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Letter

Influences of temperatures on tungsten copper alloy prepared by microwave sintering

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A B S T R A C T

The CuW80 alloy was prepared by the method of microwave vacuum sintering. The effects of temperatures on the performance of CuW80 alloy was assessed based on the relative density and hardness. The micro structure of alloy was characterized using scanning electron microscopy, while XRD was utilized to identify the structure changes. Experimental results indicate CuW80 alloy with excellent performance under vacuum conditions prepared by microwave sintering. Density was found to increase with increase in sintering temperature linearly until 1200 C, while the rate of increase was found to reduce at higher temperatures, reaching an asymptote. The maximum relative density of the alloy was estimated to be 97.95% at 1300 C. At a sintering temperature of 1200 C, CuW80 alloy was more uniform with the main phase of alloy being Cu0.4W0.6 (PDF: 50-1451) and maximum hardness being 222 HBS.

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1. Introduction

Cu–W is an important alloy as it combines many fine features of tungsten and copper. The presence of W is favorable to enhance the properties such as high melting point, high-density, arc-erosion resistance, welding resistance, high temperature strength, while the presence of Cu is favorable to enhance the properties such as high electrical conductivity, thermal conductivity, ductility, and processing workability. Cu–W alloy is widely used in high-voltage switch, EDM electrodes and microelectronic materials. An increase in the demand for this alloy is expected with the development of the electronics industry and hence an improved method for preparation of this alloy is imperative [1–5].

Since tungsten and copper are immiscible, the conventional sintering methods will encounter many difficulties in manufacturing full density tungsten–copper composite material. Currently, powder metallurgy sintering method is commonly used in the preparation of Cu–W alloy [3–5]. In this method, compacted sintering is the last step of the production process, which demands improvement in the process such as lowering the sintering temperature and shortening the sintering time.

Microwave is an electromagnetic wave with wavelength ranging from 1 mm to 1 m, and the frequency at 300 MHz to 300 GHz [6–11]. Microwave sintering technology has a favorable effect in the heating and sintering the functional ceramics, magnetic materials, carbide and hard alloys fields [10–14]. Compared with conventional sintering techniques, it has the advantages of lower sintering temperature, shorter sintering duration, higher energy and heating efficiency. Application of microwave sintering resulting in a better quality in terms of high density, hardness, toughness and an excellent overall performance is well documented [15–17].

The present work attempts to utilize microwave sintering method to manufacture Cu–W alloy. And the influence of temperature on the properties of the Cu–W alloy adopting microwave sintering is experimentally investigated. In addition, since metal tungsten powder with strong oxidizing, we must combine vacuum sintering technology to ensure the tungsten powder is not oxidized during the sintering process.

2. Experimental method

2.1. Materials

The tungsten powder (purity higher than 99.8%, average particle size, 9.63 m) was provided by Zigong Cemented Carbide Corp. Ltd., China, and electrolytic copper powder (purity higher than 99.7%, average particle size, 21.97 μm) was provided by Shanghai Longxin Chemical Industry Co. Ltd., China.

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2.2. Preparation of alloys

By using the method of microwave vacuum sintered Cu–W alloy powder compacts, was prepared with 20% copper content (mass percentage). The process steps include mixing – pressing – microwave vacuum sintering.

A mixture of Cu and W powder was prepared with copper content of 20%, with the help of a V-blender (V-10, Wuxi Fu'an Powder Machinery Co. Ltd., China) by mixing it for 2–4 h. The mixed powder was subjected to a pressure of 35 MPa for die formation, to a sample diameter of 25 mm.

The compacted of Cu–W alloy was placed in a silicon carbide crucible, and the microwave vacuum sintering procedure was initiated. The equipment adopted was 2.45 GHz microwave vacuum high-temperature sintering furnace. Schematic illustration of the microwave sintering is shown in Fig. 1.

The Cu–W alloy samples are prepared at different temperature. The sintering temperature is controlled at 1100, 1150, 1200, 1250 and 1300 C respectively, for 1 h duration. As is well-known, microwave sintering greatly reduces the duration as compared to conventional sintering. A typical comparison of the sintering between conventional and microwave heating schedules is as depicted in Fig. 2.

2.3. Material characterizations

After metallographic polishing of sample to a surface free of scratches, the microstructures of Cu–W alloy were observed by scanning electron microscopy (JSM-5610LV, JEOL, Ltd., Tokyo, Japan). Sample analysis was conducted by XRD-7000S diffractometer (Shimadzu, Ltd., Kyoto, Japan) using Cu Kα radiation (λ = 1.54060 Å). Hardness test was conducted by HB-3000 hardness tester (Yantai Huayin Test Instrument Co. Ltd., China). The density of sintered body was characterized using Archimedes principle. The relative density of the alloy was calculated as detailed below.

$$\text{Relative density} = \frac{\text{sintered density}}{\text{theoretical density}} \quad (1)$$

3. Results and discussion

3.1. Microstructure of copper–tungsten alloy

Fig. 3 shows the SEM images of CuW80 alloy prepared by microwave sintering at 1100, 1200 and 1300 C, respectively. As can be seen from Fig. 3(a), at a sintering temperature of 1100 C, the distribution of the alloy particles is uneven, tungsten particles aggregate and distributed irregularly. Coating of Cu component on W particle is limited, as well as dispersion of Cu and W. Furthermore, as the agglomerate W particles formed close pores, Cu couldn't fill the pores efficiently. Therefore, at a sintering temperature of 1100 C, more tiny pores exists in the alloy matrix, while at the sintering temperature of 1200 and 1300 C, the copper in alloy could migrate better and achieve a better liquid phase rearrangement. Thus, the tiny pores in the alloy matrix are relatively fewer.

Fig. 3(b) shows that at a sintering temperature of 1200 C, W is uniform in terms of particle size distribution, with relatively dense structure and relatively better coating of Cu component on W. At a sintering temperature of 1300 C, the size of W was found to increase marginally, however with an uneven particle size distribution of W particle. The distance between W particles was observed to be less, while the contact between the interfaces of W grains was observed to increase marginally. This indicates good wettability of the copper tungsten surfaces. Copper has good mobility, and favorable for liquid phase diffusion and aggregation. With the improvement in the liquid phase rearrangement of the inferior alloy, an enrichment of the metal copper could be observed. Hence a sintering temperature of 1300 C could be concluded to be better than 1100 and 1200 C.

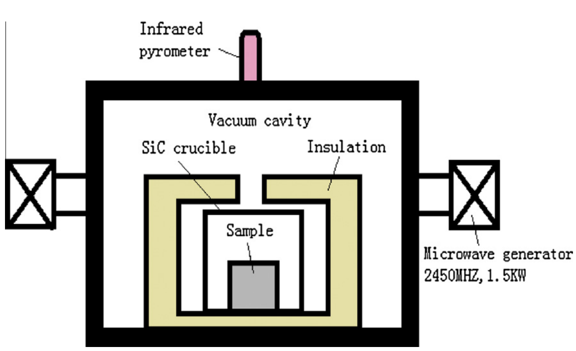

Fig. 1. Schematic of microwave sintering Cu–W alloy.

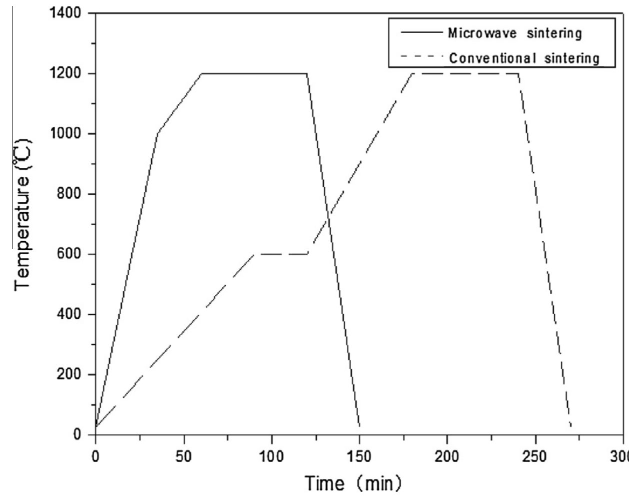

Fig. 2. Comparison of sintering Cu–W alloy using conventional and microwave processing.

3.2. Density of copper–tungsten alloy

The samples were prepared by wire cutting and were tested for the density. Fig. 4 shows density of copper tungsten alloy prepared by microwave sintering at different temperatures.

As can be seen from Fig. 4, with the increase in sintering temperature, a linear increase in the density could be observed until a temperature of 1200 C, while it tends towards an asymptote at temperatures higher than 1200 C. Chen et al., have reported Cu–W alloys with 20% Cu content with the relative density of 95.58% using the powder injection molding method [18]. In the present work the absolute density of Cu–W alloy was estimated to be 15.31 g/cm^3 with the relative density being 97.95%, at the sintering temperature of 1300 C.

Luo et al. have reported the maximum relative density of W-20Cu alloys sintered at 1250 C to be 95.7%, however, with a decrease in relative density at 1300 C [19]. Liu et al., have reported an increase in relative density of the W/Cu FGM samples in the temperature range of 1150–1350 C, however at a relatively slower rate at temperature in excess of 1250 C [20]. The present work a rapid increase in the density was observed until a sintering temperature of 1200 C, while at a relatively slower rate at temperature in excess of 1200 C. Under the microwave field, copper–tungsten alloy is rapidly heated to a temperature above 1100 C, rather more uniformly, melting copper powder in the alloy, facilitating a better liquid flow driven by capillary force, resulting in more uniform filling of the pores by molten copper. Additionally the tungsten particles are rearranged such a way having lowest total surface area due to tight stuffing. With the increase in sintering temperature, an improvement in flow properties of Cu is evidenced, however, at temperatures near about 1200 C, the tungsten particle rearrangement and pore-filling is complete and hence at higher temperature a relatively slower increase in density.

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