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Thermal properties of VPS-W coatings on CuCrZr alloy with Ti bonding layer

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Abstract

Tungsten coating of 0.2 mm thickness was successfully deposited by vacuum plasma spraying technique on CuCrZr alloy with Ti bonding layer. Microstructure and chemical composition of deposited W were examined. Its thermal response and thermal fatigue properties were studied with active cooling. No cracks and no exfoliation occurred on the W surface after thermal response test with a heat flux from 0 to 8 MW/m^2. It survived up to 200 cycles under 8 MW/m^2. These results indicate that VPS-W coated Ti/CuCrZr is a potential candidate for a high heat resistance armor material on plasma facing components.

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Keywords: Tungsten; VPS-W; Heat load experiment; HT-7U

1. Introduction

Tungsten has been considered as candidate materials for plasma facing components such as limiter blocks and diverter tiles in fusion experiment devices because of their prominent thermal properties and the low sputtering yield. At present stage, tungsten coatings on light carbon materials has been successfully used in current fusion devices such as TEXTOR and ASDEX-Upgrade [1–3]. But it is difficult to fix tungsten coated carbon tiles mechanically on copper sink. So tungsten coating on copper alloy has attracted much attention which can provide simultaneously the joining of the W amour with the heat sink to make up PFM. Problems related to the manufacturing of thick tungsten coatings on copper alloy substrates are low adhesion and the high residual stress following the deposition process due to the difference in the thermal expansion coefficient, which is four times smaller for tungsten than for copper [4]. So it is a key issue to select an intermediate bonding layer between the W coating and the heat sink, with an intermediate thermal expansion coefficient and high compliance. Therefore, in this work, tungsten coatings of 0.2 mm thickness were successfully deposited by vacuum plasma spray method on CuCrZr alloy with Ti as bonding layer. High heat flux experiments were performed on such coating materials.

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2. Experimental

Blocks of CuCrZr alloy were coated with tungsten by vacuum plasma spraying technique. The interplayer is Ti. The thickness of the VPS tungsten was 0.2 mm and its density was 90% of the theoretical value. The chemical composition of coatings and Ti layer were examined by EDS. Mock-up was made with a cooling tube for heat load experiments. Fig. 1 shows a photograph and a cross-sectional view of mock-up for heat load experiments. Heat load tests were carried out in the electron beam facility at ASIPP with maximum electron beam power of 20 kW. And irradiation area was $15 \times 15\ mm^2$ by electron beam sweeping with 200 Hz. Thermal response tests were carried out by stepwise increase of the heat flux which changed from 2 to 8 MW/m^2. Thermal fatigue tests were also carried out up to 200 cycles at a heat flux of 8 MW/m^2. The heat flux duration with ramp up, plateau and ramp down were 30, 100 and 30 s, respectively and it paused for 200 s per cycle. Surface temperature was measured by IR and optical pyrometers. Bulk temperature distribution was measured by thermocouples by three thermocouples with the diameter of 1.5 mm. Before and after the heat load tests, surface morphology of the tested samples was observed with scanning electronic microscope.

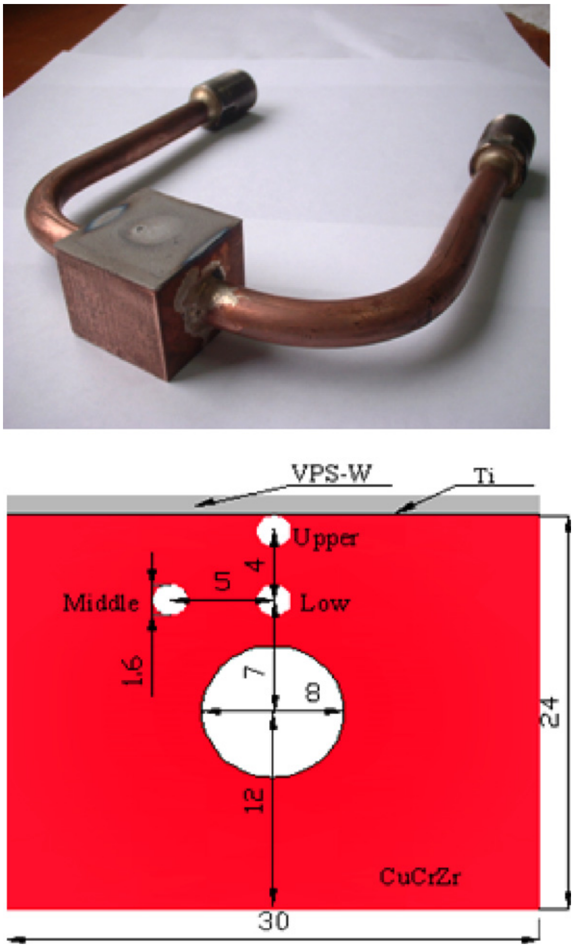

Fig. 1. Photograph and cross-sectional view of mock-up for heat load experiments.

3. Results and discussion

3.1. Microstructure observation

Fig. 2(a) shows the surface of deposited tungsten. It can be seen that most of the sprayed tungsten were melted or partially melted and joined each

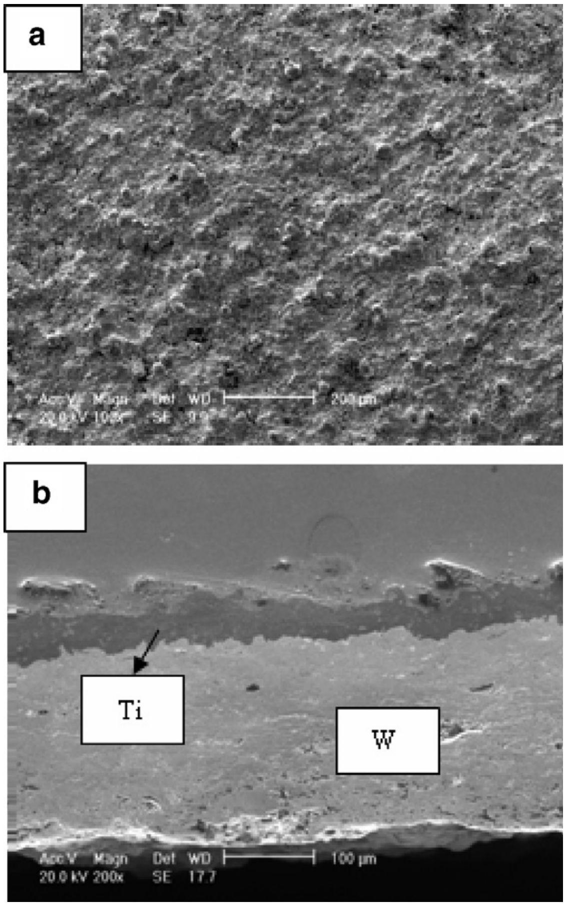

Fig. 2. SEM image of VPSW/Ti/CuCrZr : (a) surface of coating; (b) cross-section.

other and small pores were found in the coatings. As shown in Fig. 2(b), a dense deposit was observed. No segmentation of coating and cracks were found in bonding layer.

3.2. Chemical composition analysis

Fig. 3 shows the position of EDS point analysis of W layer and Ti layer and the results are shown in Tables 1 and 2, respectively. It can be seen that oxygen content in Ti layer was higher than that in W layer. This is because Ti has the ability to deoxidize the adjacent copper and tungsten to form an oxide. Additionally, W dissolved in Ti layer, which is expected to improve the bonding strength.

3.3. Heat response test

Fig. 4 shows the SEM image of VPSW/Ti/CuCrZr after thermal response test with a heat flux from 0 to 8 MW/m^2. No exfoliation occurred on the W surface and no cracks were found at the joint areas. It indicates VPSW/Ti/CuCrZr has good heat resistance. As shown in Fig. 5, surface temperature of VPSW/Ti/CuCrZ was always higher than that of substrate; e.g. the difference is about 500 °C at the heat flux of 8 MW/m^2. This large difference may be caused by the lower thermal conductivity of VPS-W. It was reported that thermal conductivity of VPS-W is about 60% of pure W [5]. Fig. 6 shows heat flux dependence of plateau temperatures measured at the surface. It can be seen that

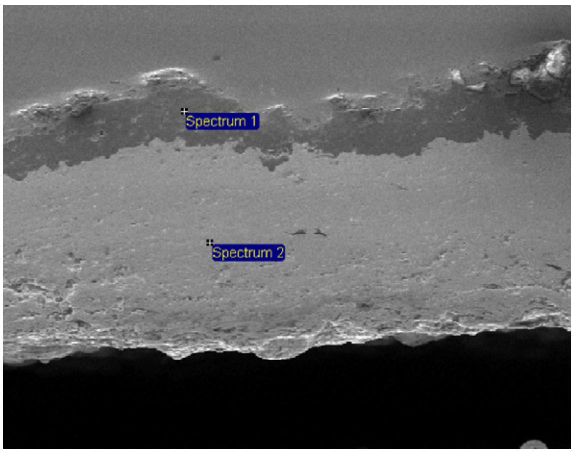

Fig. 3. The position of EDS point analysis of W layer and Ti layer.

Table 1
EDS point analytical results of W coating layer

Element	wt%	at.%
C K	4.19	38.18
O K	0.78	5.30
W M	95.03	56.52
Totals	100.00	100.00

Table 2
EDS point analytical results of Ti layer

Element	wt%	at.%
N K	4.34	11.11
O K	11.94	26.73
Ti K	82.88	62.00
W M	0.84	0.16
Totals	100.00	100.00

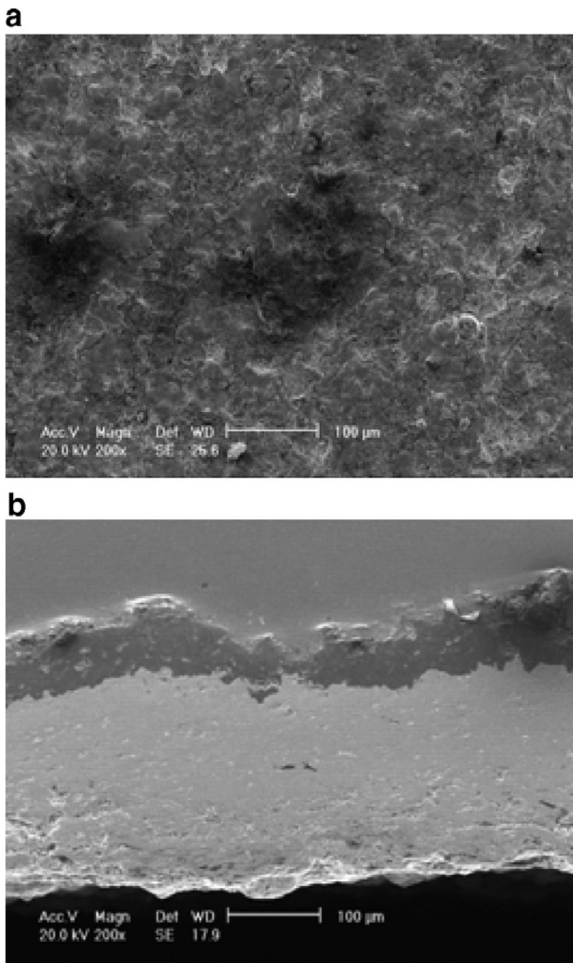

Fig. 4. SEM image of VPSW/Ti/CuCrZr after thermal response test with a heat flux from 0 to 8 MW/m^2: (a) surface of tungsten coating; (b) cross-section.

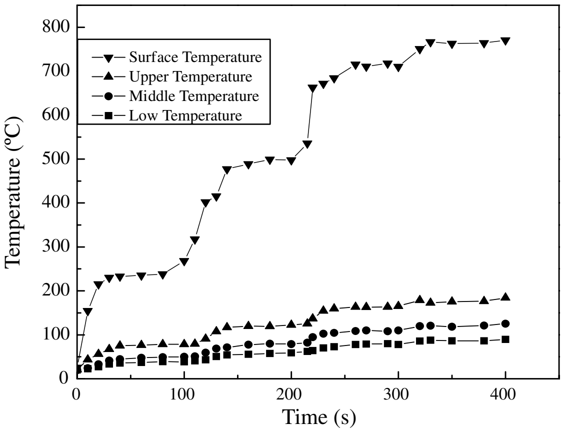

Fig. 5. Time evolution of the temperature distribution of VPSW/Ti/CuCrZr under the heat flux from 0 to 8 MW/m^2 with water flow rate of 10 m/s.

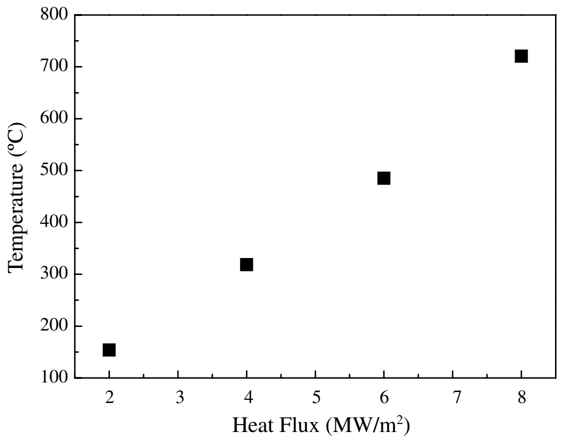

Fig. 6. Plateau temperatures at the surface of VPSW/Ti/CuCrZr.

the surface temperature of the samples increased with increasing heat flux.

3.4. Thermal cycle test

Microstructure of VPSW/Ti/CuCrZr after thermal fatigue test to 200 cycles at 8 MW/m^2 was observed, as shown in Fig. 7. It shows that cracks formed on the surface and propagated from the surface center to the lower side. But no cracks or delamination were observed around the joint areas. Surface temperature was also recorded during thermal cycle tests. As shown in Fig. 8, it did not increase obviously. Although cracks formed on the surface during thermal cycle test, it was considered that the cracks hardly influence the degradation of thermal conduction of VPS-W coatings [6]. Therefore, heat exhaust capability was little influenced and the change of surface temperature was little.

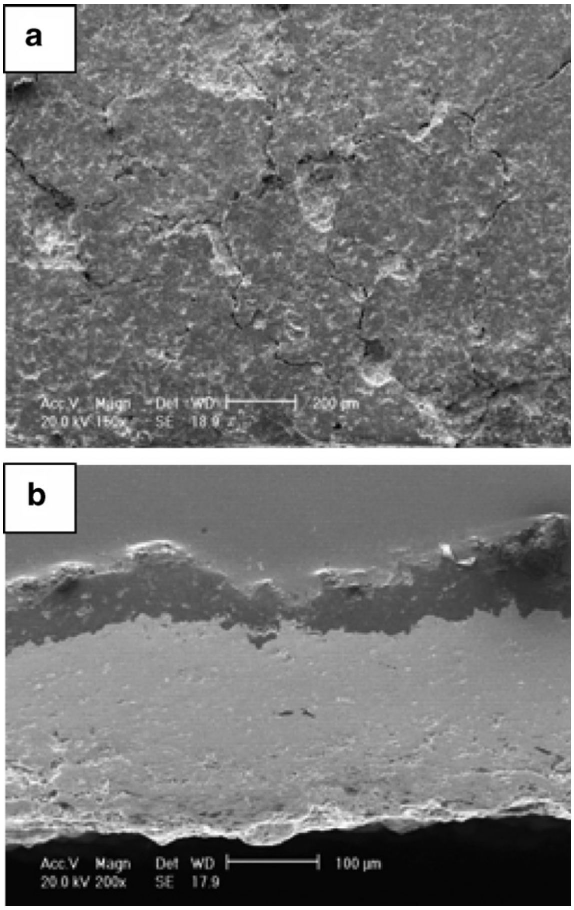

Fig. 7. Microstructure of VPSW/Ti/CuCrZr after thermal fatigue test to 200 cycles at 8 MW/m^2: (a) surface of tungsten coating; (b) cross-section.

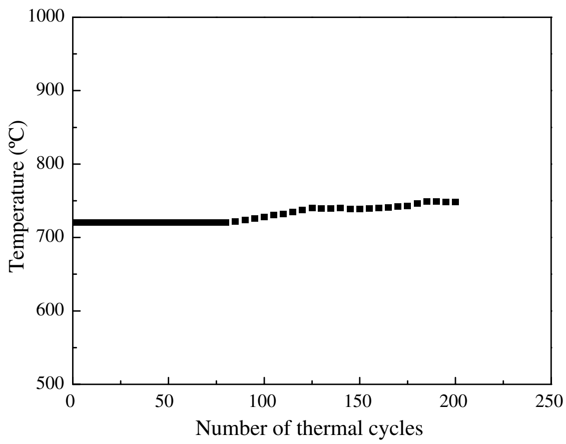

Fig. 8. Thermal fatigue test for VPSW/Ti/CuCrZr to 200 cycles at 8 MW/m^2.

4. Summary

From the heat load tests of VPS-W coated CuCrZr with Ti as bonding layer, the following conclusions were obtained.

W coated Ti/ CuCrZr was successfully developed by vacuum plasma spraying technique. Chemical composition analysis showed oxygen content was very low in W coating but higher in Ti layer and W dissolved in Ti layer. No exfoliation occurred on the W surface or at the joint areas after thermal response test with a heat flux from 0 to 8 MW/m^2. Surface temperature is was $\sim$750 °C that is $\sim$500 °C higher than substrate temperature at 8 MW/m^2. W/Ti/CuCrZr survived up to 200 cycle under 8 MW/m^2 and a few cracks were observed on the surface. But joint areas were intact. These results indicate that VPS-W coated Ti/CuCrZr is a potential candidate for a high heat resistance armor material on plasma facing components.

Acknowledgement

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