Kyushu University have been carried out. In addition, steady-state temperature profiles and thermal stress for a 1/4 three dimensional model of the mock-up (VPS-W/F82H/OFHC) were calculated using the finite element analysis code ANSYS. Heat transfer from the mock-up to the coolant water was computed using the film code, which calculated the heat transfer coefficient as a function of wall temperature. For the model of all materials, heat conductivity, coefficient of thermal expansion, elastic modulus and Poisson's ratio as a function of temperature are defined. The steady state thermal and stress analyses were performed for the VPS-W/F82H. Only 1/4 geometry was considered due to symmetry. The temperature dependence of the materials properties of thermal conductivity, coefficient of thermal expansion (CTE), elastic modulus, Poisson's ratio and emissivity were taken into account.

Thermal response experiments on VPS-W/F82H/OFHC showed that the temperatures increased monotonically with increasing heat flux up to 3.4 MW/m^2. Surface modification, exfoliation and crack were not formed by thermal fatigue experiments up to 200 cycles at a heat flux of 3.2 MW/m^2. The thermal response and thermal fatigue experiments indicate that VPS-W/F82H has high potential of these coating as plasma-facing armor under thermal loading. The FEM analyses indicated that shear stress arises between the VPS-W and F82H and stress for center direction and outer direction are applied in F82H and VPS-W part, respectively. Based on the calculation results, it is considered that stress of VPS-W is below elastic limit judging from the result of tensile test of pure W. On the other hand, in the case of F82H, 0.2% proof stress at the temperature is about 500 MPa. Therefore, it is considered that plastic deformation did not occur at center of F82H of interface of VPS-W and F82H. The calculation results show that stress of 400 MPa was applied at the center of the interface between the VPS-W and F82H. Since formation of cracks and exfoliation has not been observed, interface is considered to be withstood by the stress of 400 MPa.

In the case of VPS-W/F82H, no cracks or exfoliation have been formed by steady state for 180 s and cyclic heat loading experiments for 60 s with 30 cycles under heat loading of surface temperature at 700 ^{o}C . The steady state thermal and stress analyses have been performed to evaluate quantitatively thermal behavior under the experimental condition. When the thermal conductivity of the VPS-W is 30% of that of pure tungsten, calculated value gives close agreement with the experimental value. In addition, in this case, thermal resistance between the VPS-W and F82H was not taken account in the calculation. These mean that thermal and adhesion properties between the substrate and the coatings are good. On the other hand, exfoliation has occurred at interlayer of the VPS-W coatings near the interface of the VPS-W and the F82H by cyclic heat loading of surface temperature at 1300 ^{o}C for 7 s with 30 cycles. This means that strengthening of the VPS-W interlayer will be necessary for improvement of thermal property of the VPS-W coated F82H.

In the case of W(ST-01)/OFHC and W(ST-02)/OFHC, surface temperature of the W(ST-01)/OFHC is always lower than that of the W(ST-2)/OFHC; for example, the difference between them is about 673 K and 973 K at the heat flux of about 8.5 MW/m^2, respectively. Temperature increase of W(ST-1)/OFHC is very low and this indicates that jointing between W(ST-1) and OFHC using NDB is extremely good. In addition, in the case of W(ST-1)/OFHC, it was demonstrated that the mock-up successfully withstood 50 cycles with heat load of 14.6 MW/m^2 at steady state.