Microstructure and Bonding Strength of Tungsten Coating Deposited on Copper by Plasma Spraying

Shu-Xiang Song[a], Zhang-Jian Zhou[b], Juan Du[c], Zhi-Hong Zhong[d], Chang-Chun Ge[e]

Laboratory of Special Ceramics and Powder Metallurgy, University of Science and Technology Beijing, Beijing 100083, China
[a]ssx1999@163.com, [b] zhouzhj@mater.ustb.edu.cn, [c] justwell0209@163.com, [d]zhonghongzhi@163.com, [e] ccge@mater.ustb.edu.cn

Abstract

Tungsten coatings with different interlayers onto the oxygen-free copper substrates were fabricated by atmosphere plasma spraying. The effects of different interlayers of NiCrAl, NiAl and W/Cu on bonding strength were studied. SEM, EDS and XRD were used to investigate the photographs and compositions of these coatings. The tungsten coatings with different initial particle sizes resulted in different microstructures. Oxidation was not detected in the tungsten coating, but in the interlayer, it was found by both XRD and EDS. The tungsten coating deposited directly onto the copper substrate presented higher bonding strength than those with different interlayers.

Keywords : plasma spraying, tungsten, copper, microstructure, bonding strength

1. Introduction

Tungsten has been decided as the plasma facing material (PFM) for some high heat flux regions of the divertor in the International Thermo-Nuclear Experimental Reactors (ITER) [1-4]，But, it is not easy to shape tungsten into the form needed for heavy weight and brittleness of tungsten. Therefore, tungsten coating on copper substrates attracts much attention. Plasma-sprayed tungsten (PS-W) coatings are of an economical alternative, with high deposition rates and a better chance of in-situ repair after melting or damaging off-normal plasma events [5].

Different thermal expansion coefficients, melting points and elastic modulus between tungsten and copper lead to high stress state on the interface during plasma spraying process. How to improve the interfacial characterization of the coating and obtain high bonding strength have not been completely clear. In this study, different interfacial interlayers and tungsten coatings were deposited on copper to investigate the influence of both material selection and spray parameters on bonding strength of the coating. In addition, the microstructure, porosity and oxidation of the tungsten coating were also discussed.

2. Experimental Procedure

The tungsten feedstock powders had mean particle size of 16μm, 28μm and 50μm. The oxygen-free copper block was selected as the substrate.The tungsten coatings were deposited on the substrate using a PT-A-3000S atmosphere plasma-spray facility. Argon was used for cooling the substrate and preventing the coatings from oxidation. Table 1 shows the experimental parameters.

The tensile test was carried out to measure bonding strength. Phase constituents of feedstock powders and coatings were identified by X-ray diffraction spectroscopy. A scanning electron microscope with back-scattered electron, as well as an energy dispersion X-ray spectroscopy (EDS) were utilized to examine the microstructures, porosities (software analysis), and compositions of the coatings.

Table 1. Plasma spraying parameters for coating and interlayers

Deposition	Input power [kW]	1st gas flow rate [Ar, l/min]	2nd gas flow rate [H_2, l/min]	Powder feed rate[g/min]	Spray distance [mm]
W coating	35	45	6	20	100-120
W/Cu (50vol%W+50vol%Cu)	30	50	5	20	100-120
N iCrAl	13	40	5	20	100-120
NIAl	15	40	5	20	100-120

3. Results and Discussion

3.1. Micrograph of Tungsten Feedstock Powder

The SEM shows the micrograph of the initial tungsten powder. The particle size distribution is not uniform. Most of fine particles connect together to form agglomerates.

3.2. Microstructure of Surface and Cross Section

By the surface morphologies of tungsten coatings made from various powder sizes, it can be seen that there are some large solidified stacks on the surface, which surround by the molten particles and some small pores. Some obvious micro-cracks are also clearly observed. The micro-cracks usually originated from the core of the stacks, extended gradually to the edges of the stacks. The reason for these may be that mechanical strain, induced by high speed impacting and cooling quickly, acts as crack initiators. And then, the mechanism strain was relieved by pore around the stacks, which resulting in the ending of the crack propagation. The larger the initial tungsten powder size, the more the cracks on the solidified stacks. By the SEM micrographs of the cross sections of the tungsten coatings, It can be clearly seen that the plasma-sprayed tungsten coating consists of laminar layers with interlocking structure. This structure leads to high cohesion strength in the coating. The interface between two laminar layers is clear and a few unmelted particles can be observed among the layers. Therefore, some pores were found scattered in the vicinity of the lamellar layers. Density measurement of the coatings by software analysis indicates that the porosities of the coatings made from initial tungsten powders with particle size of 16μm, 28μm and 50μm are 4.5%, 7.5% and 8.4%, respectively, which according with the phenomena illustrated by the SEM.

3.3. XRD Analysis of Coatings

Fig.1 shows the XRD patterns of three coatings prepared with different feedstock sizes. Oxidation of tungsten cannot be revealed in all three tungsten coatings. This result can be explained by the fact that argon was used for preventing the coatings from oxidation. Further examination using an energy dispersion X-ray spectroscopy obtained same result.

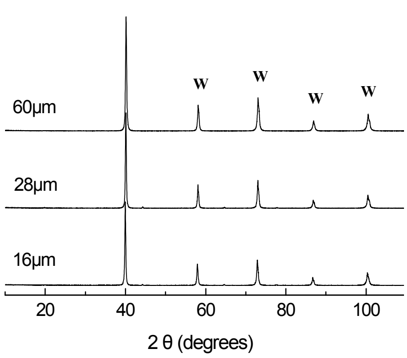

Fig. 1. XRD patterns for tungsten coatings

3.4. The Interface and the Bonding Strength Between the Coating and the Substrate

To improve the bonding strength between the tungsten and the copper substrate, we fabricated tungsten coatings with different interlayers. We found that all the interfaces adjacent to tungsten coatings are more compact than those adjacent to copper substrates.

Table 2. Bonding strength of specimen

Specimen	Interlayer composition and thickness (μm)	Tungsten coating thickness (μm)	Bonding strength (Mpa)
WCu1	Non	200	35.72
WCu2	W/Cu, 200	200	18.82
WCu3	NiCrAl, 200	200	23.82
WCu4	Ni coated Al,	200	Delamination

For comparison, the additional tensile tests were carried out to measure the bonding strength of four coatings. Table 2 shows the test results. It can be seen that the tungsten coating without interlayer shows the highest bonding strength. When tungsten-copper composite materials were selected as interlayers, the bonding strength has not been improved, which seem to differ from the traditional concept of functional graded materials (FGM).

4. Summary

Tungsten coatings with different interlayers were deposited on oxygen-free copper by atmosphere plasma spraying. The coating formed from finer initial particles has higher density than those formed from the coarse ones. Controlling the condition and parameters of the plasma spraying can reduce or even eliminate the oxidation of the tungsten coating. Introducing the interlayers of NiCrAl, Ni coated Al and W-Cu (W50%, Cu50%) did not enhance the bonding strength. The tungsten coating without interlayer shows the highest bonding strength compared to the others in this work.

5. References

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