Kovove Mater. 49 2011 131–136
DOI: 10.4149/km_2011_2_131

Some properties of Cu-SiC composites produced by powder metallurgy method

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Received 22 December 2009, received in revised form 7 July 2010, accepted 7 July 2010

Abstract

This study reports some properties of copper matrix composite reinforced with silicon carbide at ratios of 1, 2, 3 and 5 % by weight manufactured by powder metallurgy method. Composite powders were pressed by applying a uniaxial pressure of 280 MPa and sintered at 900 °C for 2 h in graphite powder. Optical and SEM studies revealed that SiC particles were located around Cu grains. The presence of Cu and SiC components in composites were verified by XRD analysis technique. The hardness of sintered compacts ranged from 104 to 108 HBN. The relative densities of Cu-SiC composites determined according to Archimedes' principle changed between 96.45 and 89.61 %. Electrical conductivities of Cu-SiC composites varied between 87.1 and 55.2 % IACS. As SiC content increases, hardness increases, but relative densities and electrical conductivities decrease. An attempt was made to investigate the possibility of predicting contour diagram of electrical conductivity variation.

Key words: composites, relative density, hardness, conductivity

1. Introduction

Copper is the one of the most investigated metals due to its excellent electrical and thermal conductivity, good ductility and superior resistance to corrosion and oxidation, it has been used in the power industry, electric industry and other engineering areas [1–3]. But its application at high temperature is limited due to poor mechanical properties [4]. There have been several efforts to develop copper alloys, which exhibit good mechanical properties even at elevated temperatures. Copper-base metal matrix composites (MMC) with reinforcing ceramic particles such as oxides, borides and carbides were developed as electrode materials because the ceramic particles are stable at high temperatures [5, 6]. SiC could be used as a reinforcement to enhance the strength of copper matrix. SiC/copper composites combine both the superior ductility and toughness of copper and high strength and high modulus of SiC reinforcements [4, 7]. They were feasible to be used as electrical contact materials in relays, contactors, switches, circuit breaks and other switch gear components and heat sinks in electronic packaging [8–10].

At the present study the influence of the concentration of SiC on mechanical and electrical properties of copper were studied. For characterization of Cu-SiC composites SEM, optical microscope, Brinell hardness instrument and GE electric resistivity measurement instrument were utilized. The original aspect of present study is to produce Cu-SiC composites by powder metallurgy method on which very few works are available in the open literature.

2. Experimental details

2.1. Production of test materials

In this study, commercially pure SiC powders with particle size of 1 μm and Cu powders with particle size of 10 μm were used as starting powders. SiC particles are added into Cu powders at amount of 1 %, 2 %, 3 % and 5 % by weight in order to manufacture Cu-SiC composites by powder metallurgy method. Mix-

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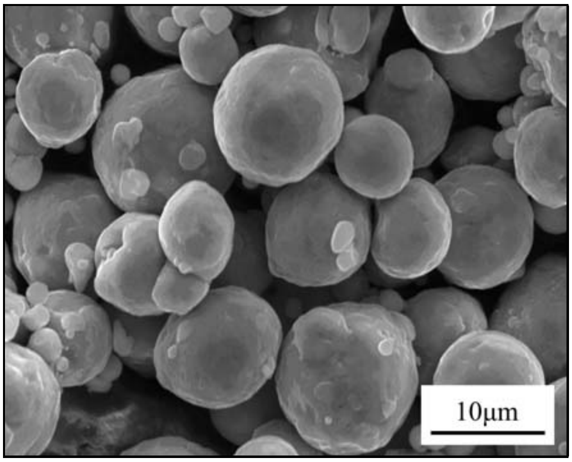


Fig. 1. SEM micrograph of copper powder, 5500×.

ture of Cu-SiC powders was pressed into a cylindrical compact in a metallic mold, which has a diameter of 15 mm by applying a uniaxial pressure of 280 MPa, and then the compacts were sintered at 900 °C for 2 h embedding into graphite powder.

2.2. Microstructure and properties

The presence of phases formed within the sintered samples was determined by X-ray diffraction using Cu $K\alpha$ radiation with a wavelength of 1.5418 Å over a 2θ range of 10 to 80°. Optical microscopy and SEM examined the microstructures of samples. In order to detect the Cu, SiC and any oxide of Cu and SiC particles, EDS analysis was performed. The hardness of sintered compacts was measured by Brinell hardness instrument. The relative density of Cu-SiC composites was measured according to Archimedes' principle. Electrical conductivity of Cu-SiC composites was determined by GE model electric resistivity measurement instrument.

3. Results

SEM micrographs of starting powders are given in Figs. 1 and 2. It is seen from Figs. 1 and 2 that copper powders are in spherical shape and 10 μm grain size and SiC powders, which are reinforcement components, have flaky and cornered morphology and 100 % purity.

Figures 3 and 4 show the optical and SEM micrographs of Cu-SiC composite samples produced by powder metallurgy method. Copper matrix is light gray and SiC particles are dark gray. It is clearly seen that the distribution of SiC in copper matrix was uniform. The second phase SiC is concentrated in grain boundary of matrix.

The presence of Cu and SiC in composites was confirmed by EDS analysis. In EDS analysis, while dark and relatively cornered components indicate SiC (e.g. 1, 2, 3 points), gray components indicate Cu matrix (e.g. 4 point) (Fig. 5).

X-ray diffraction (XRD) analysis revealed that the dominant components of composites produced by powder metallurgy method are Cu and SiC (Fig. 6).

Relative density, hardness and electrical conductivity values of sintered composites are given in Fig. 7.

The relative densities of Cu-SiC composites, determined in terms of Archimedes' principle, decreased as the amount of SiC particles increased. In composite with low SiC volume fraction, less Cu-SiC interface means less copper atom diffusion barrier, copper atoms can diffuse easily and fill the interstices between the SiC particles, thus leading to a higher densification of the composite [2].

It can be seen in Fig. 7 that hardness (HBN) of

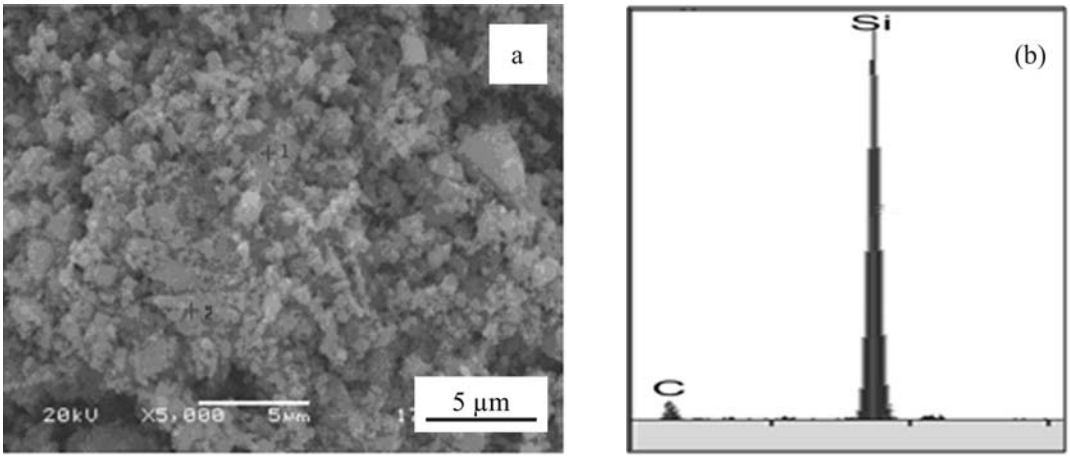


Fig. 2. SEM micrograph (a) and EDS analysis of SiC powder (b).

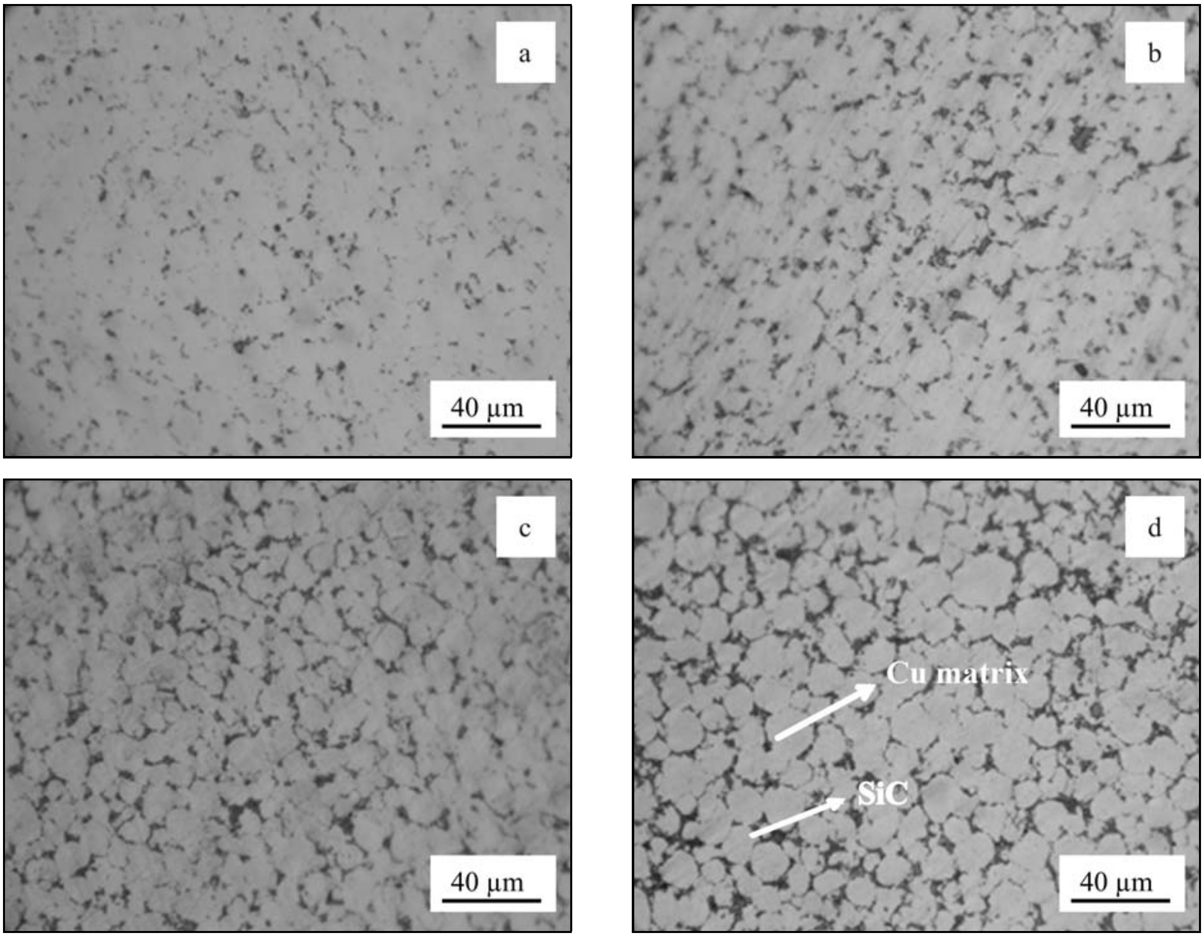


Fig. 3. Optical micrographs of Cu/SiC composites sintered at 900 °C: (a) Cu-1wt.%SiC, (b) Cu-2wt.%SiC, (c) Cu-3wt.%SiC, (d) Cu-5wt.%SiC.

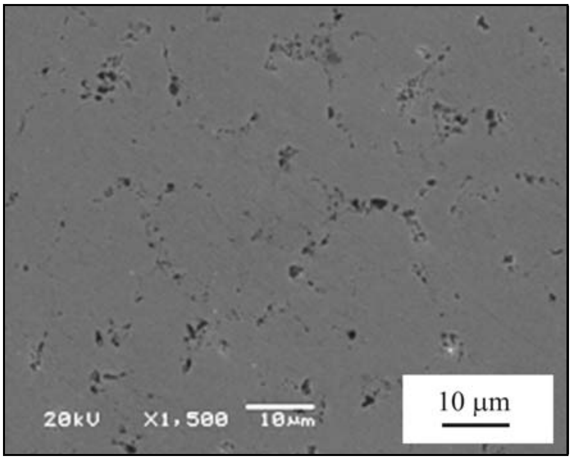


Fig. 4. SEM micrograph of Cu-1wt.%SiC composite.

Cu-SiC composite increased as the SiC content increased. The hardness of sintered compacts measured by Brinell hardness instrument ranged from 104 to 108 HBN. The results of electrical conductivity values performed (measured) on the polished samples were given in Fig. 7 and the maximum electrical conductivity of composites was measured as 87.1 % IACS.

It is seen from Fig. 8 that electrical conductivity decreases sharply with SiC amount whereas the relative density values of composites decrease slightly with increasing SiC content.

A contour diagram was established for predicting electrical conductivity of Cu-SiC composite as a function of relative density and the amount of reinforcing constituent SiC (Fig. 9).

4. Discussion

From the results presented above it is clear that SiC particles are distributed dominantly around copper grains, which were verified by optical and scanning electron microscope (SEM). As the amount of SiC increased, the relative density of composite decreased. The relative densities of Cu-SiC composites were reduced from 96.45 % to 89.61 % with increasing amount of SiC. As is well known, the hardness of ductile copper can be improved by dispersion of second hard phase. In this study the aim is to improve hardness of ductile copper at the same time kept the electrical conductivity of it at reasonable level. Electrical conductivity results revealed that the higher SiC contents decrease the electrical conductivity of Cu-SiC composites as expected. It is possible to claim that there is a linear relationship between SiC content and electrical conductivity, i.e., the higher the SiC the lower the electrical conductivity. The hardness of sintered compacts increased slightly with amount of reinforcing SiC. The hardness of material is a physical parameter indicating the ability of resisting local plastic deformation. SiC with high hardness, which act as reinforcing

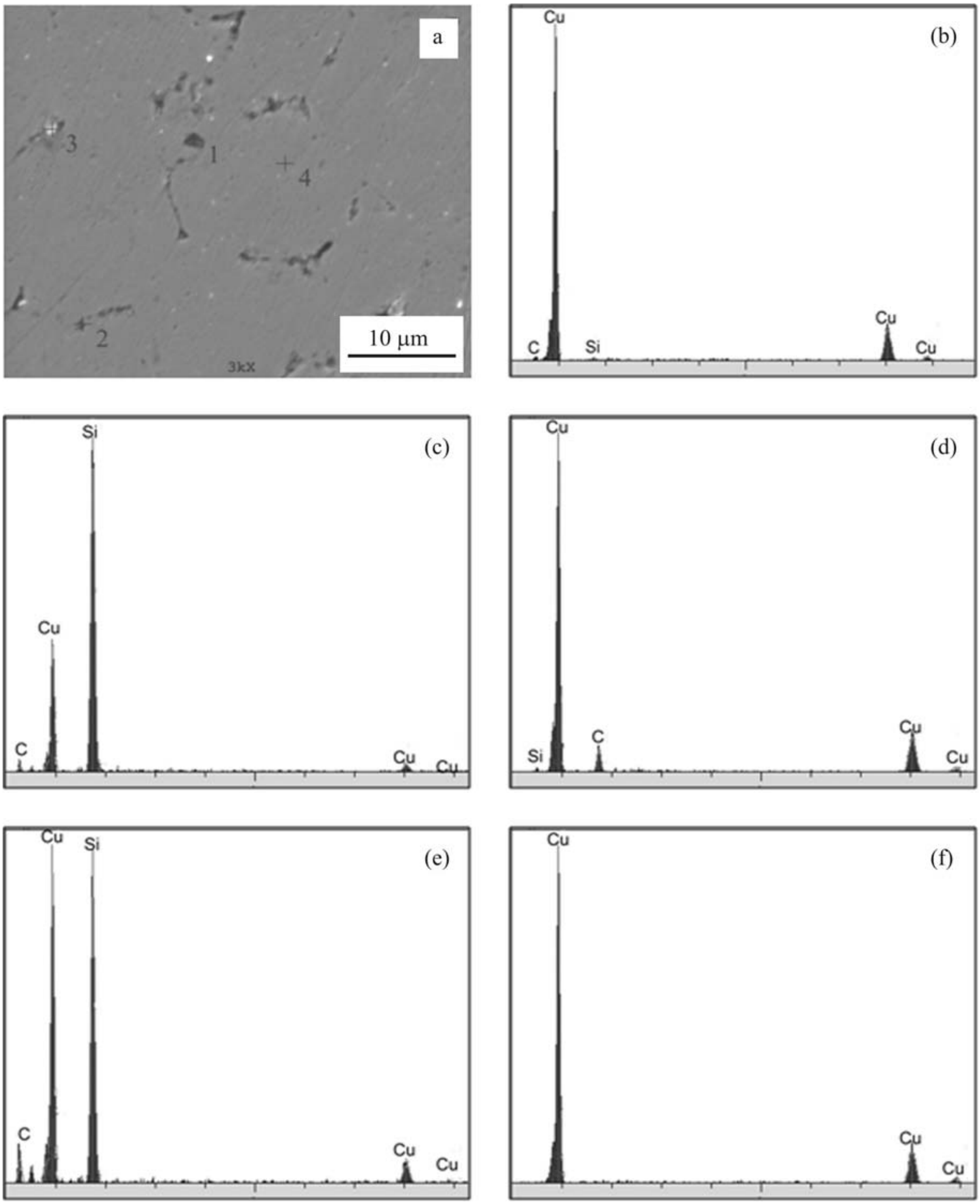


Fig. 5. SEM-EDS analysis of Cu-1wt.%SiC composites: (a) general spectrum, (b) 1, (c) 2, (d) 3, (e) 4, (f) 5.

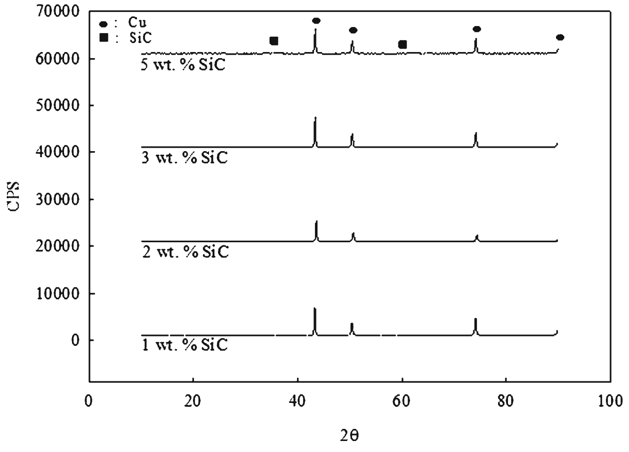
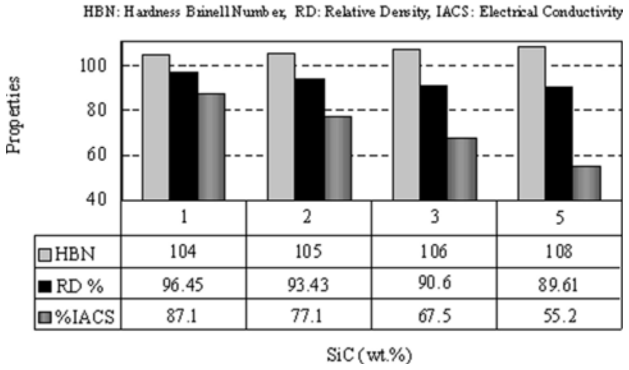


Fig. 6. XRD patterns of Cu-SiC composites.



	1	2	3	5
▨ HBN	104	105	106	108
■ RD %	96.45	93.43	90.6	89.61
▨ %IACS	87.1	77.1	67.5	55.2

Fig. 7. Variation of the composite properties in dependence on increasing SiC content.

phases, are dispersed in copper matrix and become the obstacles to the movement of dislocation when plastic deformation occurs, and resulted in the distortion of lattice, which created much internal stress in composites. The internal stress generated many dislocations and twin crystals. When the movement of dislocation was impeded by the dispersed phase and grain boundary, it would generate a strengthening effect [1, 2]. Maximum electrical conductivity of polished test materials was measured about 87.1 % IACS. The electrical conduction of the metal is mainly dependent on the movement of the internal (intrinsic) electrons. [2]. SiC particles in the copper matrix prevent the movement of the internal electron via distorting the structure and so electrical conductivity of composites decreases with increasing amount of SiC content. XRD and EDS analysis results showed that there was not any form of copper and silicon oxide in the Cu-SiC composites which were manufactured by powder metallurgy method. This result is very important from the electrical conductivity point of view of materials. Moreover, a contour diagram derived facilitates the selection of parameters in industrial application.

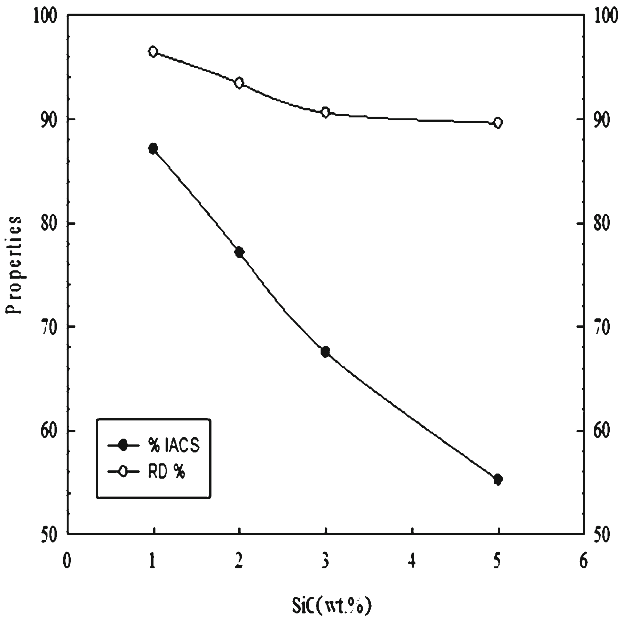


Fig. 8. Variation of relative density and electrical conductivity as a function of SiC content.

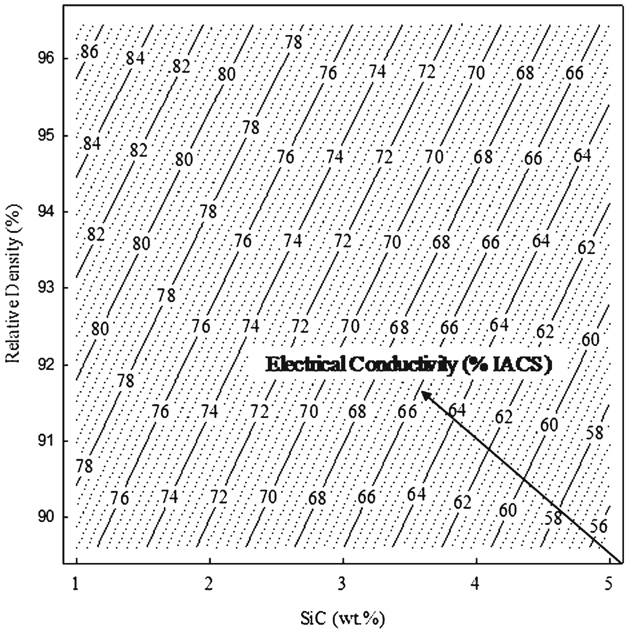


Fig. 9. Contour diagram of Cu-SiC composite as a function of relative density and the content of SiC.

5. Conclusions

The following conclusions are obtained from the present study:

a) Cu-SiC composites are manufactured in graphite powder-by-powder metallurgy method with free oxidation.

b) It was observed that during sintering of Cu-SiC composites, SiC particles are located around the copper grains.

c) The addition of SiC levelled up hardness of composites, while the electrical conductivity and relative density decreased.

d) It is to believe that with SiC addition to copper supplying electron distortion, the electrical conductivity decreased.

Acknowledgements

Authors thank to expert Fuat Kayis for performing SEM studies and special appreciations are extended to technician Ersan Demir for experimental assistance at Sakarya University. This work was conducted a project supported by TUBITAK with contract number of 106M118.

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