§2. 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. 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 will be made by low activation materials. Tungsten coated reduced activation materials could be convenient for the first wall/blanket because the thickness of tungsten on the first wall/blanket is designed about 2 ～ 3 mm and the coating technique can be used for this. In the present work, tungsten coating with a thickness of 0.6 mm on reduced-activation ferritic/martensitic steel (RAF/M) F82H (Fe-8Cr-2W), which is a leading structural material candidate for DEMO, have been produced by Vacuum Plasma Spraying (VPS). Heat flux experiments using an electron beam have been carried out on VPS-W coated F82H to evaluate their possibility as a plasma-facing armor in the fusion device. In addition, quantitative analyses about temperature profiles and thermal stress have been carried out using FEM.

Sample sizes used are dimensions of 10 mm x 10 mm x 5.6 mmt and thickness of W is 0.6 mm. Samples were placed on a water-cooled Cu block and subjected to heat loading by an electron beam irradiation. The experiments were conducted at three irradiation conditions; (1) Heat flux of 7.5 MW/m^2, duration of 180 seconds, (2) repeated irradiations of 60 second-irradiation with a heat flux of 12 MW/m^2 and 140 second-rest with 30 cycles in total and (3) 7 second-irradiation with a heat flux of 40 MW/m^2 and 230 second-rest with 30 cycles in total. Temperatures of the W surface and F82H have been measured with two-color optical pyrometers and thermo-couples. In addition, FEM analyses has been performed to evaluate quantitatively temperature profiles and thermal stresses.

In the case of (1) and (2), peak surface temperature was 700 ^{o}C, no cracks and exfoliation occurs. However, fine modification on W surface is observed after the case of (2). On the other hand, in the case of (3), the peak temperatures of VPS-W surface increases from about 1300 ^{o}C to 1700 ^{o}C as cyclic number increases. On the other hand, the peak temperature of F82H decreases from 480 ^{o}C to 300 ^{o}C as cyclic number increases. The increase of temperature difference between VPS-W and F82H is considered by decrease of heat conduction due to exfoliation for parallel direction. Figure 1 shows SEM image of cross section of the interface of the VPS-W and F82H of the sample after the irradiation. It can be seen that exfoliation occurred at interlayer of the VPS-W coatings at about 50 μm from the interface of the VPS-W and the F82H, and micro-cracks were also formed. In addition, cracks were observed on the VPS-W surface and penetrated to bottom layer of the VPS-W, which was exfoliated. These results indicate that the thermal stress caused exfoliation between the VPS-W layer at first, then, the cracks from the surface to bottom of the VPS-W layer occurred by the further cyclic heat loading. In addition, it is considered that exfoliation occurred at the location near to the interface between the VPS-W and F82H, where large thermal stress was applied and weak interlayer existed.

The steady state thermal and stress analyses have been performed to evaluate quantitatively thermal behavior under the experimental condition (1). Figure 2 shows von Mises stress in the dimension of 5 mm x 5mm x 1.6 mm near the interface in the sample. In this case, temperature of the VPS-W is above DBTT. Therefore, the VPS-W and F82H are regarded as ductile materials. The calculation results show that stress of 541 MPa was applied near the interface between the VPS-W and F82H. It is considered that stress of VPS-W is below elastic limit judging from the result of tensile test of pure W. However, evaluation may be difficult because mechanical property of VPS-W may be different from that of pure W. On the other hand, because stress of the part of F82H just below the center of electron beam is slightly above 0.2% proof stress, plastic deformation may occur. In this case, stress is relaxed and become diminished.

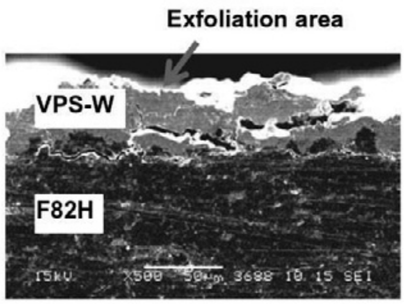

Fig. 1. SEM image of cross section after heat loading of experimental condition (3)

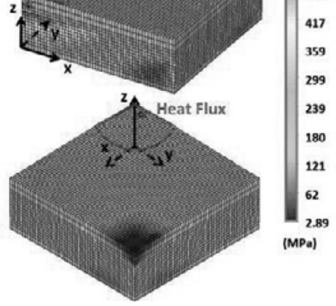

Fig. 2. Von Mises stress in the dimension of 5 mm x 5mm x 1.6 mm near the interface in the sample corresponding to experimental condition (1)