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The effect of sintering temperature on some properties of Cu–SiC composite

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ABSTRACT

Copper matrix composites reinforced with 1 wt.%, 2 wt.%, 3 wt.% and 5 wt.% SiC particles were fabricated by powder metallurgy method. Cu and Cu–SiC powder mixtures were compacted with a compressive force of 280 MPa and sintered in an open atmospheric furnace at 900–950 °C for 2 h. Within the furnace compacted samples were embedding into the graphite powder. The presence of Cu and SiC components in composites was verified by XRD analysis. Optical and SEM studies showed that Cu–SiC composites have a uniform microstructure in which silicon carbide particles are distributed uniformly in the copper matrix. The results of the study on mechanical and electrical conductivity properties of Cu–SiC composites indicated that with increasing SiC content (wt.%), hardness increased, but relative density and electrical conductivity decreased. The highest electrical conductivity of 98.8% IACS and relative density of 98.2% were obtained for the Cu–1 wt.%SiC composite sintered at 900 °C and this temperature was defined as the optimum sintering temperature.

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1. Introduction

Metal matrix composite materials can be utilized at higher service temperatures than their base metal counterparts. The reinforcement may improve specific stiffness, specific strength, abrasion resistance, creep resistance, thermal conductivity, and dimensional stability [1]. Due to low mechanical strength, a highly conductive copper matrix needs to be dispersion strengthened and new composite materials with superior characteristics have been developed [2]. The incorporation of ceramic particulate reinforcement, such as SiC, can improve high-temperature mechanical properties and wear resistance significantly, without severe deterioration of thermal and electrical conductivity of the matrix [3,4]. Cu–SiC composites combine both the superior ductility and toughness of copper and high strength and high modulus of SiC reinforcements [5]. They are feasible to be used as electrical contact materials in relays, contactors, switches, circuit breaks and other switch gear components [6]. In this study, the main aim was to improve hardness of ductile copper while keeping its electrical conductivity at a reasonable level. In order to perform this, an attempt was made to fabricate Cu composites reinforced with SiC particles by means of PM process and to study the effect of sintering temperature on mechanical and electrical properties of composites. The morphology, microstructure, microhardness, and electrical property of Cu/SiC composite are investigated and the relationship between the microstructure and performance of the composite is also analyzed.

2. Experimental details

Commercial copper powder (10 μm) and SiC powder (1 μm) in a range of composition of 100-99-98-97-95% Cu and 1-2-3-5% SiC were mixed mechanically. The mixture was then compacted with a compressive force of 280 MPa in a steel mold of 15 mm in diameter. The sintering process was performed in an open atmospheric furnace at the temperatures of 900 and 950 °C for 2 h with the samples embedded in graphite. In order to increase the relative density and mechanical properties of test samples, following sintering they were immediately pressed with a load of 850 MPa while the samples were hot. The presence of phases formed within the sintered samples was determined by X-ray diffraction using CuKα radiation with a wavelength of 1.5418 A over a 2θ range of 10–80°. The microstructures of the composites were observed by means of optical microscopy and Scanning Electron Microscope (SEM). In order to detect the Cu, SiC and any oxide of Cu and SiC particles EDS analysis was performed. Microhardness of both pure copper and composites was measured by a Leica WMHT-Mod model Vickers hardness instrument under an applied load of 50 g. Microhardness measurements were performed by taking care of constituting the indentation mark including the Cu grains and SiC particles homogenously. The relative densities of composites were measured by Archimedes' principle. The measurements of electrical conductivity of specimens were performed on a GE model electric resistivity measurement instrument.

3. Results and discussion

3.1. Microstructure

Optical microstructures of Cu/SiC composites sintered at 900 and 950 °C are shown in Fig. 1. In micrographs, light grey areas indicate Cu matrix and dark grey and cornered shapes indicate the reinforcement component SiC. Particles which dispersed in Cu matrix homogeneously, generally surround the Cu particles. For the

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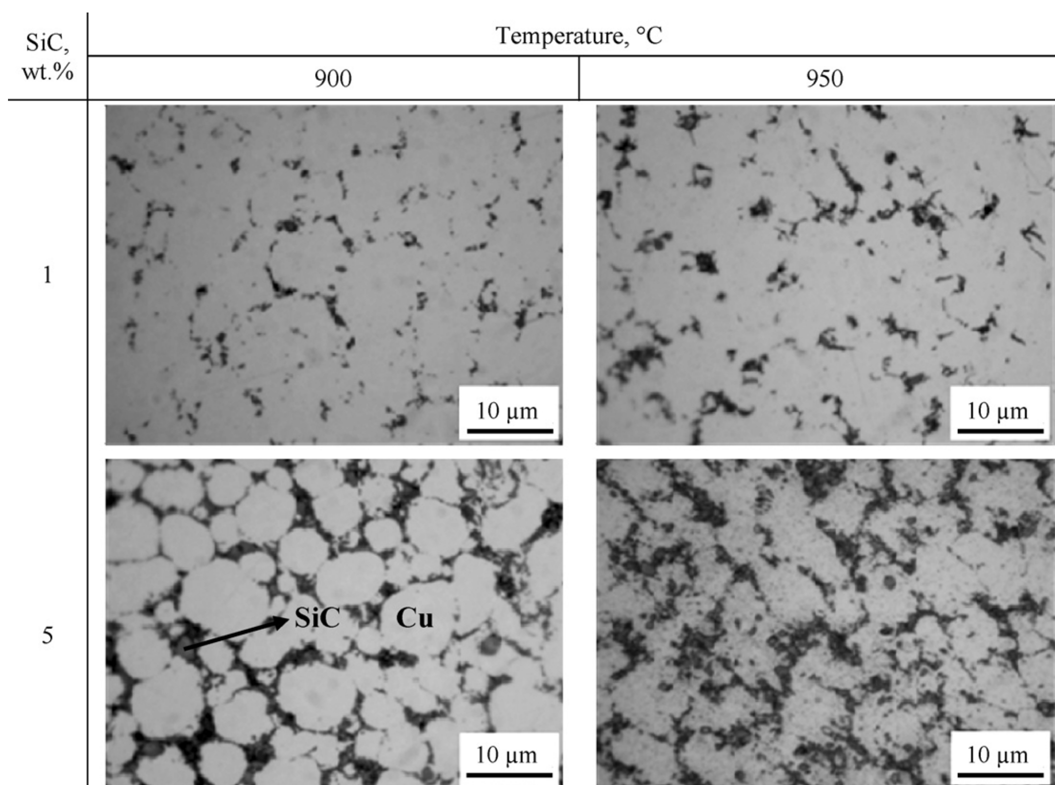


Fig. 1. Optical micrographs of Cu–SiC composites sintered at 900–950 °C.

composite materials, it is very important to obtain homogeneous distribution of reinforcement in the matrix in order to enhance mechanical, electrical and thermal properties [7]. If reinforcement particles in the composites do not disperse uniformly, this affects mechanical and electrical properties of composites negatively [8]. Optical and SEM studies showed that a homogenous and regular dispersion was seen in the composite samples sintered at 900 °C. As the sintering temperature and SiC addition increases, SiC particles spread towards the copper particle boundaries, like a homogenous network. At high percentage of SiC content, SiC particles got into the copper particles due to ductile nature of copper (Fig. 2). As it can be seen from Fig. 2, the increase in sintering temperature results in a slight increase in oxygen content of composites which was confirmed by selected field EDS mapping analyses.

Pure coppers sintered at 900 and 950 °C were etched by 40%HNO_3–H_2O solution (Fig. 3). Copper grains in Fig. 3b are bigger than grains in Fig. 3a therefore it can be claimed that the grain size of copper increases with increasing sintering temperature (Fig. 3).

Next to SEM micrographs, EDS analyses show that oxygen content increases with sintering temperature and the weight content of SiC. Similarly, the amount of Si increases with the weight percentage of SiC. This shows that oxygen exists together with Si [9].

SEM-EDS analyses of composites sintered at 900 °C and 950 °C were performed so as to analyze the presence, morphology and distribution of current components (Figs. 4 and 5). Black regions show the SiC particles and grey areas show the copper matrix. In the analyses while oxygen was generally detected on the small SiC particles, it could not be found in the big SiC particles. Oxygen probably results from the free surfaces of SiC particles [10].

Cu–SiC interface within the samples sintered at 950 °C, was scanned at high magnification and the results were given in Fig. 6. Similarly, in the EDS analysis taken from the centre of SiC particles, oxygen was not detected, but in the analysis of Cu–SiC interfaces little oxygen was observed. Kang and Kang [11] reported that SiC in contact with Cu was decomposed into Si and fine carbon at about 1000 °C. The presence of oxygen in the Cu–SiC interface may be related with this phenomenon.

3.2. XRD analysis

XRD patterns of composites are similar to each other and consist of the copper and SiC peaks dominantly (Figs. 7 and 8). SiC peaks become clear with increasing weight percentage of SiC. No oxide peak was observed in the XRD analysis of Cu–SiC composites sintered at the 900 °C but, just a very small Cu_2O peak was detected in the XRD analysis of composites sintered at the 950 °C. This probably results from the tendency of copper to oxidation with increasing sintering temperature [12].

3.3. Relative density, hardness and electrical conductivity

Relative densities of Cu and Cu–SiC composites, at different sintering temperatures, determined by using Archimede's principle were given in Table 1. Increment in the sintering temperature caused the decrease in the relative density of the samples. The decrease in relative density of composites sintered at 950 °C can be attributed to the formation of oxides confirmed by XRD and EDS analyses. The relative density of pure copper was determined as 98.2% and 97.8% for the samples sintered at 900 °C and 950 °C respectively. The densities of composites decreased from 97.05% to 90.92% and 94.3% to 89% for the samples sintered at 900 °C and 950 °C respectively with increasing the amount of SiC. This is due to the density of SiC particles being much lower than that of copper [13]. In composite with low SiC volume fraction, less Cu–SiC interface means less copper atom diffusion barrier, copper atoms can diffuse readily and fill the interstices between the SiC particles, thus leading to a higher densification of the composites [14].

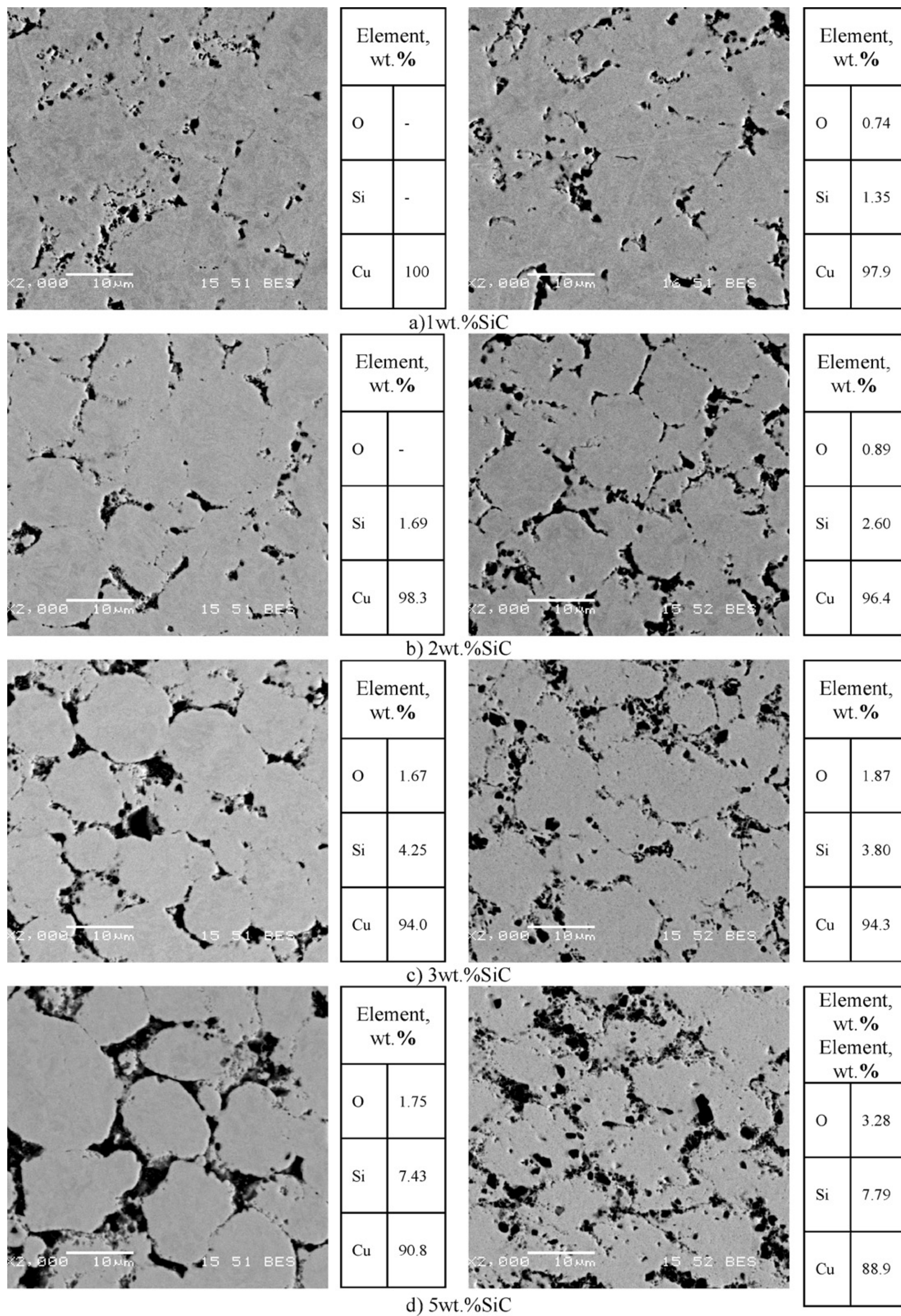


Fig. 2. SEM micrographs and EDS analysis of (a) Cu–1 wt.%SiC, (b) Cu–2 wt.%SiC, (c) Cu–3 wt.%SiC and (d) Cu–5 wt.%SiC composites sintered at 900 °C (left side) and 950 °C (right side).

Hardness values were determined by taking the average of five different measurements on each sample. The hardness of Cu and Cu–SiC composites were given in Table 1. Hardness of the samples generally decreased with increasing sintering temperature. This may result from the increase of the grain size (Fig. 3). The hardness of pure copper sintered at 900 °C is 126 HV for and increased to 149 HV with increasing SiC content. These values are quite bigger than that of pure copper having hardness value of 37 HV [8] and this may result from the hot pressing applied after the sintering. It is well known that, the

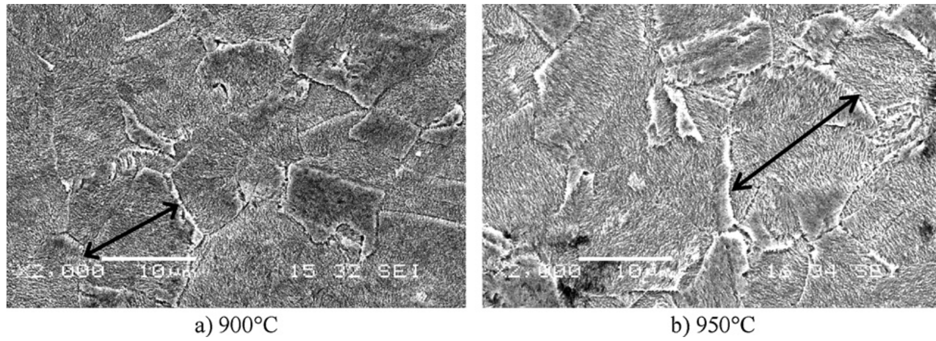
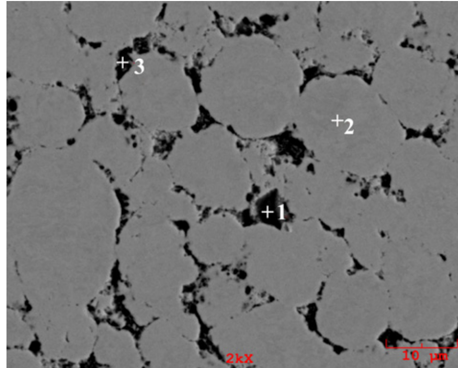
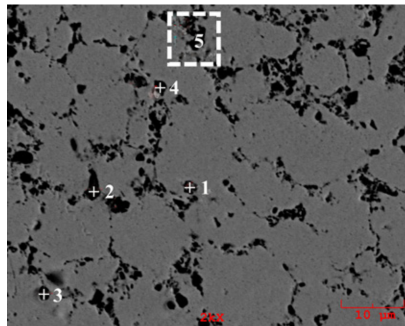


Fig. 3. SEM micrographs of etched pure copper samples sintered at 900–950 °C.



Elements	Marks		
	1	2	3
	wt. %		
O			1.116
Si	33.312		34.214
C	44.364		47.777
Cu	22.324	100	16.893

Fig. 4. SEM-EDS analyses of Cu–3 wt.%SiC composite sintered at 900 °C.

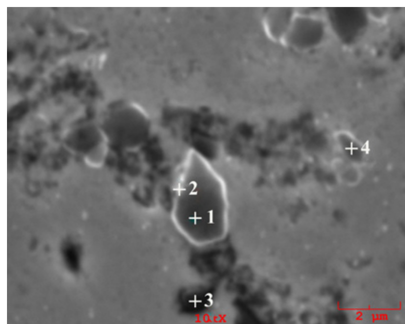


Elements	Marks				
	1	2	3	4	5
	wt. %				
C	26.286	53.038	48.129	30.904	5.979
O	3.578			2.071	5.066
Si	21.150	33.940	24.249	24.456	11.464
Cu	48.985	13.022	27.622	42.568	77.491

Fig. 5. SEM-EDS analyses of Cu–3 wt.%SiC composite sintered at 950 °C.

hardness of ductile copper can be improved by dispersion of second hard phase. It is thought that higher amount of the ceramic particles in the matrix results in more dislocations, and as a result, the hardness of the composite increases [14–17]. In this study, the aim is to improve hardness of ductile copper, at the same time keeping its electrical conductivity at a reasonable level [5,17].

Electrical conductivity of Cu and Cu–SiC composites, varying depending on the sintering temperature, and rate of reinforcement component, were given in Table 1. With regard to Table 1, electrical



Elements	Marks			
	1	2	3	4
	wt. %			
C	31.943	37.986	47.838	10.748
O		5.479		2.728
Si	39.388	22.318	28.916	4.466
Cu	28.670	34.217	23.246	82.057

Fig. 6. SEM-EDS analyses of Cu–5 wt.%SiC composite sintered at 950 °C.

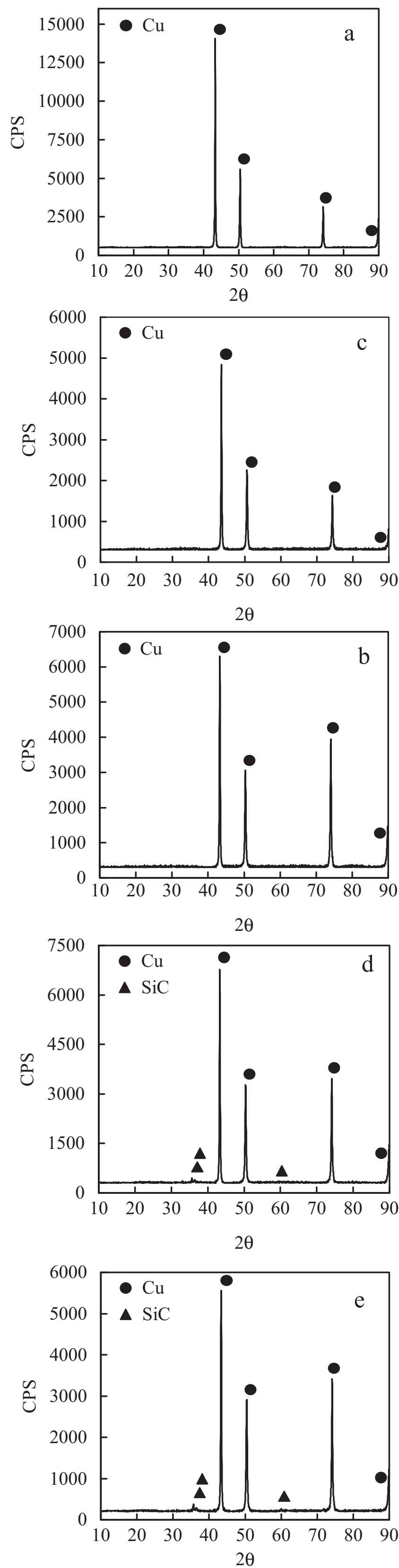


Fig. 7. XRD patterns of (a) Cu, (b) Cu–1 wt.%SiC, (c) Cu–2 wt.%SiC, (d) Cu–3 wt.%SiC and (e) Cu–5 wt.%SiC composites sintered at 900 °C.

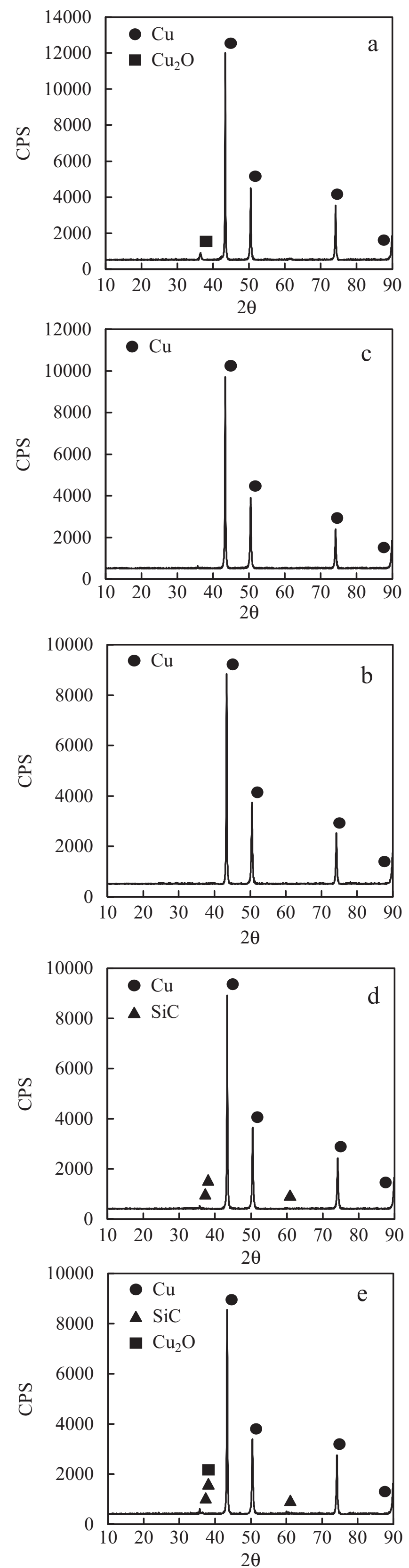


Fig. 8. XRD patterns of (a) Cu, (b) Cu–1 wt.%SiC, (c) Cu–2 wt.%SiC, (d) Cu–3 wt.%SiC and (e) Cu–5 wt.%SiC composites sintered at 950 °C.

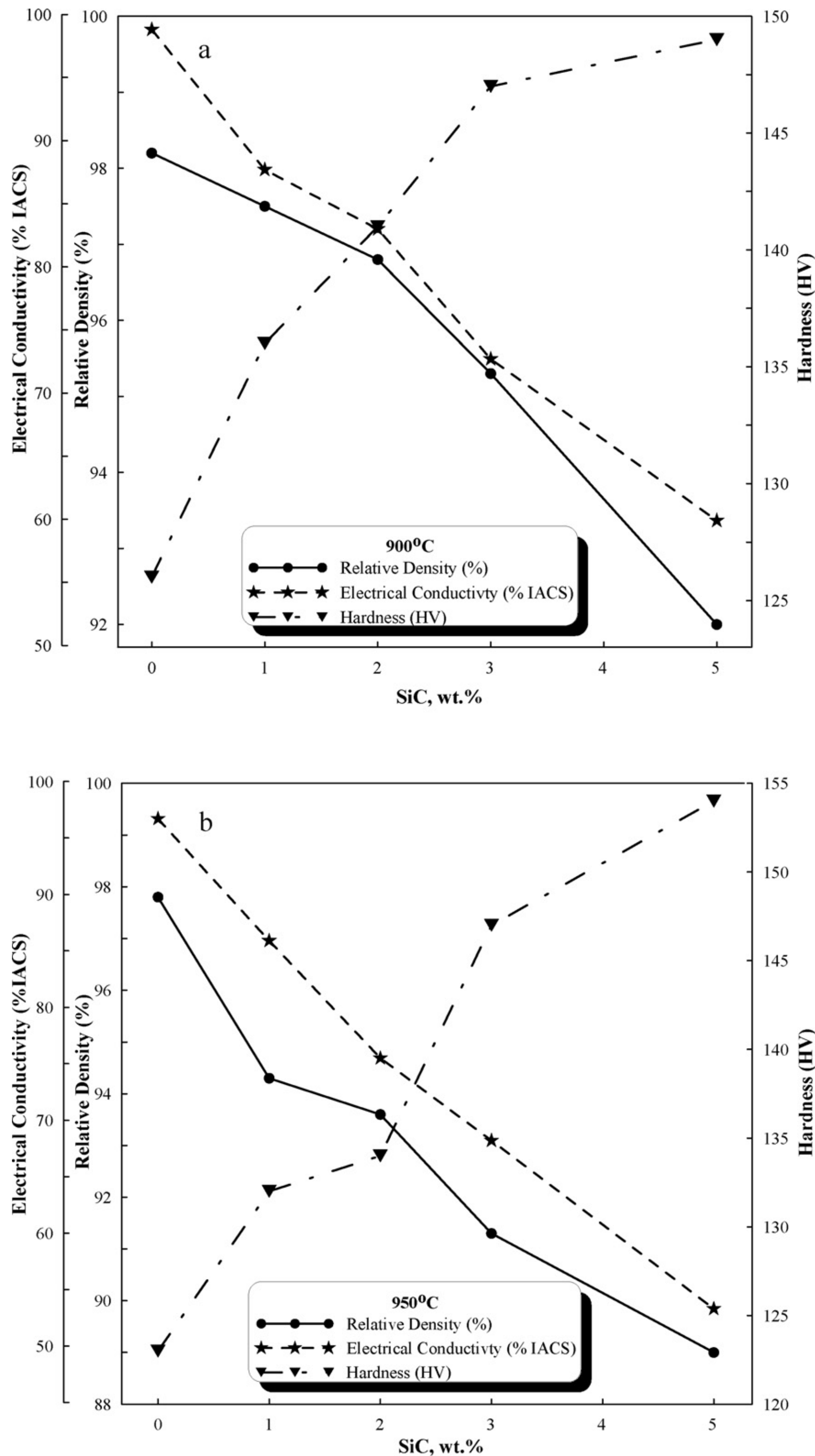


Fig. 9. The variation of relative density, hardness and electrical conductivity of Cu and Cu–SiC composites sintered at (a) 900 °C, (b) 950 °C as a function of SiC.

conductivities of the samples decreased with increasing sintering temperature and SiC content. It is possible to claim that the lower electrical conductivity of composites containing higher amount of SiC can be attributed to increased amount of SiC and the higher sintering temperature which causes formation of a small amount of oxidation.

Schematic illustrations of relative density, hardness and electrical conductivity values of composites sintered at 900 and 950 °C were given in Fig. 9 comparatively. It is seen from Fig. 9 that relative density and electrical conductivity values of composites decrease and the hardness values of composites increase with SiC content.

Table 1
Presentation of relative densities, hardness and electrical conductivity values of Cu–SiC composites sintered at 900, 950 °C.

SiC (wt.%)	Properties					
	Relative density (%)		Hardness (HVN)		Electrical conductivity (%IACS)	
	Temperature (°C)		Temperature (°C)		Temperature (°C)	
	900	950	900	950	900	950
0	98.2 ± 1.2	97.8 ± 1.8	126 ± 2.1	123 ± 1.0	98.8 ± 0.6	96.7 ± 1.3
1	97.5 ± 0.8	94.3 ± 0.9	136 ± 5.6	132 ± 3.2	87.7 ± 0.8	85.9 ± 0.9
2	96.8 ± 1.3	93.6 ± 0.7	141 ± 3.6	134 ± 1.1	83.0 ± 1.3	75.5 ± 1.5
3	95.3 ± 1.4	91.3 ± 1.0	147 ± 2.5	147 ± 2.4	72.7 ± 1.7	68.2 ± 0.9
5	92.0 ± 1.5	89.0 ± 1.2	149 ± 3.1	154 ± 4.6	59.9 ± 1.6	53.3 ± 1.0

4. Conclusions

The major conclusions resulting from the work presented in this paper can be listed as follows:

1. Cu and Cu–SiC composites reinforced with 1 wt.%, 2 wt.%, 3 wt.% and 5 wt.% SiC particles were produced by PM method successfully.
2. Optical and SEM studies reveal that it is clear that SiC particles are homogeneously distributed and dominantly occupy around copper grains.
3. The presence of copper and SiC were confirmed by X-ray diffraction (XRD) analysis and a slight Cu_2O peak was detected in the XRD analysis of composites sintered at 950 °C.
4. EDS analyses of composites show that the main components of Cu–SiC composites are copper and SiC and small amount of oxide was found on the free surface of SiC particles, especially for composite sintered at 950 °C.
5. The relative densities of Cu–SiC composites were reduced from 98.2% to 92% and from 97.8% to 89% for the samples sintered at 900 °C and 950 °C respectively.
6. Hardness of composites was increased as the sintering temperature and the amount of reinforced particle increased.
7. High SiC contents decrease the electrical conductivity of Cu–SiC composites as expected. The highest electrical conductivity value of 98.8% IACS was obtained for Cu–1 wt.%SiC composite sintered at 900 °C.
8. It is possible to claim that there is a linear relationship between SiC content and electrical conductivity of composites which are coherent with relative density and hardness values.
9. More homogenous microstructure, higher hardness, relative density and electrical conductivity values were obtained for Cu–SiC composites sintered at 900 °C. Therefore it can be claimed that results obtained at 900 °C are better than that of 950 °C.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.jallcom.2011.02.170.

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