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Original Research Paper

Effect of Cu content and heat treatment on the properties and microstructure of W–Cu composites produced by hot extrusion with steel cup

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ABSTRACT

In this paper, the effect of Cu content on the properties and microstructure of W–Cu composites produced by hot extrusion with steel cup and heat treatment was investigated. W–Cu products were sintered at 1150 °C under vacuum conditions for 1 h and then the sintered billets were hot extruded with steel cup at 950 °C with extrusion ratio 10.56. After heat treatment, W–Cu composites with highly comprehensive properties will be acquired. Metallographic microscopy and scanning electron microscope were used to observe microstructure. Experimental results showed that when the Cu content (10–20 mass%), a little deformation was observed in W phase. When the percentage composition of Cu is high (30–40 mass%), little deformation appeared in W phase, while main deformation occurred in Cu phase. Tungsten phase contiguity in extruded composites is increasing with the decreasing of Cu content. It is hard to achieve the full densification for W–Cu composite with low Cu content (below 20 wt.%Cu) by plasticity deformation technology with small deformation amount.

1. Introduction

W–Cu composite provides the advantages of W and Cu. The presence of W is favorable to enhance the properties such as high melting point, high density, high hardness, arc-erosion resistance, high temperature strength, the low thermal expansion coefficient, while the presence of Cu is favorable to enhance the properties such as high conductivity, thermal conductivity and ductility. Thus, W–Cu composite is one of the most promising materials, which is widely used for electrical contact materials, electrode material, heat sink materials and functionally graded materials [1–3].

However, because W and Cu have no mutual solubility through the whole range of compositions, the W–Cu composite has to be fabricated by powder metallurgy. Generally, W–Cu composites are produced by liquid phase sintering and infiltration sintering [4–8], activated sintering [9–10], microwave sintering [11–14], laser sintering [15], ultra-high pressure sintering [16], high pressure torsion [17–18], hot extrusion [19–20], and hot-hydrostatic extrusion [21–22]. However, it is difficult to obtain a W–Cu composite with high density and homogeneous microstructure by adopting sintering method, because in equilibrium W and Cu are free from mutual chemical interactions. If sintering aids were added, it would cause the deterioration of thermal conductivity and electrical conductivity of the composite material. Thus, the aim of the plastic deformation technology is the improvement of phase interface bonding and density of the W–Cu composites without addition of any sintering aids, such as swaging, hot extrusion and hot-hydrostatic extrusion.

However, it is not easy to conduct the hot-hydrostatic extrusion when the content of W is above 60 wt.%. So the present work attempts to utilize hot extrusion with steel cup and heat treatment methods to manufacture W–Cu composites. Effects of variation in the copper content on W–Cu composites structure by hot extrusion with steel cup and heat treatment techniques have been experimentally investigated.

2. Experimental

In this experiment, the average grain size of electrolytic Cu powder and reduced W powder are 50 μm and 4.7 μm respectively, and the purity of Cu and W powders is above 99.9%. The morphologies of W and Cu powders are shown in Fig. 1(a) and (b), respectively. First, these four kinds of W–Cu powders were mixed in a V-type powder mixing machine for 30 h.

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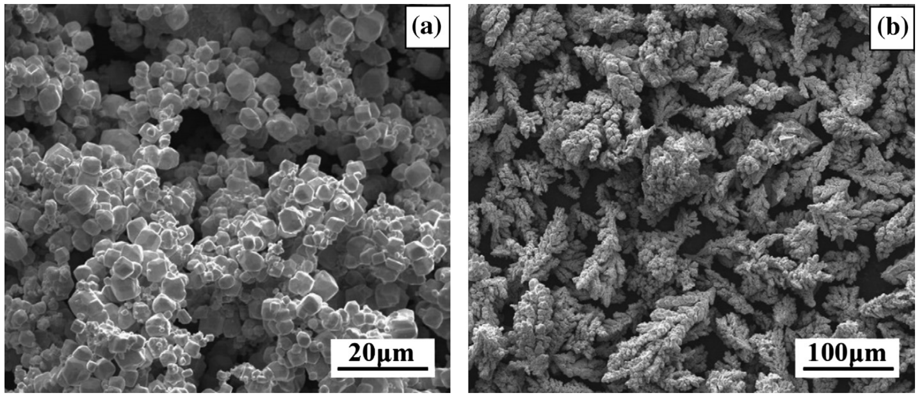

Fig. 1. The SEM micrographs of initial powders of (a) W and (b) Cu.

Then, the composite powders were cold pressed in one direction with a diameter of 42 mm by using steel mould under 650–800 MPa pressure. The relative densities of cold pressing blanks are shown in Table 1. Liquid phase sintering was carried at 1150 °C under vacuum atmosphere for 1 h. Finally, the specimens were hot extruded at 950 °C with extrusion ratio of 10.56. After hot extrusion, the rods undergo heat treatment under 750–900 °C at air atmosphere, holding time 2 h.

Metallographic observations of the specimens were performed on an OLYMPUS GX51 optical microscope (OM). The morphology of the tungsten–copper composites was observed by a VEGA II SBH scanning electron microscope (SEM). The metallographic specimens for optical microscope (OM) and scanning electron microscope (SEM) observation were prepared by mechanical grinding and polishing followed by a slight etching with a dilute solution of mixed 10% sodium hydroxide and 10% potassium ferricyanide. The density of the tungsten–copper composites was measured by Archimedes method. Vickers hardness was measured in a HSV-20 machine, and the center point indentation and eight indentations on two uniformly-distributed hardness rings were done in each sample to obtain the average value. Electrical conductivity was measured in a machine which works on eddy current principle and directly gives digital readings in %IACS (International Annealed Copper Standard) unit. Elemental analysis was performed by energy dispersive spectroscopy (EDS) method. Quantitative metallographic method was used for evaluating of W–W contiguity in samples structure. The contiguity (C_{SS}) was calculated using the following equation [23]

$$C_{ss}\frac{2N_{ss}}{2N_{ss}+N_{sL}} \tag{1}$$

where N_{SS} and N_{SL} are numbers of solid–solid interfaces and solid–liquid interfaces, respectively.

3. Results and discussion

3.1. Properties

3.1.1. Relative density of extruded W–Cu composites

Fig. 2 shows the relationship between W content and relative density of as-extruded W–Cu composites. As shown in this figure, the relative density of as-extruded W–Cu products increases obviously compared with cold pressing blanks. The relative density of extruded W–40 wt.%Cu (W4), W–30 wt.%Cu (W3), W–20 wt.%Cu (W2) and W–10 wt.%Cu (W1) can achieve 98.11%, 99.57%, 96.68%, 94.35%, respectively. The densification reason is that the Cu phase is easy to fill pores in the composite under high hydrostatic pressure with severe plastic deformation technique of hot extrusion. But Cu content in W1 and W2 composites is lower and it makes the densification effect weaken. So the relative densities of W1 and W2 composites are lower compared with W4, W3 composites.

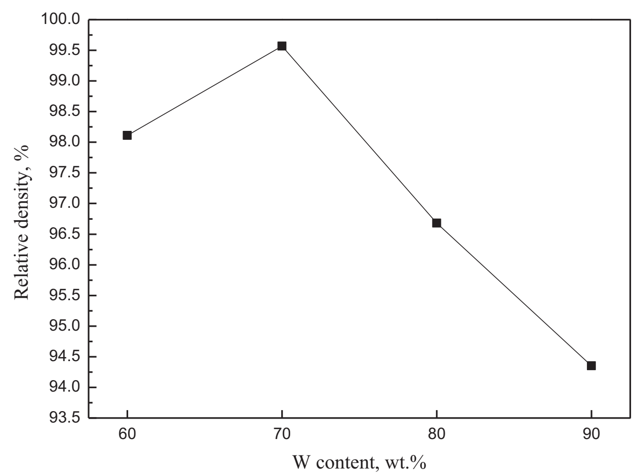

Fig. 2. The relationship between W content and relative density of as-extruded W–Cu composites.

In general, plastic deformation technology is an effective method to obtain tungsten–copper composite with high relative density that accounts for important influence to the properties. And another significant benefit is that the specimen with different specification can be fabricated by the bonding of plastic deformation technology, such as hot extrusion and rotary swaging.

3.1.2. Specific conductance and hardness before and after heat treatment

The relationship between W content and properties of extruded W–Cu composites is shown in Fig. 3. The electrical conductivity of extruded W4, W3, W2 and W1 can achieve 66.89%IACS, 54.22%IACS, 45.91%IACS, 33.43 %IACS, respectively. Compared with

Table 1
The relative densities of cold pressing blanks.

Composition	W–40 wt.%Cu	W–30 wt.%Cu	W–20 wt.%Cu	W–10 wt.%Cu
Relative density (%)	78.3	76.4	73.8	71.2