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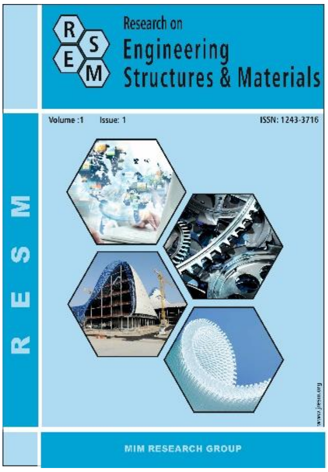

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Research Article

Some properties of Cu-MgO composites produced by powder metallurgy

Gözde F. Çelebi Efe[1,2*], Mediha İpek[1], Sakin Zeytin[1], Cuma Bindal[1,2]

[1] *Department of Metallurgy and Materials Engineering, Sakarya University, Turkey*
[2] *Biomedical, Magnetic and Semi Conductive Materials Research Center, Sakarya University, Turkey*

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Abstract

Pure Cu matrix composite reinforced with MgO were successfully produced by powder metallurgy method. Nano sized MgO particles with 0.5, 1, 2 and 3 wt.% were mixed with copper powder in size of 40 μm mechanically and compacted by applying 220 MPa pressure and sintered at 700°C for 2 hours in an open atmospheric furnace followed by hot pressing with the pressure of 590 MPa. SEM studies revealed that MgO particles were dispersed homogenously in copper matrix and any oxides of copper matrix were not detected which confirmed by EDS and XRD analyses. With the addition of 3wt.% MgO particles, hardness of composites increased from 89 HVN to 122 HVN while, relative density decreased from 94.2% to 84.1% and electrical conductivity from 90.15 to 43.5 IACS (International Annealed Copper Standard). As a result, optimum electrical conductivity and hardness balance for promising contact material was obtained with the addition of max. 2wt.% of MgO.

1. Introduction

The copper-matrix composites are attractive for their excellent combination of thermal and electrical conductivities, strength retention with temperature, and micro structural stability. These characteristics make copper-matrix composites popular for a wide range of applications in electronic packaging or manufacturing of electrodes and contact terminals [1,2]. However, low hardness, low creep strength as well as poor wear resistance are the major limitations of copper and its composites in many fields, especially application at high temperature is limited due to poor mechanical properties [2-5]. Many reports have showed that copper and its composites often suffer serious damage at heavy loads. Therefore, it is imperative to develop high performance copper-based composites to broaden their applications [3]. Copper can be dispersion strengthened by various dispersed particles such as oxides, carbides, and borides [1]. Ceramic particles, such as TiC, SiC and Al2O3, reinforced copper matrix composites have been extensively studied due to their important engineering applications [6]. Adding hard particles into copper matrix, not only enhances the mechanical performance and wear resistance but also keeps its desirable electrical and thermal conductivity, thus the application scope of copper is extended [2]. Due to low density, high thermal conductivity and a small difference in coefficients of thermal expansion, as well as the super thermodynamic stability, MgO is a desired reinforced phase for copper matrix composite [1]. Aim of this study is to increase the strength of copper matrix by dispersing the MgO particles and without decreasing the electrical conductivity a lot. In the present study, powder metallurgy (P/M) method was utilized to fabricate Cu-MgO composites. Furthermore, the microstructure, mechanical

*Corresponding author: gcelebi@sakarya.edu.tr
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properties and electrical resistivity of the as-fabricated composite with different MgO additions in wt. were studied.

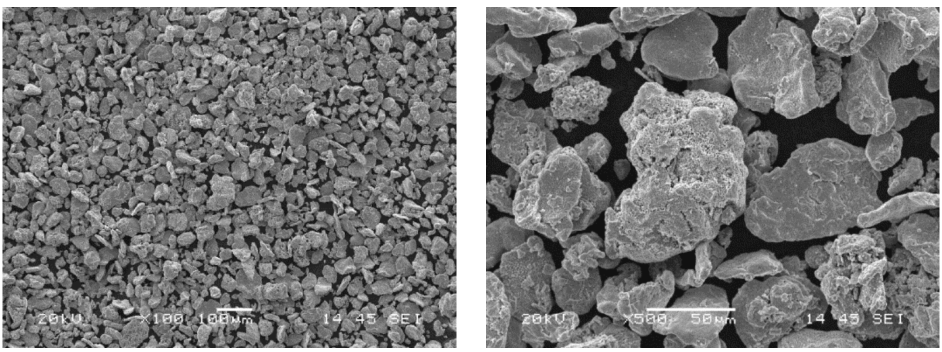
2. Experimental Procedure

In order to manufacture Cu-MgO composites copper powder with 99.9% purity and 40 μm particle size and MgO powder with 99.5% purity and 0.1μm particle size was used as starting materials. The powders including 0.5, 1, 2 and 3 wt.% MgO reinforcement were mixed mechanically and were pressed in a steel mold of 15 mm in diameter with an axial pressure of 220 MPa and sintered at 700°C in an open atmospheric furnace for 2 h embedded in graphite powder in order to prevent oxidation. Following sintering, sintered compacts were immediately get out of the furnace and pressed with a load of 590 MPa, while sintered compacts were still hot, to have higher relative density and electrical conductivity. The microstructures of specimens were examined by scanning electron microscopy (SEM). In order to detect the Cu, MgO and any oxide X-ray diffraction (XRD) and energy dispersive spectroscopy (EDS) analyses were performed. Relative densities of copper and Cu- MgO composites were determined according to Archimedes' method. Micro hardness of both pure copper and composites were determined using a Leica WMHT-Mod model Vickers hardness instrument under an applied load of 50 g. The measurements of electrical conductivity of sintered specimens were performed on a GE model electric resistivity measurement instrument in terms of S/m. At least mean of five measurements were transformed to %IACS by multiplying with 1.7241.

3. Results and Discussion

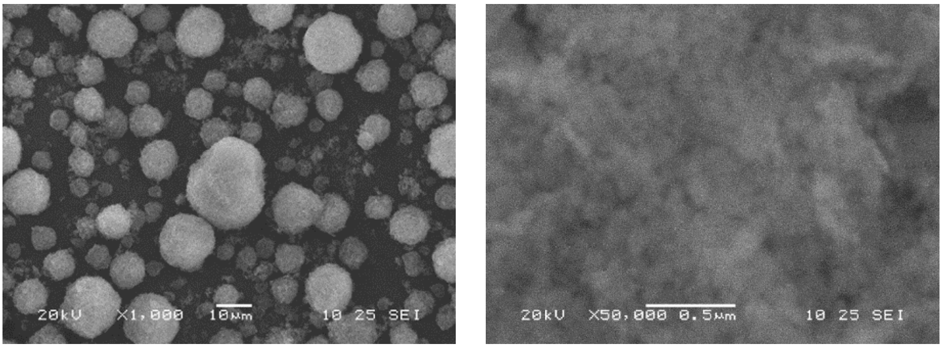
3.1 Microstructure

SEM micrographs of starting powders, Cu and reinforcement agent MgO, used in experimental studies were given in Fig. 1 and Fig. 2 respectively. Copper powder is flat and irregular shape with particle size of 40 μm (Fig. 1). MgO particles are in spherical shape and 0.1 μm particle size but significant powder agglomeration was observed (Fig. 2). As it can be seen in Fig. 2a there are agglomeration and agglomerated MgO particles are about 10 μm size. At higher magnification it is obvious in Fig. 2b that the real size of MgO particles are submicron.



(a) (b)

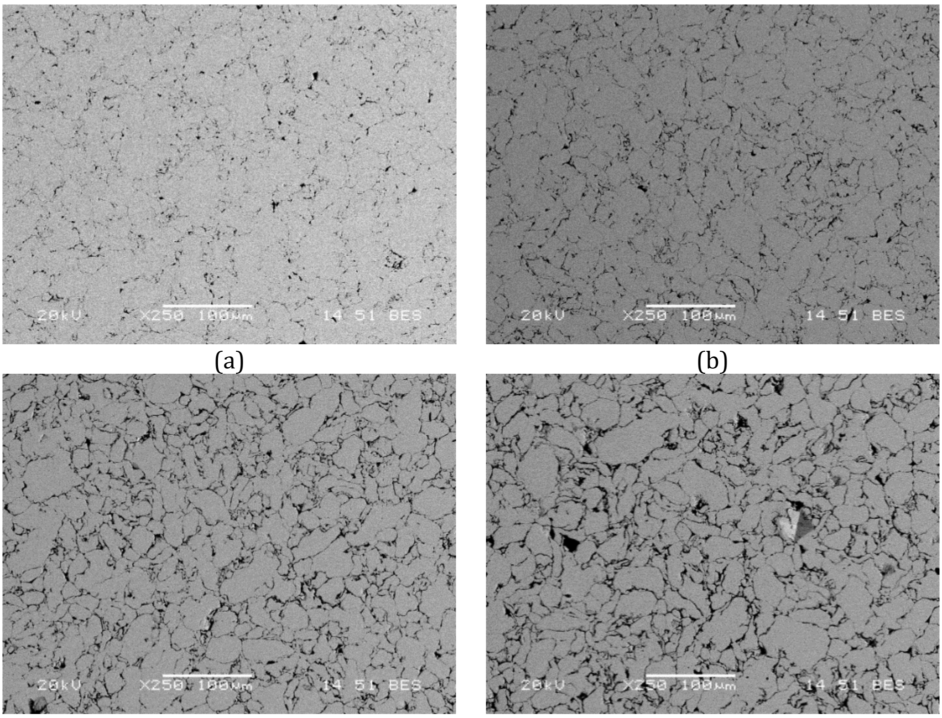
Fig. 1 SEM micrographs of Cu powder at different magnifications



(a) (b)

Fig. 2 SEM micrographs of MgO powder at different magnifications

SEM microstructures of sintered and polished Cu-MgO composites consisting of different MgO contents in weight were given in Fig. 3 and 4. Black areas reflect granite particles and light grey areas show Cu matrix. It is seen from Fig. 3 that MgO particles dispersed homogeneously in Cu matrix. At higher magnification, it was observed that MgO agglomerated on copper grain boundaries and were generally surrounded by Cu particles (Fig. 4). For the composite materials, it is very important to obtain homogeneous reinforcement in the matrix in order to enhance mechanical, electrical and thermal properties [7].



(a) (b) (c) (d)

Fig. 3. SEM micrographs of a) Cu-0.5wt.% MgO, b) Cu-1wt.% MgO, c) Cu-2wt.% MgO and d) Cu-3wt.% MgO composites sintered at 700°C for 2 hrs

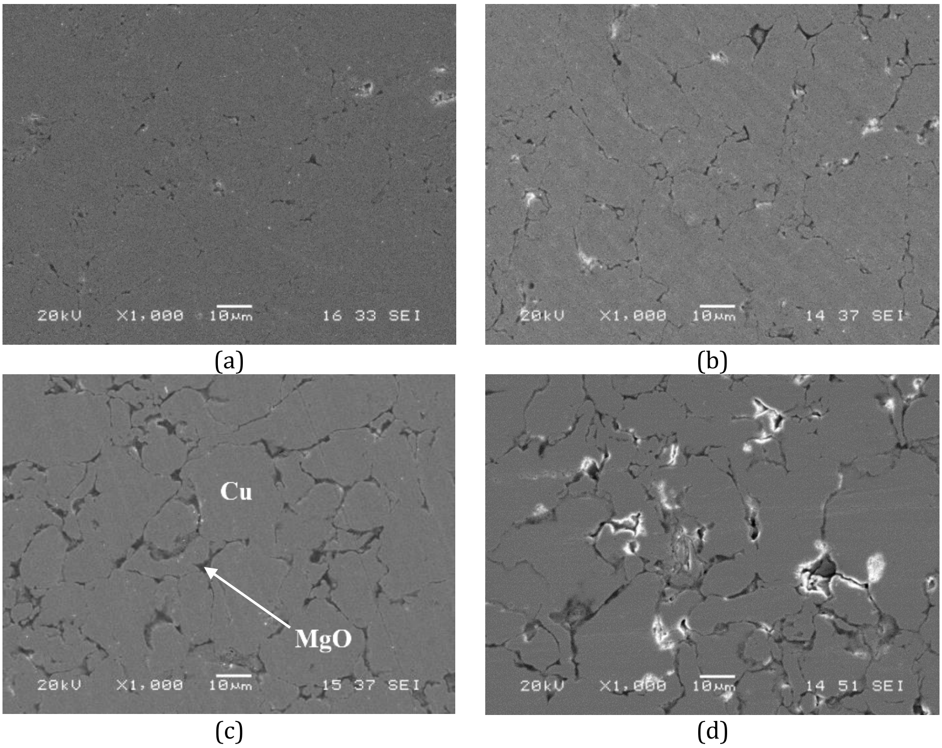
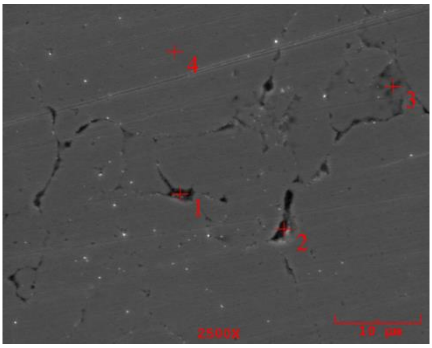


Fig. 4. SEM micrographs of a) Cu-0.5wt.% MgO, b) Cu-1wt.% MgO, c) Cu-2wt.% MgO and d) Cu-3wt.% MgO composites sintered at 700°C for 2 hrs

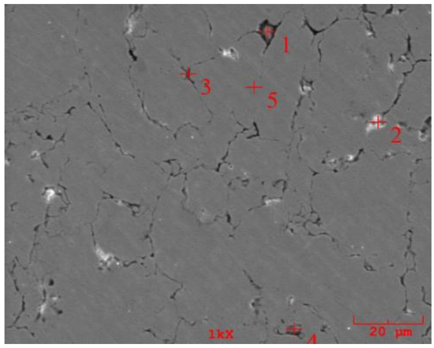
SEM-EDS analyses of Cu-0.5, 1 and 2wt.% MgO composite were given in Fig. 5. In EDS analyses, while dark areas indicate MgO particles (e.g. marks 1, 2, 3, 4), grey components indicate Cu matrix (e.g. mark 5). In Fig. 5 it is seen that some nano MgO particles got closed to each other and clustered together. Consequently, the disconnected MgO particles probably fell off the surface.

SEM-map analyses of Cu-3wt.% MgO composites reveals that O exists together with Mg and there is no oxide in the copper matrix. Black and white areas indicate MgO particles and grey regiongs belong to Cu matrix (Fig. 6).



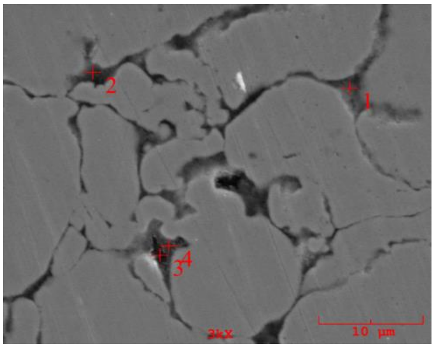
wt. %	1	2	3	4
O	14.883	9.746	7.555	
Mg	17.543	4.456	8.710	
Cu	67.574	85.798	83.735	100

(a)



wt. %	1	2	3	4
O	8.883	11.246	5.469	7.101
Mg	14.077	10.917	3.841	6.461
Si		3.835		

(b)



wt. %	1	2	3	4
O	18.494	15.740	22.601	24.944
Mg	25.968	24.305	42.896	40.046
Cu	55.537	59.955	34.503	35.011

(c)

Fig. 5. SEM–EDS analyses of Cu–MgO composite containing a) 0.5wt.% MgO, b) 1wt.% MgO and c) 2wt.% MgO sintered at 700°C for 2 hrs

3.2 XRD Analyses

Fig. 7 shows XRD diffraction patterns of the Cu-3wt.% MgO composite. It was found that the dominant components which are confirmed with XRD analyses are copper and MgO. In composite any another phase and oxide peaks were not detected. XRD patterns of Cu-MgO composites having MgO lower than 3wt.% were not given because they are below the detection limit of XRD.

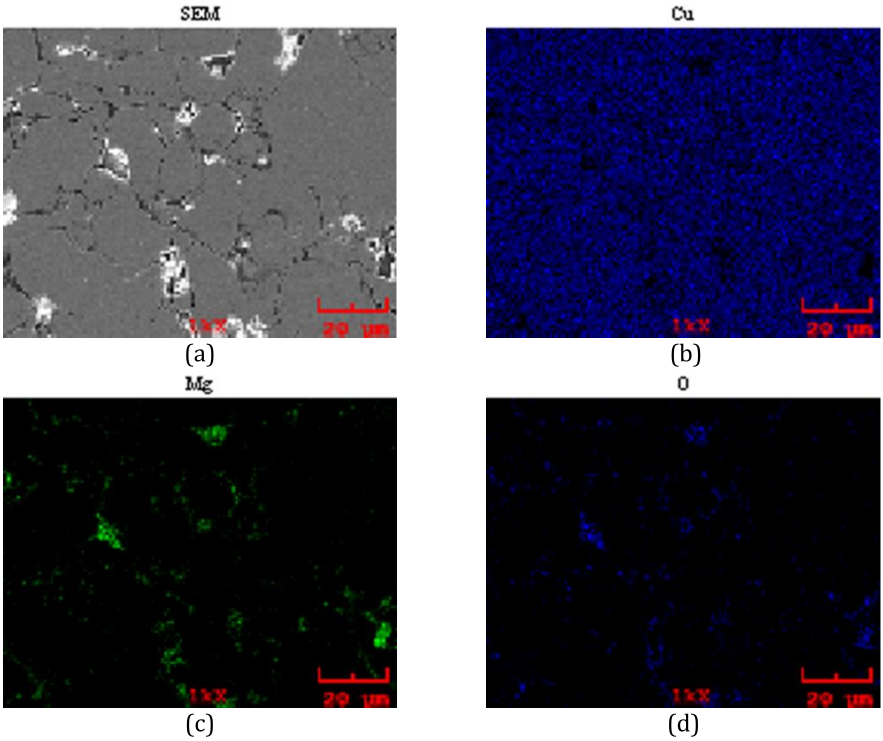


Fig. 6. EDS map analysis of Cu-3wt.% MgO composites sintered at 700°C for 2 hrs

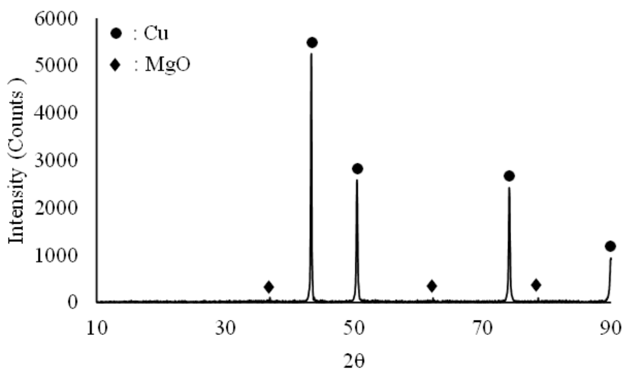


Fig. 7. XRD patterns of Cu-3wt.% MgO composite sintered at 700°C for 2 hrs

3.3 Relative Density, Electrical Conductivity, Hardness

Relative densities of sintered pure Cu and Cu-MgO composites calculated using Archimedes' principle were given in Table 1. It was found that relative densities of composites decreased with increasing MgO content. Duo at al. claimed in their studies that there is a poor bonding between copper matrix and ceramic reinforcement. Higher MgO particles preclude copper atom diffusion [1]. Also adding of MgO particles having lower density than copper into the Cu matrix leads to decrease of composite density. Low MgO addition to Cu matrix means less Cu-MgO interface and less copper atom diffusion barrier thus copper atoms can diffuse easily and fill the interstices between the MgO particles [6, 8]. Higher MgO addition prevents diffusion of Cu atoms and increases the porosity content of composites resulting in decrease relative density. The electrical conductivity of annealed pure copper is described as 100% IACS (International Annealed Copper Standard) [8]. The electrical conductivity values of composites determined by taking inverse of resistivity were given in Table 1. Electrical conductivity values of Cu-MgO composites decreased with addition of MgO particles as well as relative density results. The addition of ceramic MgO particles being nonconductive into the Cu matrix by decreasing relative density prevents the mobility of electrons, distorse the structure and increases the electrical resistivity so result in decrease in electrical conductivity of composites.

Table 1. Relative density and electrical conductivity values of Cu and Cu-SiC composites

Sample	Relative Density, %	Electrical Conductivity (%IACS)
Cu	94.19	90.15
Cu+0.5wt.%MgO	91.52	83.92
Cu+1wt.%MgO	88.94	76.35
Cu+2wt.%MgO	86.72	58.26
Cu+3wt.%MgO	84.09	43.46

Hardness of composites increased with increasing weight percentage of MgO particles (Fig. 8). Each value shown in Table 1 and Fig. 8 is the average value of five measurements. Hardness measurements were performed taking care of the indenter in containing both Cu and MgO areas. As it is well known that, the hardness of ductile copper can be improved by dispersion of second hard phase. It is thought that higher amount of ceramic particles in the matrix result in more dislocations that increases the hardness of the composite. MgO particles reduce grain boundary energy and its mobility, hinder the motion of dislocations, stabilize the size of Cu grains by preventing the grain growth at elevated temperatures, remain stable in Cu matrix and thereby improve the strength of the composites [9]. In the present, study hardness of copper increased considerably with the additions of MgO particles that can be attributed to higher hardness and dispersion hardening of MgO. This result was consistent with another research [10].

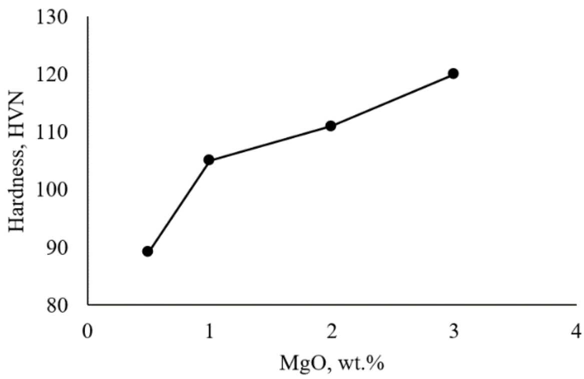


Fig. 8. Micro hardness of the Cu-MgO composites vs. MgO content

4 Conclusions

MgO particles reinforced copper matrix composites were successfully fabricated by powder metallurgy method. The microstructure of the composites revealed that the MgO particles were distributed uniformly in the matrix phase and no micro-cracks were observed. The presence of Cu and MgO were verified by XRD analysis technique and EDS analysis. As a result of hot pressing just after the sintering process, conductive Cu-MgO composite with remarkable density has been produced through powder metallurgy method at lower sintering temperatures. The hardness of the composite increased with MgO content. Relative density and electrical conductivity of composites decreased with increasing the amount of MgO. Hardness of copper are effectively improved without much loss of the electrical conductivity. It is possible to claim that MgO is a promising reinforcement for copper, especially in the field of electrical components.

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