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Fabrication of thick W coatings by atmospheric plasma spraying and their transient high heat loading performance

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ABSTRACT

Both tungsten coatings with or without a W/Cu graded interlayer on an oxygen-free copper substrate were fabricated by atmospheric plasma spraying. High purity argon gas was used for cooling the substrate and preventing the coating from oxidation. The thickness of both coatings is ~1 mm. XRD and EDS measurements of the coatings show that minimal oxidation occurred during the deposition process. Transient high heat load tests by electron beam with a pulse duration of 5 ms were performed on both coatings. The single pulse loading was applied on the virgin surfaces at several power densities (from 0.22 to 0.9 GW/m^2). Although the weight loss of the W/Cu FGM (functionally graded materials) based coating was slightly lower than that of the pure W coating, their transient high heat loading performances were quite similar.

1. Introduction

Due to the advantages, such as the highest melting point of all metals and low vapor pressure, very low erosion rate under plasma loading and low tritium retention, tungsten is being considered as a plasma facing material (PFM) in some existing tokamaks (ASDEX-Upgrade, JET) and in the next step fusion devices such as the divertor of International Thermo-Nuclear Experimental Reactor (ITER) [1–4]. There are also obvious disadvantages of tungsten for using as PFM, such as difficult to shape tungsten into the necessary form due to its brittleness at room temperature. For the near term application, a possible convenient solution for W-based PFM (especially for the first wall application) is the coating of the heat sink (copper based alloy) or structural materials (such as reduced activation ferritic/martensitic steel) with a thin tungsten layer [5–7]. Coating technology can provide simultaneously the fabrication of W and joining it to heat sink even with complex shape. The tiles could be easily replaced or repaired without a big change in heat transfer properties of cooling channels [8].

Plasma spraying (PS), physical vapor deposition (PVD) and chemical vapor deposition (CVD), have been proposed for fabrication of W coatings [8]. Among these three coating technologies, PS is a well-established and widely used coating process for its economical alternative, high deposition rate and a better chance of in-situ repair for the damaged coating. For avoiding oxidation during plasma spraying, W is usually sprayed under controlled atmospheric conditions, i.e. vacuum or inert gas atmosphere. Due to the mismatch of thermal expansion and Young's moduli, the direct joining of W and Cu or steel results in high residual and thermal stresses at the interface, ultimately reducing the component lifetime. One potential solution way for this problem is the concept of functionally graded materials (FGM), which can smoothen the transition of material properties [9].

In this work, the focus is on the fabrication of thin W-based coatings by atmospheric plasma spraying (APS). Both W coatings with or without a graded W/Cu interlayer were fabricated on an oxygen-free copper substrate. Single pulse transient high heat load tests by electron beam with a pulse duration of 5 ms were performed on the W coatings at several power densities (from 0.22 to 0.9 GW/m^2).

2. Experiments

Tungsten powders with an average particle size of 28 μm and copper powders with a particle size <76 μm were used as starting materials. The purities of both materials are higher than 99.9%. The substrate material is oxygen-free copper with a thickness of 8 mm and diameter of 40 mm. High purity argon gas was used for cooling the substrate and preventing the coatings from oxidation. The

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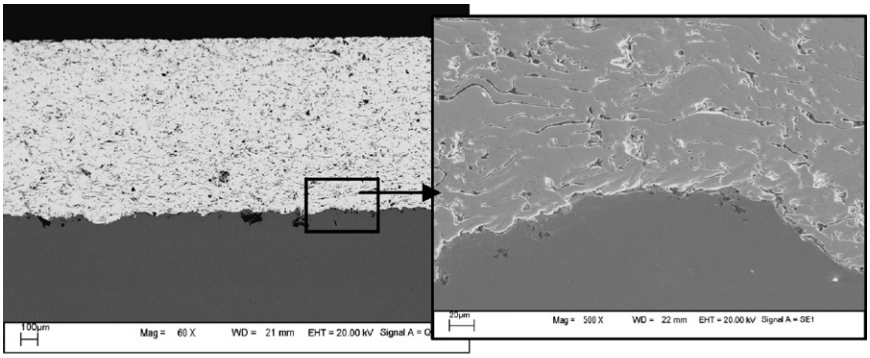
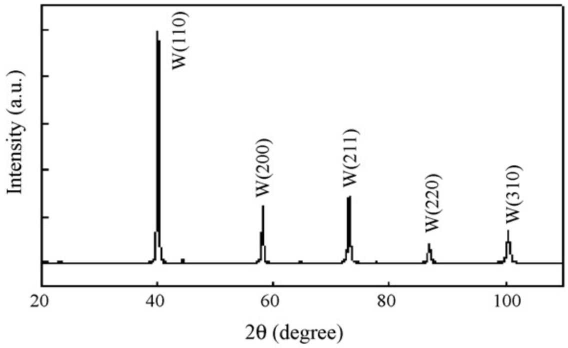


(a) cross section morphology of APS-pure W coating



(b) the XRD pattern of APS-pure W coating

Fig. 1. SEM micrographs of the cross-section morphology of (a) APS-pure W coating and (b) the XRD pattern.

coatings were fabricated using a PT-A-3000S plasma-spray facility. The powder injection spot was inside the anode-nozzle very near the plasma flame. The spraying powder suspended in a carrier gas was fed inside plasma flame in radial direction. So, the spraying powders were molten enough in the plasma and protected under a shroud of inert gas for avoiding oxidation [10].

For fabrication of W/Cu graded interlayer, two feedstock chambers with different feeding powder rate were used. During the process, Cu and W powders were fed synchronously and intermixed adequately inside the plasma plume. Both W and Cu melted particles with high-kinetic energy were sprayed to the substrate and finally formed the graded interlayer.

The fabricated samples were cross-section polished to analyse the microstructure and to obtain the porosity from image analysis. Phases of the coatings were identified by X-ray diffraction spectroscopy (XRD). The microstructures and compositions were examined by a scanning electron microscope (SEM) with an energy dispersion spectroscopy (EDS).

Transient high heat load tests were performed by the electron beam facility JUDITH installed in the Hot Cells of Juelich Forschungszentrum, Germany. Electrons are generated by a W cathode and accelerated to an energy of 120 keV. The given power density is a time averaged value. The loading is fairly homogeneous in area and constant in loading time because of fast scanning (with a frequency of 31 kHz in x-direction and 40 kHz in y-direction) on a small well-defined square area (16 mm^2) with beam spot focused to diameter of 1 mm.

The test samples with a diameter of 15 mm and a height of 5 mm were mechanically fixed on a copper holder. The heat load tests were performed in single shot experiments at room temperature on a spot size of $4 \times 4\,\text{mm}^2$ with a pulse length of 5 ms at different absorbed power densities from 0.22 to 0.9 GW/m^2 to investigate the damage evolution. The absorbed power density was quantified by measurements of the applied current. The loaded surface and cross-section were examined by SEM.

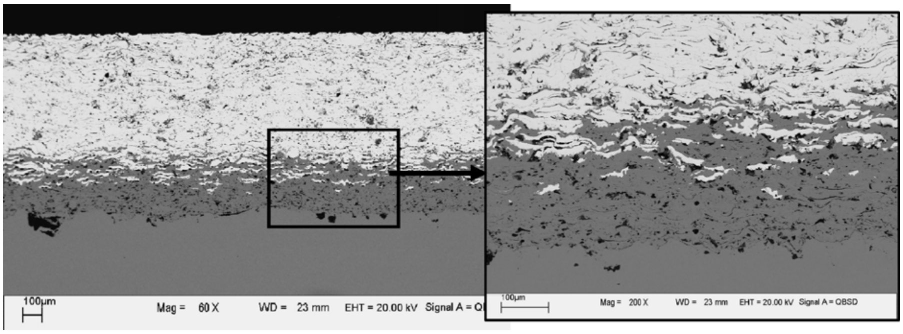


Fig. 2. SEM micrographs of the cross-section morphology of APS-W/Cu FGM coating.