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Influence of Ni, Fe and Co on the microstructure and properties of 75% Cu–25% Sn alloy in hot pressing

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ABSTRACT

Ni, Fe and Co were added in 75% Cu–25% Sn alloys respectively for improving its microstructures and properties and decreasing the large weight loss of specimens in the high hot pressing temperature. Densification and mechanical tests were performed, and structures were investigated by X-ray diffraction, energy dispersive spectroscopy and scanning electron microscopy. When the hot pressing temperature was more than 700 °C, there were few weight loss of specimens with Ni added, a few weight loss of specimens with Fe added, and the large weight loss of specimens with Co added. All the Ni was dissolved in the Cu and δ-phase. Few Fe was dissolved in the Cu and δ-phase and most of Fe formed a single-phase. A portion of Co was dissolved in the Cu and δ-phase while the rest formed a single-phase. The fracture of all the specimens was brittle. The wear resistance and TRS increased due to the solution strengthening of Ni.

1. Introduction

The Cu–Sn alloy bond is widely used in manufacturing diamond grinding wheels [1]. As the Sn content is increased in the grinding wheel, the Cu–Sn bond becomes more brittle and self-sharpening, which means the bond is more prone to wear, and the grinding efficiency improves remarkably. For instance, 80% Cu–20% Sn was used as metal bond which allows the diamonds to do the cutting, while 90% Cu–10% Sn, has a tendency to glaze [2]. The bonding strength between a bronze based metallic bond and diamond is well known and is often influenced by a variation of the copper alloy composition [3]. With about two-third filled 3 d-orbitals Ni, Fe and Co were emerged to be carbon solvents [4]. The Ni compounded Cu-Sn wheel is durable, the Co in a Cu-Sn alloy make the wheel of the high grinding efficiency [2]. The Fe provides the strength and hardness in composites based on the Cu–Fe system [5]. The Fe and Co additions can beneficially enhance the sintering kinetics of W–pre-alloy bronze composites, and Co manifested higher activation effect than Fe [6]. In order to improve the Cu-Sn alloy properties, Ni, Fe and Co can be introduced.

The sintering process also has a great effect on the structure and mechanical properties of the Cu–Sn alloy system. Hot pressing is an effective and a very common method to fabricate the segments of the diamond tools. Metal bond powder can be densified at a lower temperature and at a shorter cycle time by hot pressing than those required by conventional sintering [7]. These characteristics of the material are formed during hot pressing and mainly depend on the temperature as well as the diffusion processes and phase transformations in the starting materials [8–12].

The 75% Cu–25% Sn alloys in the hot pressing is suitable for obtaining a self-sharpening bond [9]. However, the 75% Cu–25% Sn alloys have the large weight loss of specimens in the high sintering temperature, and a large number of the high temperature liquid phase will be squeezed out of graphite die under pressure. In this work, Ni, Fe and Co were added in 75% Cu–25% Sn alloys, the weight loss of specimens in high sintering temperature was weighed. The effect of Ni, Fe and Co on the microstructure and mechanical properties were investigated in different hot pressing temperature. The results of this study can be used as a guide to design the appropriate Cu–Sn alloy bond in diamond grinding wheels.

2. Experimental procedure

2.1. Differential scanning calorimeter (DSC) analysis

The DSC test was used to obtain the temperatures of phase transition in the 67.5% Cu–22.5% Sn–10% X (Ni, Fe or Co) with a 3:1 ratio of Cu to Sn. The specifications of all types of powders which were used in this study are listed in Table 1. Mixtures of Cu with 22.5 wt.% Sn and 10 wt.% X (Ni, Fe or Co) were prepared from these starting powders by mechanical mixing for 2 h, respectively. The test was performed by DSC and thermogravimetry with a NETZSCH DSC (Model STA409, Germany). The mixture was heated up to 800 °C at a rate of 20 °C min^{-1} in

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Table 1
The characteristics of the as received powders used in the study.

Powder	Copper (Cu)	Tin (Sn)	Iron (Fe)	Cobalt (Co)	Nickel (Ni)
Supplier	Grinm Advanced Materials	Shanghai Sanlian Powder Metallurgy	Shanghai Sanlian Powder Metallurgy	Umicore GROUP	JINCHUAN GROUP
Particle size (μm)	≤45	≤45	≤74	≤45	≤60
Purity	99.9%	99.9%	99%	99.9%	99.8%
Particle shape	Dendrite	Sphere	Sponge	Irregular	Dendrite

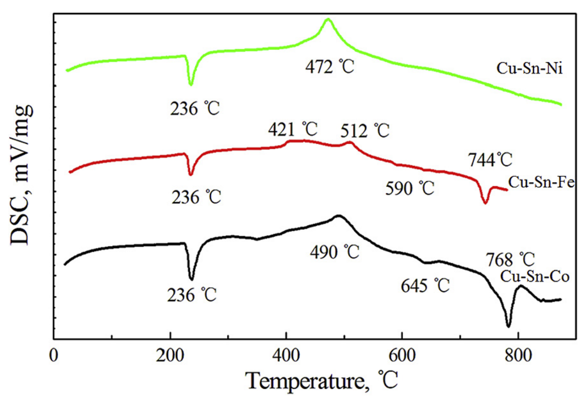

Fig. 1. DSC curves of 67.5% Cu–22.5% Sn–10% X (Ni, Fe or Co) alloys under an ultimate temperature of 800 °C.

argon atmosphere.

Fig. 1 shows the differential thermal curves of 67.5% Cu–22.5% Sn–10% X (Ni, Fe or Co). In 67.5% Cu–22.5% Sn–10% Ni, two peaks were observed. The peak at 472 °C was an endothermic peak while the peak at 236 °C was an exothermic peak. In 67.5% Cu–22.5% Sn–10% Fe, four peaks were observed at 236 °C, 421 °C, 512 °C and 744 °C. The peaks at 421 °C and 512 °C were endothermic peaks while the peaks at 236 °C and 744 °C were exothermic peaks. In 67.5% Cu–22.5% Sn–10% Co, four peaks were observed at 236 °C, 490 °C, 645 °C and 768 °C. The peak at 490 °C was an endothermic peak while the others peaks were exothermic peaks. The endothermic peaks at 236 °C in the three curves are ascribed to Sn melting.

Three temperature points were chosen to determine the effect of the hot pressing temperature on microstructure and mechanical properties, respectively. The temperatures of 490 °C, 645 °C and 768 °C were chosen in Cu–Sn–Co. The temperatures of 421 °C, 590 °C and 744 °C were chosen in Cu–Sn–Fe. The temperatures of 472 °C, 645 °C and 744 °C were chosen in Cu–Sn–Ni. For purposes of comparison and researching, 645 °C and 744 °C were chosen from Cu–Sn–Co and Cu–Sn–Fe, respectively. The transformations of the microstructure were observed by comparing the specimens sintered at the three different temperatures.

2.2. Specimen fabrication and test methods

Mixtures of 67.5 wt.% Cu with 22.5 wt.% Sn and 10 wt.% X (Ni, Fe or Co) were hot-pressed in graphite molds under vacuum (10^{-3} mbar) respectively. The temperature measurement was controlled by thermocouple. During each experiment the chosen temperature was reached with a ramp rate of 100 °C min^{-1} under 10 MPa. When the hot pressing was reached the chosen temperature, the pressure was reached to 25 MPa. The sample was kept at the chosen temperature for 4 min and then spontaneously cooled under vacuum until ambient temperature, and then the pressure was relieved. The fabricated rectangular size of the specimens was 32 mm × 12 mm × 6 mm.

Density measurements were carried out using the Archimedes' principle, according to ASTM B962-08. The relative density was determined considering a theoretical absolute density. The measurement of hardness was carried out on the polished surface at room temperature using a Rockwell hardness tester with steel ball diameter of 1.588 mm and a load of 100 kg, according to ASTM E18-12. The transverse rupture strength (TRS) was measured by a three-point bending test, according to ASTM B528-12. The TRS can be calculated by the following equation: $TRS = 3PL/2wt^2$, where P is the loading force, L the distance between the supports, t the thickness of the specimen, and w is the width of the specimen. The wear loss was measured using a pin-on-disk wear testing rig at a sliding speed of 2.18 m s^{-1} for 2 min, according to the method of Venkateswarlu et al. [11]. This test was conducted against a 100 grit emery paper, and the applied load was 1.5 kg. A solution of 3 g of $FeCl_3$, 50 mL of water, 25 mL of HCl and 100 mL of ethanol was used to reveal the structures of the polished specimens under an optical microscope. Structural aspects were analysed through X-ray diffraction (XRD), and chemical analysis was conducted via X-ray energy dispersive spectroscopy (EDS) coupled to a scanning electron microscope (SEM). The fracture surfaces from the TRS tests were also examined by SEM for microstructure evaluation.

3. Results

3.1. Effect of hot pressing temperature on densification and mechanical properties

Table 2 shows the densification and mechanical properties of the 67.5% Cu–22.5% Sn–10% Ni alloys at the hot pressing temperatures of 472, 645 and 744 °C. After the alloy was hot-pressed at 472 °C, the density, hardness, TRS and wear loss of the specimens were 7.5 g cm^{-3}, HRB 74.7, 99.8 MPa and 1.151 g, respectively. With the hot pressing temperature increased to 645 °C, the density of the specimens slightly increased from 7.5 g cm^{-3} to 7.6 g cm^{-3}. The hardness and TRS increased by 7.1% and 93.1%, reaching HRB 80.0 and 192.7 MPa, respectively. However, the wear loss decreased by 39.8% to 0.693 g, which indicates an increase in wear resistance. With the hot pressing temperature further increased to 744 °C, the density slightly decreased from 7.6 g cm^{-3} to 7.5 g cm^{-3}. The hardness and TRS of the specimens almost did not change, reaching HRB 81.3 and 187.5 MPa, respectively. The wear loss of the specimens further decreased from 0.693 g to 0.586 g.

Table 3 shows the densification and mechanical properties of the 67.5% Cu–22.5% Sn–10% Fe alloys at the hot pressing temperatures of 421, 590 and 744 °C. After the alloy was hot-pressed at 421 °C, the density, hardness, TRS and wear loss of the specimens were 7.4 g cm^{-3}, HRB 70.6, 68.5 MPa and 1.132 g, respectively. With the hot pressing temperature increased to 590 °C, the density of the specimens slightly increased from 7.4 g cm^{-3} to 7.6 g cm^{-3}. The hardness and TRS increased by 26.6% and 183.4%, reaching HRB 89.4 and 194.1 MPa, respectively. However, the wear loss decreased by 28.4% to 0.811 g,

Table 2
Results of density, Rockwell B hardness (HRB), wear loss and transverse rupture strength found for the 67.5% Cu–22.5% Sn–10% Ni alloys hot pressed at 472 °C, 645 °C, and 744 °C respectively.

Hot pressing temperature (°C)	Average bulk density (g cm^{-3})	Hardness (HRB)	Weight loss (g)	TRS (MPa)
472	7.5	74.7	1.151	99.8
645	7.6	80.0	0.693	192.7
744	7.5	81.3	0.586	187.5