Journal of Korean Powder Metallurgy Institute
Vol. 5, No. 4, 1998

Development of Tungsten Dispersed Copper Based Alloy and its Physical Property

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(Received October 28, 1998)

Abstract Copper-10 wt. % tungsten alloyed powder was obtained by co-reduction of mixed tungsten-trioxide and copper oxide powders at 973 K for 7.2 Ks. In the alloy obtained by pressure-assisted sintering of this co-reduced powder, ultra fine tungsten particles (about 100nm) were dispersed uniformly in the copper matrix. At room temperature, the hardness of this alloy was Hv151 and the electrical conductivity was 85% IACS. After annealing at 1173 K for 3.6 Ks, the hardness and electrical conductivity were Hv147 and 84% IACS, respectively, and were same as before annealing. It was confirmed that the hardness and electrical conductivity of this alloy were hardly influenced by annealing condition since the microstructure of this alloy is highly stabilized.

1. Introduction

The copper-zirconium alloy, copper-chromium alloy and aluminum oxide dispersed copper alloy are well known by its high hardness and high electrical conductivity at both room temperature and high temperature. These alloys are commonly used as electrodes for spot welding. In the copper-zirconium and copper-chromium alloys which are manufactured by precipitation hardening process, a rapid coarsening occurs at high temperature and thus decrease the hardness. In the aluminum oxide dispersed copper alloy which is manufactured by internal oxidation process, the aluminum oxide particles are stable at high temperature, and the degradation of hardness is not observed. However, the electrical conductivity over 80% IACS is not easily obtained, because it is difficult to oxidize aluminum completely by the internal oxidation method. Consequently, the high hardness with high electrical conductivity at both room temperature and high temperature cannot be obtained in either of these alloy systems. To solve this problem, a new material by a new processing method which is neither precipitation hardening nor internal oxidation has to be developed.

Tungsten is well known by its little solubility in copper and very high melting temperature. It is conceivable that applying tungsten as dispersed particles can be an efficient way to improve the property of dispersion strengthened copper alloys. It is very difficult to obtain a uniform dispersion of fine tungsten particles by mixing metallic tungsten and copper powders as starting raw materials. Therefore, in this work, co-reduction method of tungsten-trioxide and copper oxide powders was applied to develop a tungsten dispersed copper.

2. Experimental procedure

Commercially available tungsten-trioxide (WO_3) and copper oxide (Cu_2O) powders were used as starting materials. Powders were mixed by attrition mill for 14.4 Ks, and followed by co-reducing in hydrogen atmosphere, at 573 K, 773 K, and 973 K for 7.2 Ks. The co-reduced powders at different temperatures were examined by X-ray diffraction to monitor the reduction process. When the oxides were completely reduced to the metal, the composition of Cu-10 wt. % W was obtained.

The co-reduced powders were hot-pressed under the pressure of 20 MPa for 3.6 Ks at 1173 K. The microstructures of sintered alloys were examined by optical microscope, scanning electron microscope (SEM) and transmission electron microscope (TEM). The hardness of this alloy was measured after annealing at elevated temperatures up to 1073 K for 3.6 Ks in order to investigate the influence of annealing temperature on the hardness.

The sintered alloy was warm rolled at 873 K and annealed at 1173 K for 3.6 Ks. Tensile tests of as-rolled and annealed specimens were carried out at a strain rate of 1.7×10^{-3}/s in order to investigate the influence of annealing on the tensile properties.

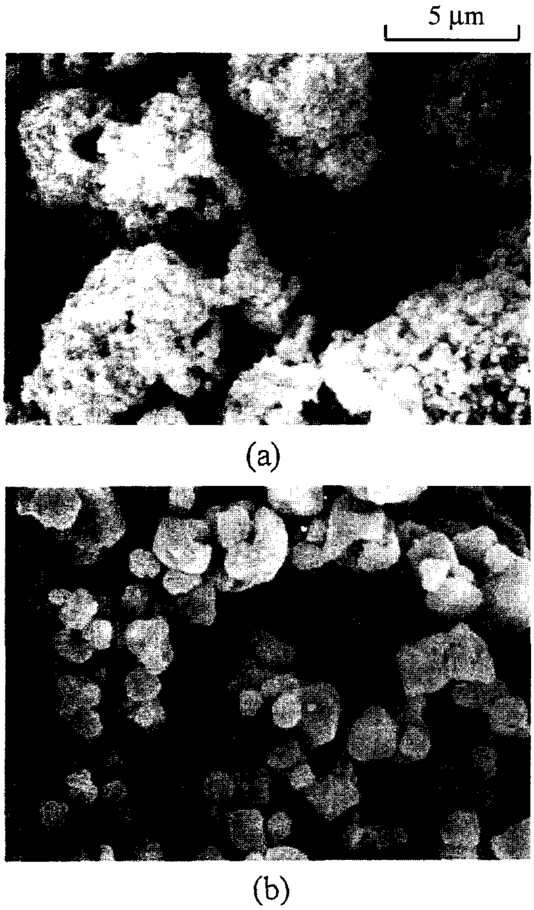


Fig. 1. SEM photographs of raw oxide powders. (a) tungsten-trioxide powder (b) copper oxide powder.

3. Experimental Results and Discussions

3.1. Co-reduction process of mixed powders

The SEM photographs of raw oxide powders are shown in Fig. 1. The shape of copper oxide powder was almost globular, and its size was 1~3 μm. The tungsten-trioxide powders were agglomerated. The primary particle size of tungsten-trioxide powders was about 0.5 μm or less, and the size of the agglomerate was about 10 μm. Fig. 2 shows X-ray diffraction patterns of the mixed raw powders and co-reduced powders reduced at 573 K, 773 K, and 973 K for 7.2 Ks. In the X-ray pattern of mixed powders, the broadening of tungsten-trioxide and copper oxide peaks was observed. The broadening may be caused by refinement and residual stress on mixing process. Copper oxide was easily reduced to metallic copper at 573 K while tungsten-trioxide was not reduced completely even at 773 K. At this tempera-

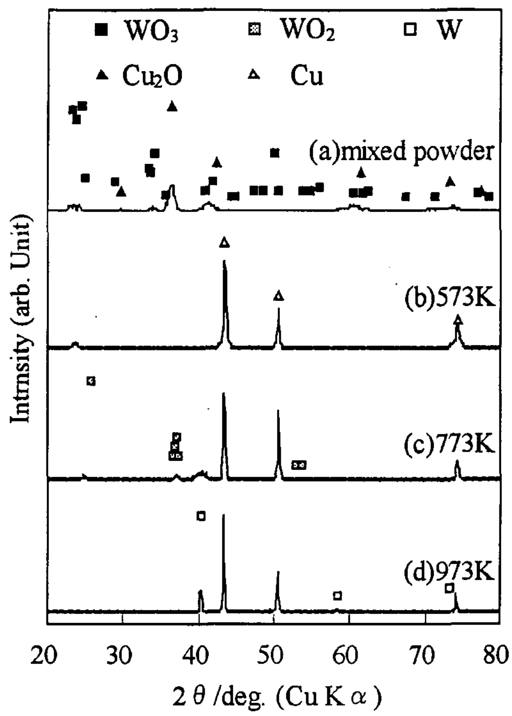
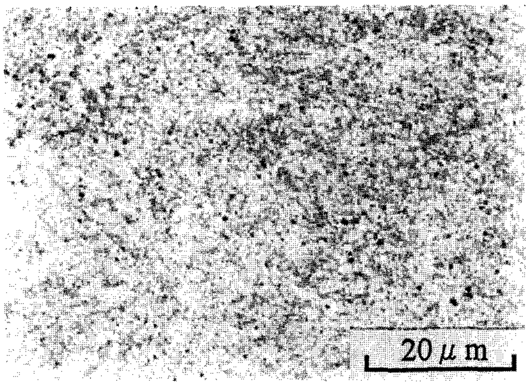
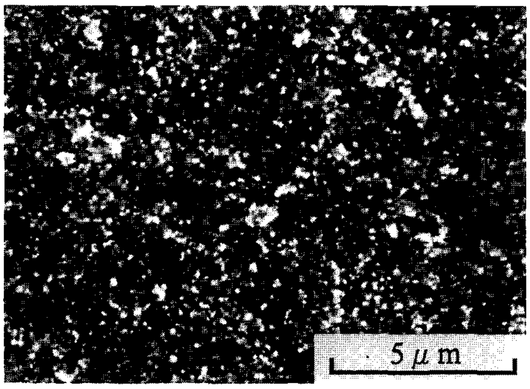


Fig. 2. X-ray diffraction patterns of mixed powder (a) and coreduced powders reduced at 573 K (b), 773 K (c), and 973 K for 7.2 Ks (d).



(a)



(b)

Fig. 3. Microstructures of sintered coper-10 mass% tungsten alloy obtained by the powder reduced at 973 K. (a) optical microstructure, (b) SEM microstructure.

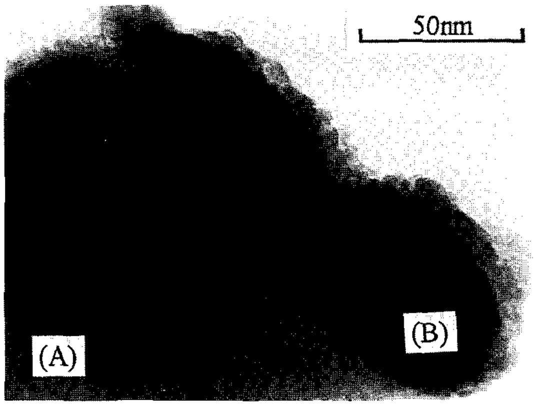


Fig. 4. TEM microstructures of sintered copper-10 mass%tungsten alloy obtained by the powder reduced at 973 K.

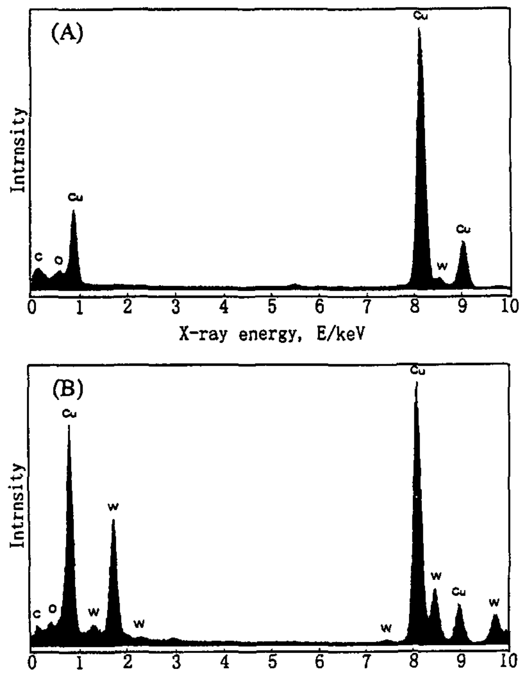


Fig. 5. EDX spectrums obtained from the corresponding areas, (A) and (B), marked in photo 3.

ture, a part of tungsten-trioxide was reduced to tungsten-dioxide. Tungsten-trioxide was completely reduced to metallic tungsten at 973 K. From these results, the reduction temperature of 973 K is considered suitable for the co-reduction of the mixed powders.

3.2. Properties of sintered alloy

3.2.1 Microstructure

Fig. 3 shows optical microstructure of sintered copper-10 wt.% tungsten alloy obtained from the powder reduced at 973 K. As shown in Fig. 3(a), pores were hardly observed. According to the SEM observation (Fig. 3(b)), the uniformly distributed fine particles were assumed to be tungsten. Fig. 4 shows TEM microstructure of this alloy. Particles embedded in the matrix were observed and the particle size was about 70 nm. Fig. 5 shows EDX spectrums of the matrix (A) and the black particles (B). Copper was detected from the matrix, and tungsten was detected from the black particle, which confirms that the black particle is tungsten. From these

Table 1. Physical properties of the sintered copper-10 mass%tungsten alloy and copper-zirconium alloy

	Sintered copper-10 mass%tungsten	Copper-zirconium alloy
Relative density (%)	99	
Hardness (Hv 0.3)	151	138
Electrical conductivity (% IACS)	85	80

results, it is found that copper-10 wt.% tungsten alloy fabricated by sintering co-reduced powders has tungsten particles of less than 100 nm, uniformly dispersed in the copper matrix.

3.2.2 Physical properties of sintered alloy

Table 1 shows some physical properties of the sintered copper-10 wt.% tungsten alloy. The relative density of this alloy was 99% of the theoretical density. In comparison with the commercially available copper-zirconium alloy, both hardness and electrical conductivity at room temperature were higher than those of the copper-zirconium alloy. Fig. 6 shows the hardness of the sintered copper-10 wt. % tungsten alloy tested at elevated temperatures. The hardness of this alloy is higher than that of copper-zirconium alloy at the every testing temperature. Fig. 7 shows the hardness at the room temperature after annealing at high temperature for 3.6 Ks. Above the annealing

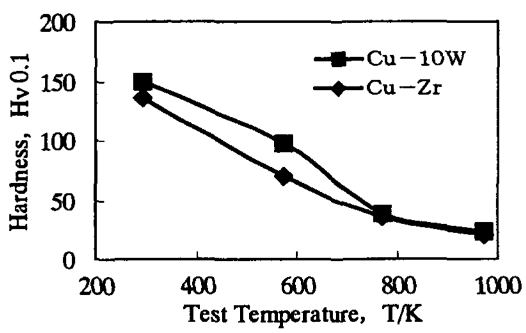


Fig. 6. Effects of testing temperature up to 973 K on the hardness of the copper-10 mass%tungsten sintered alloy.

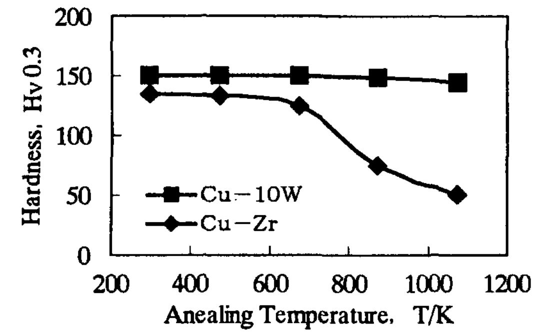


Fig. 7. Effects of annealing temperature on the hardness of the copper-10 mass%tungsten sintered alloy.

temperature of 673 K, the hardness of the copper-zirconium alloy decreased rapidly. But, the hardness of the sintered copper-10 wt. % tungsten alloy did not decrease even after annealing at 1073 K. Table 2 shows the hardness and electrical conductivity of the sintered alloy at the room temperature after annealing at 1173 K for 3.6 Ks. Both hardness and electrical conductivity were same as before annealing, which are Hv147 and 84% IACS, respectively.

Table 3 shows the influence of annealing on the tensile properties of warm rolled copper-10 wt. % tungsten alloy. The tensile strength and elongation of as-rolled alloy were 530 MPa and 14.6%, respectively. After the annealing, the tensile property remained neary the same as those of as-rolled alloy. Since the tungsten has little solubility in copper matrix even at high temperature, the dispersed tungsten

Table 2. Physical properties of sintered alloy at the room temperature after annealing at 1173 K for 3.6 ks

	Sintered copper-10 mass% tungsten
Relative density (%)	99
Hardness (Hv 0.3)	147
Electrical conductivity (%IACS)	84

Table 3. Effect of annealing on the tensile properties of the rolled copper-10 mass%tungsten alloy

	fAs-rolled	Annealed
Tensile strength (MPa)	530	510
Elongation (%)	14.5	16.0

particles do not coarsen. Consequently, strength of the alloy is maintained after the annealing at high temperatures. In the case of copper-zirconium alloy, on the other hand, the intermetallic precipitates dissolve easily in copper matrix and coarsen very rapidly at high temperatures, which results in the deterioration of the alloy strength.

4. Conclusions

Tungsten dispersed copper alloy was fabricated by co-reduction process and its physical properties were examined. The results of this work is summarized as follows;

1. The newly developed sintered alloy was strengthened by dispersion of fine tungsten particles of less than 100 nm.

2. At the room temperature, the hardness and electrical conductivity of this alloy is Hv151 and 85% IACS, respectively. At high temperature the hardness of this alloy was higher than that of commercial copper-zirconium alloy.