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Fabrication and characterization of W-Cu functionally graded material by spark plasma sintering process

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ABSTRACT

In this study, seven-layered W/Cu functionally graded material (FGM) (100 W, 80W-20Cu, 60W-40Cu, 50W-50Cu, 40W-60Cu, 20W-80Cu, 100Cu, by wt %) were fabricated by a spark plasma sintering process (SPS). The influences of sintering temperature on microstructure, physical and mechanical properties of the sintered bulk FGM were investigated. Results indicated that the graded structure of the composite densified after the SPS process and interfaces of the layers are clearly visible. All of the layers had a very high relative density, thereby indicating their densification and excellent sintering behavior. SEM and EDX study of the bulk sample cross-section reveal that the graded structure can be retained up to sintering temperature of 1050 °C. In addition fine microstructure within each layer with good interface bonding was also observed. Sample sintered at 1050 °C exhibited excellent mechanical and physical properties (hardness 239 ± 5 Hv and relative density of 90.5%). The result demonstrates that SPS is a promising and more suitable process for fabrication of W-Cu functionally graded materials.

1. Introduction

Plasma-facing components (PFCs) for divertor applications play an important role in fusion reactors. They are made of armour material and heat sink material. Tungsten and Copper alloys are the most suitable candidate for armour and heat sink materials respectively for fabrication of plasma facing components. Tungsten has a high melting temperature, high sputtering threshold, low tritium retention, good thermal-mechanical properties [1–3] as well as the low coefficient of thermal expansion; those properties make it a promising plasma facing material. Additionally, copper is an ideal heat sink material due to high thermal conductivity and high coefficient of thermal expansion [4,5]. However, the large difference in melting point and coefficient of thermal expansion (CTE) of tungsten and copper makes very difficult to fabricate by conventional methods (i.e., brazing, conventional sintering, liquid infiltration, etc.) due to high thermally induced stresses at the interfaces. FGM can be used as interlayer's and could effectively mitigate thermal stresses effectively and also improve the lifetime of the component.

FGM is an inhomogeneous material with a gradually changing composition of two metals with different properties. The property gradient in the FGM is caused by position-dependent chemical composition and microstructure [6,7]. In this study, the composition gradient was maintained by powder metallurgy through different layers of W-Cu as a function of position. These graded layers minimize thermal stresses caused by the difference of the CTE of W and Cu and thus have gained considerable importance in extremely high-temperature environments [8,9]. W/Cu FGM can additionally benefit from a strengthening effect, since the hard W particle embedded in the soft Cu matrix act as reinforcing particles [10,11]. Thus, W/Cu based FGM can additionally strengthen the heat sink while reducing thermal stresses between the plasma facing and heat sink part of the divertor components. It not only reduces the problems caused by the mismatch of the CTE and other physical properties of both metals but also combines the features of W and Cu as mentioned above. Hence, the use of FGM between plasma facing and heat sink in divertor could be one of the appropriate solutions to improve the life of plasma facing component.

Techniques like plasma spraying slip casting, chemical vapor deposition, and pressure infiltration have been employed previously for the fabrication of PFCs, but they are expensive, complex and give porous microstructure to the FGM [7,12–16]. In recent decades, spark plasma sintering gained momentum and widely used for fabricating

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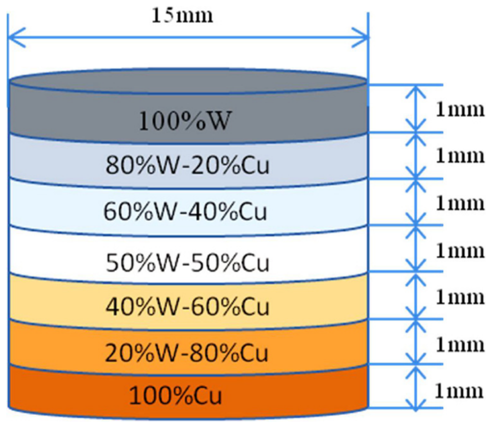

Fig. 1. The schematic view of seven layers W-Cu FGM showing the staked layer with varying composition.

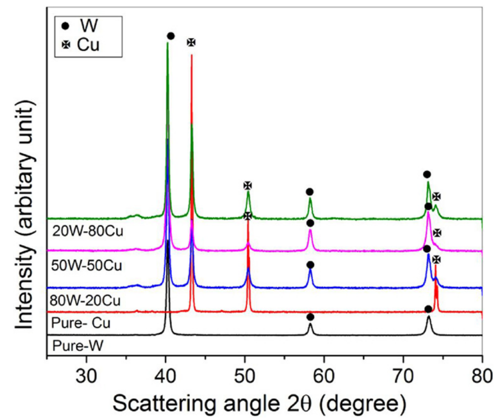

Fig. 3. XRD pattern of milled different composition powder used for grading in W-Cu FGM sample.

Table 1
Parameters used for milling of the powder in planetary ball mill.

Material	W and Cu elemental powder
Speed	150 rpm
Milling Time	20 h
Grinding Medium	Stainless steel balls (10 mm dia.)
Ball to powder ratio	10:1
Milling vessel	Stainless steel jar
Milling atmosphere	Normal

ceramics, composites, FGM, etc. SPS offers significant advantages with various kinds of new materials and consistently produces a highly dense compact in a shorter sintering time and of finer grain than conventional methods. Material produced by SPS expected to have higher irradiation resistance because it is possible to retain primary fine microstructure in the material [17–22]. Hence, SPS is one of the most attractive techniques for producing innovative materials at a moderate cost. Therefore, in the present work Spark Plasma Sintering was used to achieve higher density and microstructural homogeneity of W-Cu Compact.

2. Material and methods

High purity (> 99.7%) tungsten and copper powders with average particle size 4.3 μm and 35.78 μm, respectively, were used as starting materials for FGM preparation. Seven-layered W/Cu FGM samples were stacked and compacted according to the design as shown in Fig. 1 with varying wt% of W and Cu (100%W, 80%W-20%Cu, 60%W-40%Cu, 50%W-50%Cu, 40%W-60%Cu, 20%W-80%Cu, 100%Cu) in each layer, respectively. The thickness of the layers was kept constant is about 1 mm. W/Cu as received powders with desired weight ratios were homogeneously mixed in a planetary ball mill (Retsch PM 400). The details of ball milling parameters are listed in Table 1. Phase analysis of the milled powders was done using powder diffraction technique with the help of X'Pert PRO PANalytical's materials research Diffractometer (λ = 1.54184 Å), and particle size was analyzed by particle size analyzer (MASTERSIZER) with water as a dispersant. The particle morphology observation was performed using Scanning Electron Microscopy (SEM, Zeiss Supra-55). In order to prepare a bulk composite sample with desired compositions, milled powders of different

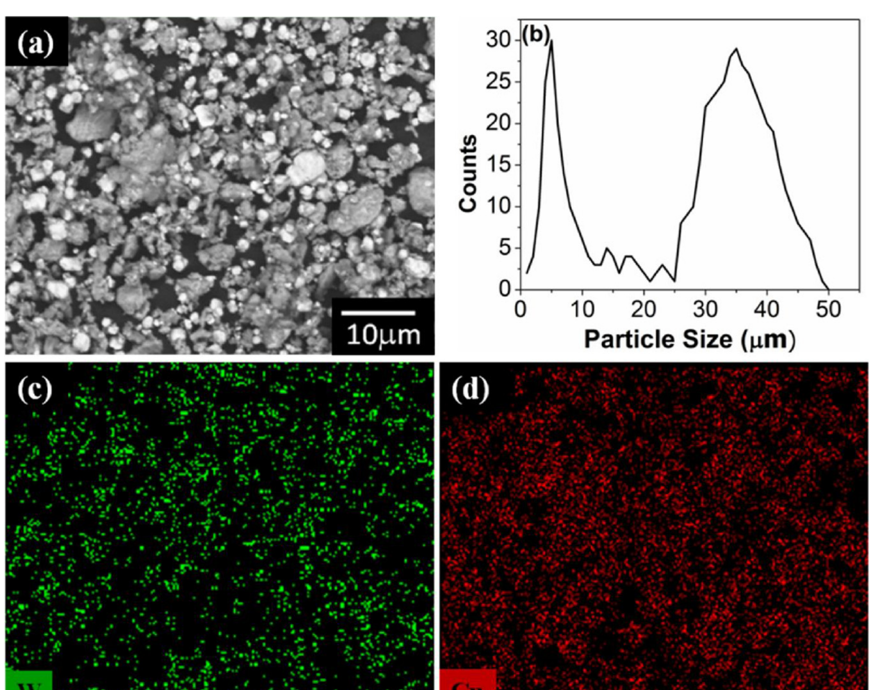

Fig. 2. W-Cu milled powder used for FGM synthesis (a) SEM micrograph (b) particle size distribution (c) & (d) elemental mapping of W and Cu respectively.