Proceedings of the 4th International Congress APMAS2014, April 24-27, 2014, Fethiye, Turkey

An Evaluation of Cu-B_4C Composites Manufactured by Powder Metallurgy

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In this study, the influences of B_4C ratios on some mechanical and physical properties such as relative density, microhardness and electrical properties of cold pressed Cu-B_4C composites were investigated. Curve fitting is applied for the estimation of electrical conductivity. Commercial copper powders with 40 μm particle size were reinforced with B_4C, with particle size of 40 μm, at ratios of 1, 2, 3 wt.%, for improving mechanical properties of copper used as electrical conductor. Cu-B_4C composites have been fabricated by powder sintering process at a temperature of 900 °C for 2 h. The presence of Cu and B_4C, which are dominant components in the sintered composites, were confirmed by X-ray diffraction analysis technique and SEM-EDS. Scanning electron microscope (SEM-EDS) has shown that B_4C particles are distributed homogenously in the copper matrix. The relative densities of Cu and Cu-B_4C composites, sintered at 900 °C, ranged from 95.7 to 91.6%. Microhardness of composites ranged from 84.5 to 94.6 HB. It was observed that cold pressed Cu-1 wt.% B_4C composites revealed promising physical properties. Results of electrical conductivity measurement of Cu-B_4C composite material are compared to the results of the model and the overall accuracy level above 96% is obtained.

DOI: 10.12693/APhysPolA.127.1045

PACS: 81.05.Ni, 81.20.Ev, 72.80.Tm

1. Introduction

Metal matrix composites (MMCs) reinforced with ceramic nanoparticles (less than 100 mm), are termed as metal matrix nano composites [1]. With the development of industry and technology, metal matrix composite materials (MMCs) have been applied in numerous fields, which include energy, defense, aerospace, biotechnology, optics and automobile, due of their reinforced high performance mechanical properties and reduced weight [2–5]. The improved properties of metal matrix composites are strongly related to the characteristics of the matrix and the reinforcement, as well as the reinforcement-matrix interface. B_4C, SiC and Al_2O_3 are excellent reinforcement materials for copper like ductile matrix composites [5]. Among metallic materials, copper exhibits high formability, good resistance to oxidation and corrosion and it occupies a special position between all metals because of its electrical and thermal conductivity. So, the most general application of Cu is where high electrical and thermal conductivity are needed. Low strength and poor wear resistance are the major limitation of Cu and its alloys [6]. Pure copper is used extensively for cables and wires, electrical contacts, and a wide variety of other parts that are required to pass electrical current. The electrical conductivity scale established in 1913 was based on a copper standard defined as 100%, and the electrical conductivity of any material is still expressed as percent IACS (International Annealed Copper Standard), equal to 100 times the ratio of the volume resistivity of the annealed copper standard (0.017241 $\mu\Omega$ m) at 20 °C (68 °F) to the measured value for the material concerned [7–9].

Boron carbide (B_4C) serves as a potential reinforcement for making composite material due to its high hardness (2900–3900 kg/mm^2), high neutron absorption cross-section and excellent thermo-electrical properties in addition to low density (2.52 g/cm^3), high melting point ($\sim$ 2450 °C), high elastic modulus (448 GPa) and chemical inertness. B_4C high modulus ratio (1.8×10^7 m) and preserved hardness, even at temperatures above 1100 °C, makes it a good strengthening medium in high temperature applications. These are unique properties of B_4C, which at room and high temperature make it a key material for various high technology applications, such as fast-breeders, neutron moderators in nuclear reaction, power generation in deep space flight applications, microelectronic, medicinal, light-duty bulletproof armors, blasting nozzles, abrasive water-jet cutting equipment, high temperature thermoelectric devices, high-temperature structural parts, cutting tools, rocket propellants, wear-proof parts and thermo-mechanical applications [10]. In the present study B_4C was selected as reinforcement for its superior mechanical properties of high hardness, high anti-wear stiffness during grinding operation, high electric conductivity to comply with the IACS's electrode standard, and high thermal conductivity, to obtain higher thermal shock resistance. In this investigation, the effect of B_4C on the mechanical and physical properties on copper matrix composites was studied.

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2. Experimental study

Copper powder (99.9% purity; 40 μm in diameter) and B_4C particle (99.5% purity; 40 μm in diameter), purchased from Alfa-Aesar, were used as starting materials. Commercial copper powders were reinforced with B_4C at ratios of 1, 2 and 3 wt.%, respectively. These powder mixture samples were pressed by a die with a compression load of 280 MPa, for 1 min by uniaxial hydraulic press and then sintered at 900 °C for 2 h in open atmosphere. Then, the sintered composites were exposed to cold pressing by unaxial hydrolic press with a pressure of 850 MPa. Following the manufacturing process, composites were analyzed by XRD technique using Cu K_α radiation with a wavelength of 1.5418 Å, in order to determine the phases formed in the composite's body. Microstructures of the samples were examined by Jeol LV6000 scanning electron microscope. EDS analysis was conducted to detect Cu, B_4C and possible copper oxides, copper boron compounds within and at Cu-B_4C interfaces. The relative density of the composites was measured according to Archimed's principle, the micro hardness and the electrical conductivity of both pure copper and composites were determined by Brinell Hardness with a load of 31.25 kg and GE model electrical resistivity measurement instrument. The results of electrical conductivity values were performed on the polished samples. The electrical conductivity of samples was determined by taking inverse of resistivity.

3. Results and discussions

Figure 1 shows the morphologies of as-received Cu, and B_4C powders. The metallic Cu powder particles were generally spherical with a diameter of 40 μm in size. The B_4C powder has sharp corners and is 40 μm in size. Scanning electron micrographs of pure copper and Cu-B_4C composites sintered at 900 °C for 2 hours are shown in Fig. 2. As it can be seen in Fig. 2, copper matrix is seen as light colored areas and black-cornered shapes denote B_4C particles. It was found that B_4C Reinforcement particles are homogenously distributed in the copper matrix. Copper grain boundaries become distinguishable from the microstructures after the etching of samples with 10% nitride acid solution (Fig. 2).

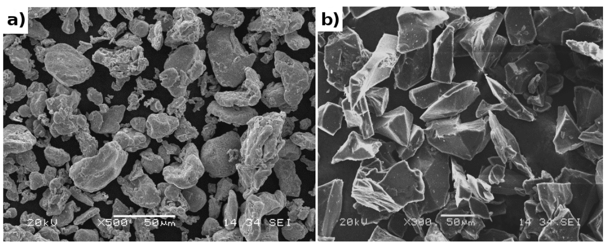

Fig. 1. SEM Micrographs of a) Cu, b) B_4C powders.

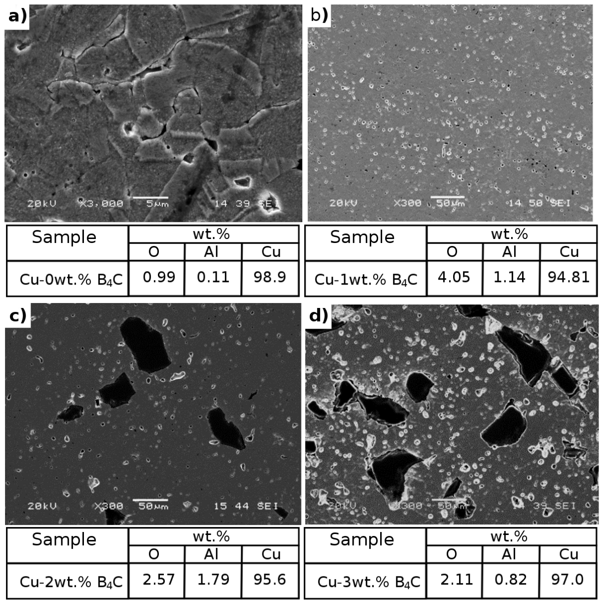

Fig. 2. SEM-EDS Micrographs of Cu-B_4C composites.

Figure 2 shows the SEM images with EDS analysis results of the composite samples, as well as of pure copper. The dark, cornered shapes indicate B_4C and gray colored zones point out copper matrix, as confirmed by EDS analysis (Fig. 2). In the SEM images, white areas probably indicate alumina resulted from polishing. EDS analysis shows that there were small amounts of oxygen element in copper and composites samples (Fig. 2). This probably resulted from the oxidation of the matrix during sintering, however evidence of Al, as well as oxygen, in the EDS analysis also indicated that some alumina has remained after the polishing process.

XRD analysis showed that no copper-oxide and B_4C phase were detected and the dominant phase consisted of copper (Fig. 3). Because of the small amount of B_4C in the samples, it was possibly under the detection limits of XRD instrument. SEM-EDS analyses revealed small amount of oxygen and the evidence that B_4C phase existed in the samples.

Relative density, hardness and electrical conductivity values of sintered and cold pressed commercial pure copper and Cu-B4C composites are given in Table I. From the Table I it is seen that the relative density and the electrical conductivities of the Cu-B_4C composites decreased, while their hardness values have increased with the increase of the amount of B_4C. Copper has high thermal expansion coefficient, while in B_4C it is low, as a result, a significant amount of dislocation occurred, because of great thermal expansion mismatch during the sintering. Thus, by increasing amount of B_4C in composites, the hardness of the composites has increased. Nevertheless, electrical conductivity of the samples decreased by decreasing the relative density, because lower density means higher porosity which acts as insulation barrier

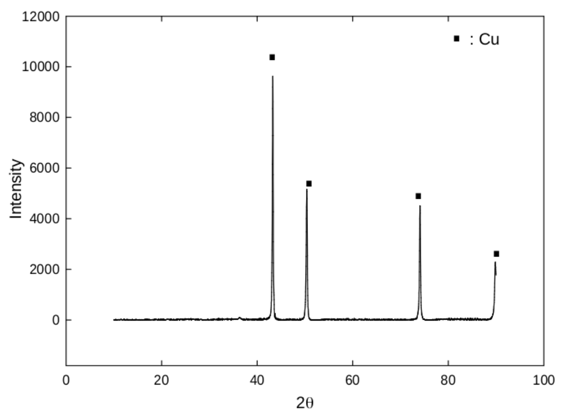

Fig. 3. XRD Analysis Cu-%3 wt.B_4C powders.

for electron passing through between Cu grains [8]. It can be claimed that cold pressed Cu-1 wt.% B_4C composites revealed promising physical properties, according to obtained results presented in Table I.

TABLE I

Relative densities, harnesses and electrical conductivity values of cold pressed copper and Cu-B_4C composites.

Properties	wt.% B_4C			
	0	1	2	3
Relative Density %	95.7	93.8	92.0	91.6
Hardness HB	84.5	87.3	90	94.6
Electrical Conductivity, %IACS	96.2	94.91	83.22	75.537

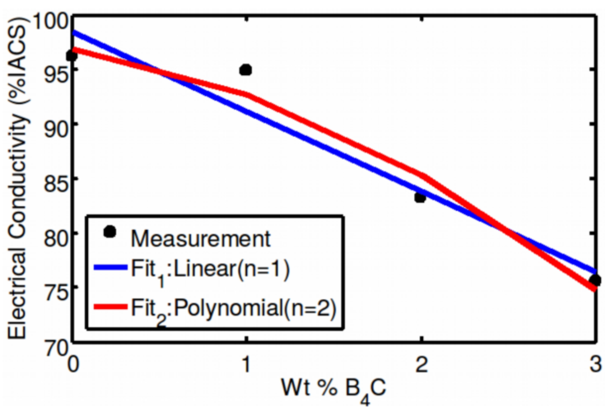

Fig. 4. Measured electrical conductivity and curve fitted model of Cu-B_4C composites as functions of B_4C concentration.

Curve fitting method is applied to the results of electrical conductivity measurement. Fitted curves of the for linear and second order polynomial functions are depicted in Fig. 4. Mean square errors are determined as 92.95% and 96.45% for linear and polynomial model, respectively.

4. Conclusion

The amount of reinforcement component on the some properties of sintered Cu-B_4C composites were investigated. Copper-B_4C composites were manufactured successfully by conventional powder metallurgy method, by embedding in graphite powder, without using any inert medium (gas or vacuum). The presence of Cu and B_4C were verified by XRD analysis technique and EDS analysis. All of the manufactured composites have remarkable high relative density. Hardness of the composites has increased with the increasing amount of added B_4C. It was observed that the electrical conductivity of all Cu-B_4C composites is in good agreement with literature. Results of the curve fitting model is compared with the measurement data and an overall accuracy level above 96% is obtained. Results of the model can be used for calculation of the electrical conductivity results for fractional order, and/or higher concentration of B_4C, for which we don't have the real measurement data.

Acknowledgments

This work was supported by Sakarya University Scientific Research Foundation (Project number: 2013-01-00-008)

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