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Author(s)	Tokunaga, Kazutoshi; Kobayashi, Akira; Araki, Kuniaki et al.
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Tungsten coatings on reduced-activation ferritic/martensitic steel by plasma spray technique†

— Thermal behavior of Tungsten coatings —

TOKUNAGA Kazutoshi *, KOBAYASHI Akira **, ARAKI Kuniaki *, FUJIWARA Tadashi *, MIYAMOTO Yoshio *, NAKAMURA Kazuo *, KURUMADA Akira ***, TOKITANI Masayuki ****, MASUZAKI Suguru ****, EZATO Koichiro *****, SUZUKI Satoshi *****, ENOEDA Mikio ***** and AKIBA Masato *****

KEY WORDS: (Plasma spray) (Tungsten) (Ferritic/martensitic steel) (Coating) (Thermal property) (Heat flux test) (Fusion device) (First wall) (Divertor) (High heat flux)

1. Introduction

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. The disadvantages of tungsten are its heavy weight and the brittleness below DBTT. 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 at about 2～3 mm and the coating technique can be used for this[1].

In the present work, tungsten coating on reduced-activation ferritic/martensitic steel (RAF/M) F82H substrate (F82H: Fe-8Cr-2W), which is a leading structural material candidate for DEMO [2], by Atmospheric Plasma Spraying (APS), Vacuum Plasma Sprayin (VPS) and Gas Tunnel Type Plasma Spraying (GTP) were prepared. Surface morphology of the deposited W and adhesion property between the substrate and the coatings have been investigated using SEM/EDS. In addition, heat flux tests and thermal fatigue tests using an electron beam have been also carried out.

2. Experimental

W coated material has been produced by APS and VPS to evaluate thermal behavior of APS-W and VPS-W. The substrate material is reduced-activation ferritic/martensitic steel (RAF/M) F82H (Fe-8Cr-2W) [2]. Size of the substrate material was 20 mm x 20 mm x 2.6 mmt. A thickness of W is 1mm. Temperatures of the substrates during the APS and VPS were 150 ^{o}C and 600 ^{o}C, respectively. In addition, mock-ups were made by brazing the tiles (VPS-W/F82H, APS-W/F82H) on oxygen free high purity copper (OFHC) block with a cooling tube of inside diameter of 7mmϕ. Heat load tests were performed on an active cooling test stand (ACT) of NIFS and an electron beam irradiation test simulator at the Research Institute for Applied Mechanics (RIAM) at Kyushu University. In the case of ACT experiments, a uniform electron beam was irradiated on the tungsten surface through a beam limiter with an aperture of 20mm×20 mm. Beam duration during ramp-up, plateau and ramp-down were 20, 40 and 0 s, respectively. Heat flux was changed from 1 to 3.4 MW/m^2. Thermal fatigue tests were also carried out for up to 100 cycles at a heat flux of 3.2 MW/m^2. Surface temperature of the tile is measured by an optical pyrometer. Temperatures of F82H (T1) and OFHC (T2) at interfaces of the brazed area were also measured with thermocouples. The heat flux tests have been carried out under the condition that the water flow velocity, pressure and temperature were 18.0 m/s, 0.7 MPa and 20 ^{o}C, respectively.

3. Results

Figure 1 shows the APS-W coated F82H brazed on OFHC with cooling tube. There is no damage after the brazing of the OFHC block with the cooling tube.

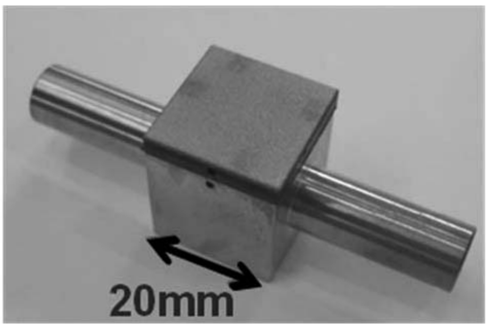

Fig. 1 Photograph of APS-W/F82H/OFHC mock-up

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* RIAM, Kyushu University, Fukuoka, Japan
** JWRI, Osaka University, Osaka, Japan
*** College of Engineering, Ibaraki University, Ibaraki, Japan
**** NIFS, Gifu, Japan
***** JAEA, Ibaraki, Japan

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Figure 2 and **3** show heat flux dependence of plateau temperatures measured at the surface, T1 and T2 for VPS-W/F82H/OFHC and APS-W/F82H/OFHC, respectively. It can be seen that the temperatures increased continuously with increasing heat flux. Surface temperature of the VPS-W/F82H/OFHC is always lower than that of the APS-W/F82H/OFHC; for example, the surface temperatures are about 700 ^{o}C and 1200 ^{o}C at the heat flux of 3.4 MW/m^2, respectively. In the case of steady state, temperature increase is inversely proportional to the thermal conductivity. The thermal conductivity of plasma spray W depends strongly on its texture structure and residual porosity. Cross sectional observation of the APS-W showed that pores partially existed between W particles. This is one of the reasons for the high temperature increase of the W surface of APS-W.

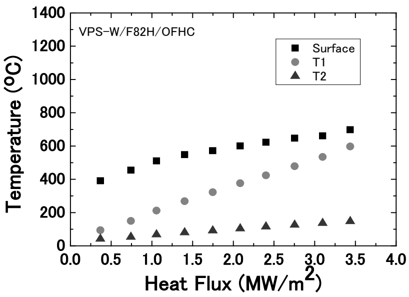

Fig. 2 Thermal response of VPS-W /F82H/OFHC

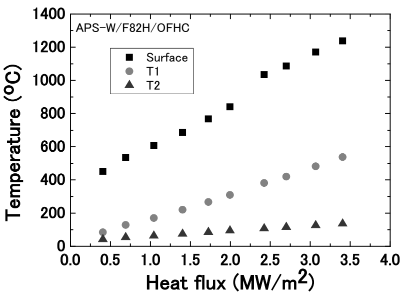

Fig.3 Thermal response of APS-W /F82H/OFHC

As shown in Figs. 2 and 3, the surface temperature of APS-W coated mock-ups is always higher than that of VPS-W coated mock-ups. This degradation in heat transfer must be caused by low thermal conductivity of the APS-W layer and/or interface of APS-W and F82H. The thermal conductivity of plasma spray W (PSW) depends strongly on its texture structure and residual porosity. It was reported that thermal conductivity of APS-W and VPS-W is about 20 and 60% of pure W, respectively [3–5] but it also strongly dependent on the fabrication process. Therefore, we estimated the thermal conductivity of the present case as follows. The heat flux q through a material layer at steady state for plane geometries is given by

$$q = -k\frac{\Delta T}{\Delta x}$$

where Δx is the thickness of material layer of PS-W and F82H, ΔT the temperature difference corresponding to the Δx and k thermal conductivity [6]. Estimated thermal conductivities of APS-W/F82H is 10 W/mk, which is about 5.6 % of normal W and 37 % of F82H at RT. On the other hand, estimated thermal conductivities of VPS-W/F82H is 77 W/mk, which is about 43 % of normal W and 285 % of F82H. It is considered that the thermal conductive of VPS-W/F82H is good enough taking into account thermal conductivity of F82H.

The thermal fatigue test up to 100 cycles (3.2 MW/m^2, 40 s ON:40 s OFF) for APS-W/F82H/OFHC and VPS-W/F82H/OFHC showed that temperatures of surface, T1 and T2 did not change. The surface morphology also did not change. In addition, no cracks and exfoliation were observed. These results indicate that no failure occurred at the interface or in the W coating during cyclic heat load.

4. Conclusions

Two types of plasma spray tungsten coatings on ferritic/martensitic steel F82H made by vacuum plasma spray technique (VPS) and atmospheric plasma spray technique (APS) have been examined to evaluate their possibility as a plasma-facing armor in the fusion device. Thermal response test and thermal fatigue tests indicate a high potential of this coating as plasma-facing armor under thermal loading.

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