§21. W-coating on Low Activation Structural Materials

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Tungsten armor has been considered to be critical for realization of fusion reactor because it suffers severe irradiation damages by highly energetic particles irradiation together with high heat loading. The estimated thermal heat loading is more than 20 MW/m^2 for divertor of Tokamak-DEMO reactors. Since tungsten is less ductile, cyclic heat loadings may cause fatigue rupture through thermal stress applied by the difference in the coefficients of thermal expansion between W-armor and structural material. In this study, heat load tests were carried out for W-armored structure component made of vacuum plasma sprayed (VPS) tungsten with reduced activation ferritic steel (F82H) or oxide dispersion strengthened (ODS) steel.

VPS-W with 1 mm thickness was coated on a reduced activation ferritic steel, F82H, with 5 mm thickness. No surface crack was observed after 100 cycles of heat loading at 4.8 MW/m^2, while 16 cycles of the loading at 5.5 MW/m^2 resulted in cracking on the surface of W. However, the reduction of plate thickness of F82H from 5 mm to 3 mm increased cyclic heat resistance to 6.0 MW/m^2. It was found that surface cracking occurred when the surface temperature increased to higher than 1150 K irrespective of amount of heat load.

Figure 1 shows the measured temperatures of VPS-W surface and Cu-heat sink versus heat load, in which heat loading tests were carried out for two F82H substrate plates with different thickness. As expected, the surface temperature of VPS-W was reduced with decreasing plate thickness from 5mm to 3mm, which is due to high cooling rate of the W surface with thinner F82H substrate plate.

Finite element method analyses of thermal stress at surface of W during heat loading tests clearly showed that occurrence of cracking was determined by balancing heat loading and cooling, suggesting that the soundness of W-armor can be controlled by system integration, especially by considering cooling rate of system components, as well as material performance of W-armor itself.

One of the methods to avoid cracking of W during operation is the elevation of service temperature of divertor system. Tungsten has BCC structure and shows ductile to brittle transition behavior at a rather high temperature than 873K. Thus, in principle, W is brittle at below 873K. According to the creep tests of substrate materials, the service temperature of F82H is limited to below 823K, while that is 1023K for ODS steels. High performance 15Cr-ODS steel, which was developed in Kyoto University, enables to elevate service temperature higher than the ductile-brittle transition temperature of W. Furthermore, a ductile W alloy, of which the grain boundary structure is modified by adding TiC and thermo-mechanical treatment, has been developed in Tohoku University. It is considered that combined use of these advanced materials is essential to meet the requirements for DEMO blanket design.

The application of an ODS steel as substrate of W-armor also enables to increase the spraying temperature for VPS process, which is considered to be effective to make a high performance VPS-W with a higher density.

In this study, some critical issues were solved towards high performance first wall production. Heat loading tests revealed that VPS-W kept soundness under the cyclic heat loading at 12 MW/m^2 for 1 min up to 30 cycles. Recent results indicate a high potential of VPS-W as an armor of first wall of blanket.

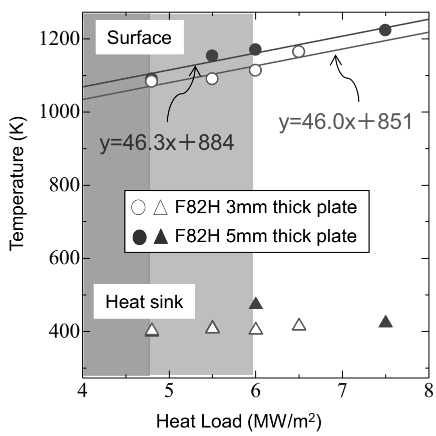

Fig. 1: Temperatures of VPS-W surface and F82H heat sink versus heat load relationship