Scholars Bulletin *(Materials Engineering)*
An Official Publication of "Scholars Middle East Publishers" ISSN 2412-9771 (Print)
Dubai, United Arab Emirates ISSN 2412-897X (Online)
Website: www.saudijournals.com

Production and Characterization of Cu-SiC Composites for Electrical Contact Materials

Acikbas Gokhan[1], Karadag Mecit[1]
[1]Vocational School, Bilecik Şeyh Edebali University, Metallurgy Program, Bilecik, Turkey

***Corresponding author**
Acikbas Gokhan

Article History
Received: 11.02.2018
Accepted: 23.02.2018
Published: 28.02.2018

DOI:
10.36348/sb.2018.v04i02.012

Abstract: In this study, the effect of SiC reinforcement on the electrical, mechanical, physical properties and microstructure of copper matrix composite contact material was investigated. The composite materials were produced by using the powder metallurgy method. The unalloyed copper and SiC powder mixtures were shaped by using a uniaxial press after mixing for 10 minutes at 300 rpm. The shaped specimens were heat treated in graphite powder bad in a capped steel chamber and sintered at 800° C for 2 hours. Electrical conductivity, hardness, density measurements, microstructure analyzes and mineralogical analyzes of the samples were performed after sintering. The structure-property relationships of the produced monolithic and composite copper contact materials are discussed. It was determined that the value of electrical conductivity decreased with increasing amount of SiC phase, and hardness value increased compared to pure copper. Cu-SiC composites revealed better mechanical properties than monolithic copper contact materials.
Keywords: Silicon carbide, Copper, Characterization, Contact materials, Electrical conductivity, Composites.

INTRODUCTION

The electrical contact is defined as the current carrying element of the electrical/electronic device interface which maintains the continuity of the electrical circuit.Electrical contacts provide electrical connections and often perform other functions. The primary purpose of the electrical connection is to ensure that the electricity passes continuously through the contact interface. This is achieved only by establishing a good metal-to-metal interface interaction [1].

The basic requirements from electrical contacts are reliability, electrical conductivity, thermal stability, and cost. Powder metallurgy is a cost effective method for production of electrical contacts [2]. Electrical contact materials are a class of metal such as pure metal, metal alloys and metal matrix composites used in the electrical interfaces of electrical connectors and electrical switches. These materials are characterized by their superior electrical conductivity properties and can be used as bulk conductors such as, silver, silver alloys, copper, copper alloys, aluminum, aluminum alloys. Some conductors, are used as coatings on the electrical contact surfaces such as precious metals, silver alloys, tin alloys, ceramic oxide and non-oxide films …etc. Another group is a metal matrix composites where copper, silver …etc. are matrix phase and SiC, B_4C, TiB_2, ZrB_2, TiC etc. are a non-oxide and Al_2O_3, SnO_2, B_2O_3 etc. oxide reinforced phases. They have been used for ranging from low voltage to high voltage circuit application [3-13].

Cu-SiC metal matrix composites have been extensively studied due to their excellent electrical and thermal conductivity, high hardness and good wear and friction properties. Powder metallurgy is the most commonly used methods in the manufacture of these composites in a cost effective way[14-16].

MATERIALS AND METHODS

Materials

The matrix material comprises copper metal which were supplied from Sentez Bir Metallurgy, Chemical, Energy, Production and Recycling Technologies Industry Inc., Turkey. SiC reinforced phase was obtained from Ridsdale Co. Ltd., Middlesbrough, Cleveland, UK. Copper and SiC material powders were milled with a Fritsch planetary mill for twenty minutes at 200 rpm. The mixtured Copper and SiC material powders was dryied in oven at 105 ^{0}C.

After that some characterization techniques were applied to copper and SiC material powders. The true density of Copper and SiC material powders were measured by He-gas pycnometer. Optical microscopy images of Copper and SiC powders were taken with

Nikon Eclipse LV150 at different mangifications. The types of phases were detected by means of X-ray diffraction analyses (Panalytical-Empyrean model with Cu-Kα radiation). The schematic presentations of preparation of Copper and SiC powders and their characterization steps are given in Figure-1.

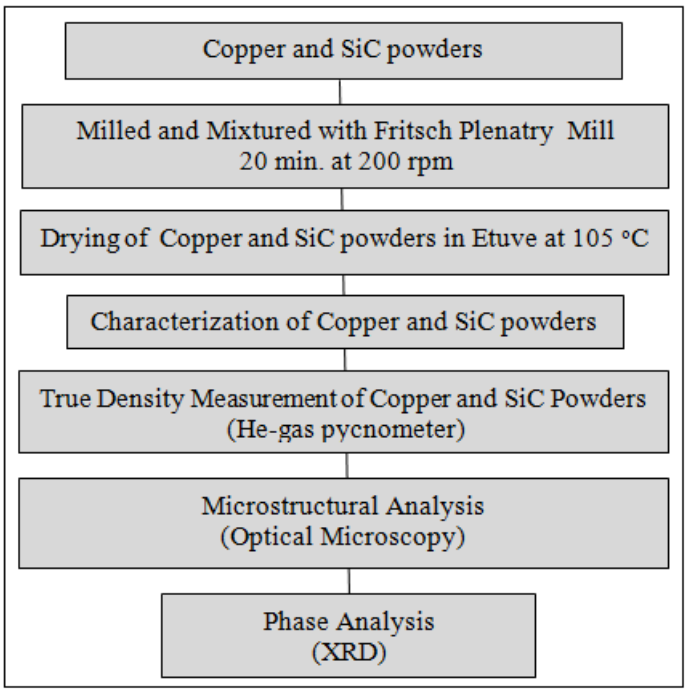

Fig-1: The schematic presentation of preparation of Copper and SiC powders and their characterization steps.

Preparation of composite contact materials

The objective of the study was to determine the effect of SiC reinforced phase to copper matrix ratio on the electrical, mechanical and physical properties of composite contact materials. Besides the properties of monolithic copper and Cu-SiC composites were compared. During the manufacturing of composite material, SiC powder to copper powder ratio compositions were changed between 0.005-0.01-0.02 respectively. Prepared composite's recipes were shown in Table-1.

Table-1: Prepared composite recipes

Sample Codes	SiC Phase %wt.	Copper Matrix %wt.	SiC:Copper Ratio ~
SB	0	100.0	Pure copper
S1	0.5	99.5	0.005
S2	1.0	99.0	0.010
S3	2.0	98.0	0.020

SiC particle reinforced copper matrix composites were produced with the powder metallurgy method. Calcium Stearate was used as lubricant to easy remove the composite from mold. SiC and Copper powders were milling in a plenatry mill at 200 rpm for 20 minutes and obtain a homogeneous mixture. The blended mixture was pressed into the lubricated steel molds. The pressed copper and SiC composites were sintered at 800 ^{o}C for 2 hours with a steel crucible in a graphite bed. And then, the graphite on the sintered specimens was cleaned. The samples were stored in the desiccator to protect it from oxidation until it was analyzed. The composite sample preparation process and their characterization steps are given in Figure-2, schematically.

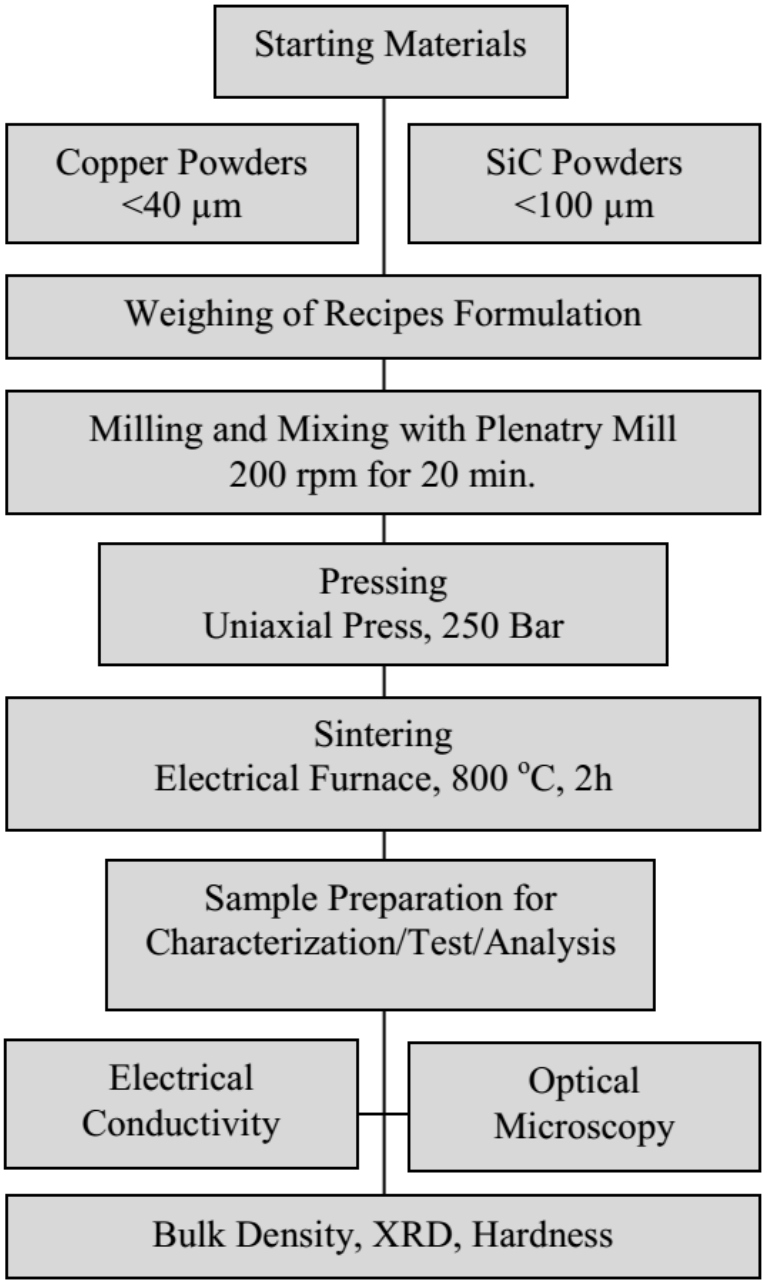

Fig-2: Metal matrix composite preparation and their characterization steps

Physical, mechanical, electrical, mineralogical and microstructural characterizations

In order to determine the true density value of the composites, the theoretical densities of the copper and the SiC powders were used. Theoretical densities of composite samples were calculated from the theoretical densities and the volume fractions of the constituting materials given by Eq. 1 [17]. The known weight fractions were converted to volume fractions.

$$\rho_c = (\rho_m * V_m) + (\rho_g * V_g) \qquad \text{(Eq.1)}$$

where, ρc is theoretical density of composite samples, ρm is theoretical density of copper matrix, ρg is the theoretical density of SiC filler, respectively, while Vm is the vol. fraction of the matrix, and Vg is the volume fraction of the respective filler.

The Archimedes principle was used to measure the density and porosity of the samples. Bulk density, % theoretical density and % total porosity were calculated by Eqs 2.

$$\text{Bulk Density}(\text{B. D.}) = \frac{W_1}{W_3 - W_2} * \rho_{water} \quad \text{(Eq.2)}$$

where, W1 is the dry weight, W2 is the wet weight suspended in water, W3 is the wet weight, B.D. is the bulk density, T.D. is the theoretical density of the samples.

The Brinell hardness was measured with samples in 1,6 cm diameter. The average of the five measurements was taken.

Electrical conductivity value of all composite samples was measured with Eddy Current Conductivity device. The average of the five measurements was taken.

The microstructural examinations of the polished composite surfaces were performed by optical microscope imaging. Optical microscopy images of composite materials were taken with Nikon Eclipse LV150 at 100x, 200x manginifications.

The mineralogical analysis was performed using XRD device.(Panalytical-Empyrean model with Cu-Kα radiation)

RESULTS AND DISCUSSIONS

Copper and SiC Powders characterization

Optical microscopy images of copper powders showed that particles had spherical shape with the mean particle size of copper changed from 5 to 50 µm with broad particle size distributions (Fig-3a). On the other hand, the SiC particles have sharp-angled spherical shape with the mean particle size changed from 40 to 100 µm with broad particle sizedistributions (Fig-3b). The particle shape and distribution are important parameters that affect a number of mechanical, electrical and physical properties of composites.

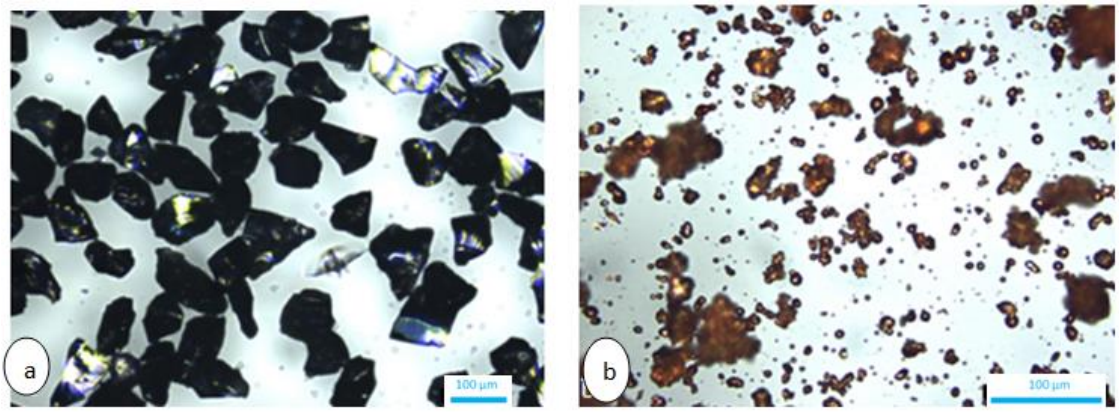

Fig-3: Optical microscopy image of as a received powder, (a) The SiC powder image (100x), (b) The copper powder image (200x)

He-gas pycnometer results of copper matrix and SiC reinforced phase were 8.93 g/cm^3 and 3.21 g/cm^3, respectively.

The phase analysis of copper powder and SiC powders were conducted by XRD technique. XRD paterns of SiC and Copper powders were given in Figure-4a and b respectively. The very narrow and sharp peaks in SiC and Copper powder X-ray diffraction patterns indicated that the main phase was SiC (Figure-4a) and Copper(Figure-4b) were crystalline. Small amount of Cu_2O phase is observed in pure copper powder due to oxidation of copper.

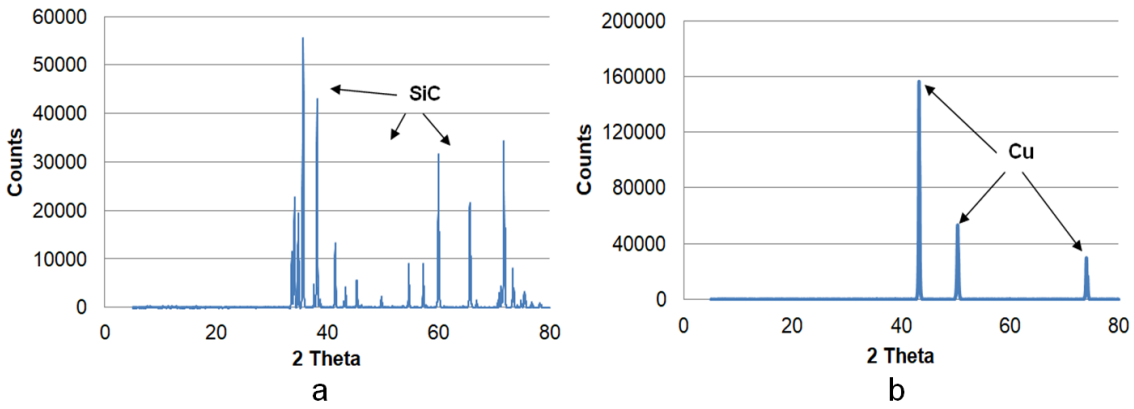

Fig-4: X-ray diffraction pattern of, a) SiC Powder, b) Copper Powder

Mineralogical Analysis of Composites

The phase analysis of samples were performed by XRD technique. XRD paterns of composite samples were given in Figure-4a and b. The very narrow and sharp peaks in SiC and Copper powder X-ray diffraction patterns indicated that the main phases are SiC and graphite(Figure-4a) and Copper (Figure-4b). Small amount of Cu_2O phase is observed in pure copper powder due to oxidation of copper.

The XRD pattern of the composite sample containing 0.5% SiC(S1) reinforcement was given in Figure-5a. The results showed that just coppper peaks available. This means that the amount of SiC reinforcement phase is below the detection limits of XRD device. In the same manner, the copper oxide phase peak was not detected. The pattern of the mineralogical analysis of the composite sample containing 1%SiC(S2) reinforcement was given in Figure-5b. The XRD were examined, peaks of Cu, SiC and CuO phases were determined. The pattern of the mineralogical analysis of the composite sample containing 2% SiC(S3) reinforcement was given in Figure-5c. When peaks were examined, peaks of Cu, SiC phases were detected.

The Cu_2O phase is derived from the oxidation of copper and is not desirable in contact materials. Environmental and service conditions cause the formation of this phase in contact samples with over time and lead to a decrease in contact performance [18].

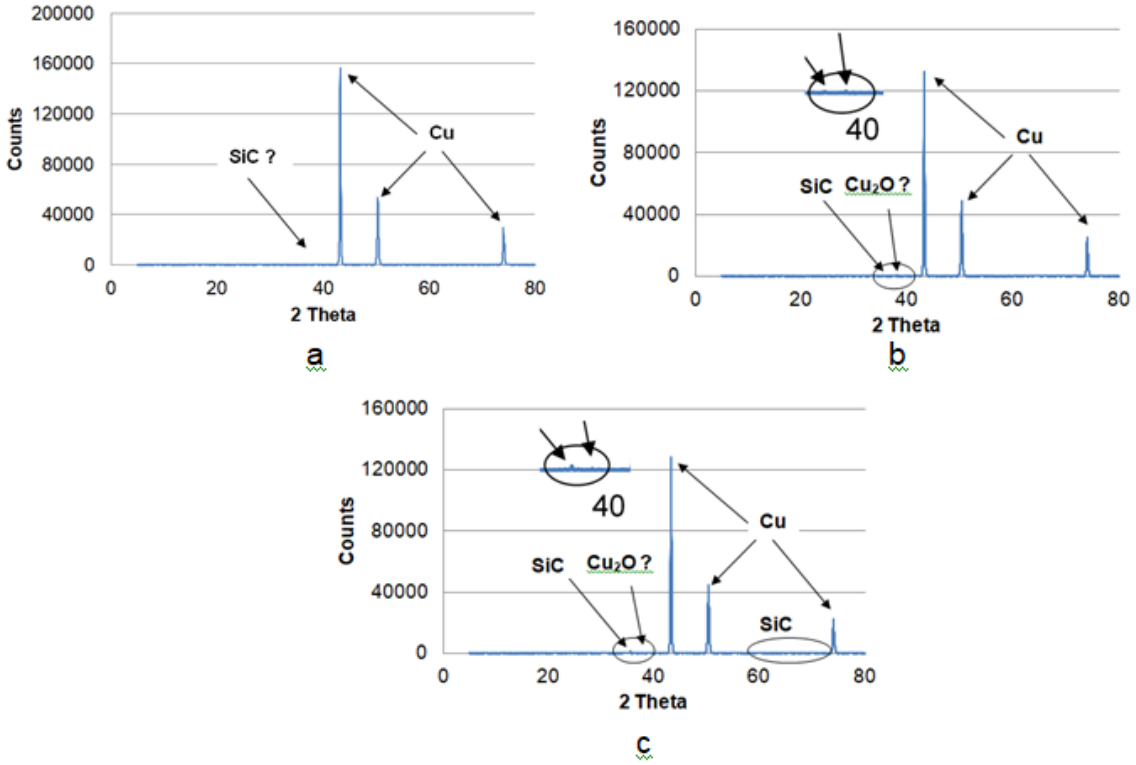

Fig-5: X-ray diffraction pattern of composite samples, a) S1, b) S2, c) S3

Mechanical, physical and electrical properties of composite contact materials

When the hardness of pure copper and 0.5%, 1% and 2% SiC reinforced copper matrix composites are examined, it is seen that the hardness value of reinforced composites increases compared to monolithic copper(Figure-6). The highest hardness value was obtained with S2. It has been determined that there is a decrease in the hardness value of S3 sample compared to S2. This can be resulted from low bulk density and weak matrix grain interface interaction.

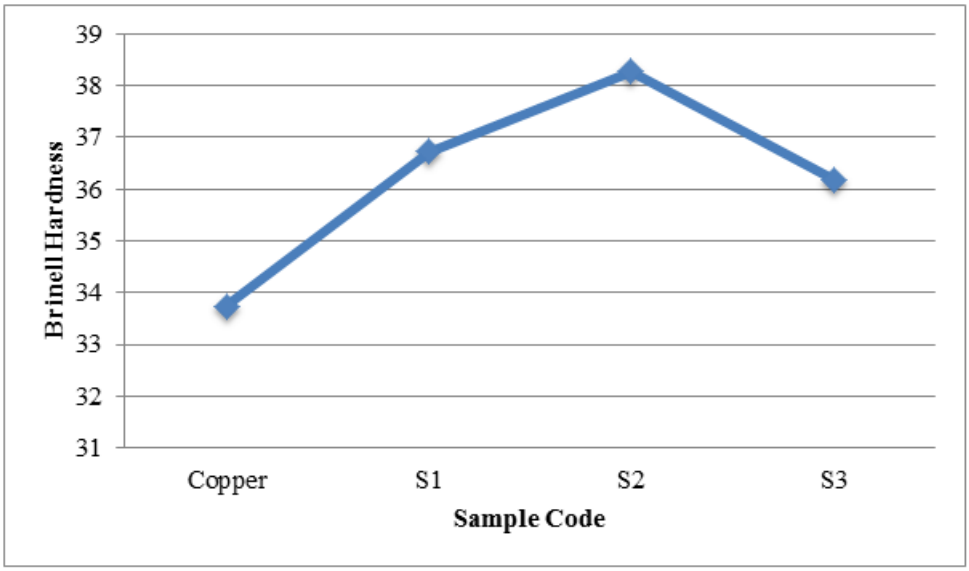

Fig-6: Brinell hardness of Cu-SiC composites

When the changes in bulk density values and bulk density amounts are examined, it is seen that the bulk density of the composite samples decreases with the increase of the amount of low density reinforcing phases (Figure-7). Even in pure copper there was a 4.3% decrease in bulk density after sintering. This indicates the presence of open and closed pores after sintering in the structure, which will adversely affect electrical and mechanical properties.

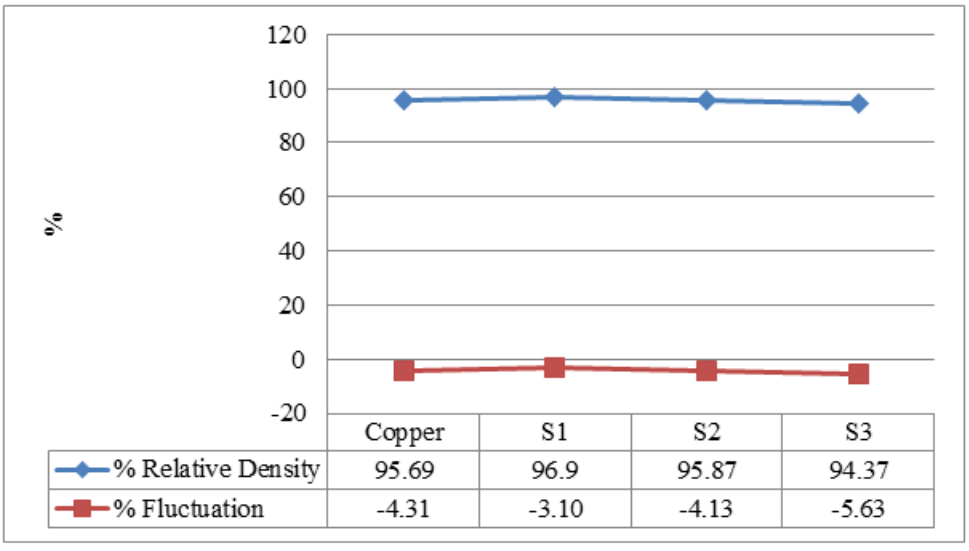

Fig-7: Bulk density and % differences (according to copper) of composite samples

When the electrical conductivity of pure copper and SiC reinforced composite specimens at different ratios and the% electrical conductivity change values according to pure copper are examined, it is seen that electrical conductivity value decreases with increasing amount of reinforcement and 67.9% IACS value can be reached even in pure copper(Figure-8).

The lowest electrical conductivity value was obtained at the highest amount of reinforcement. This is due to the low conductivity value of the added reinforcement phase and to the microstructural faults that the copper matrix structure causes together with the process conditions.

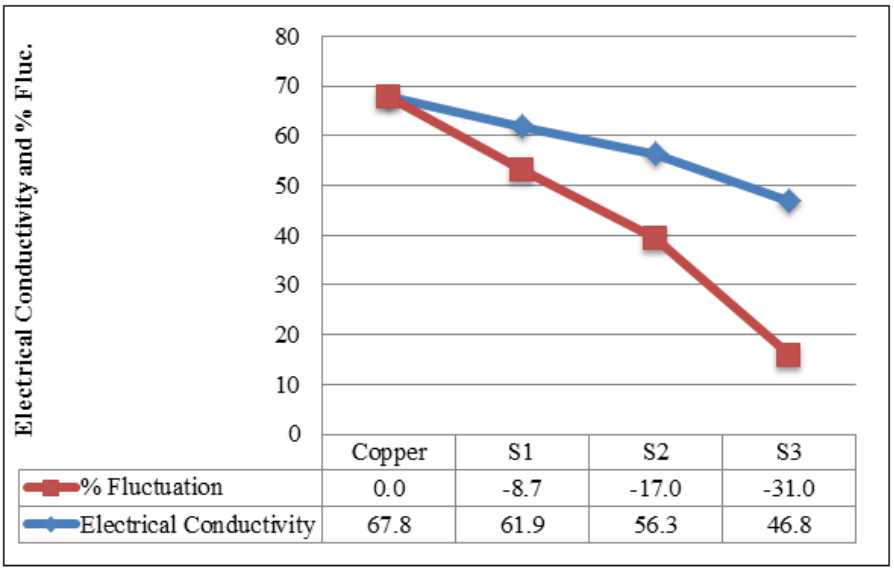

Fig-8: Electrical conductivity and % differences(according to copper) of composite samples

Kim *et al*., observed that with the increase in TiB2 content from 2.5 to 10 wt.% relative density decreased 95.5 to 93.2%. Hardness increased with the increase in TiB2 content but electrical conductivity worsens [19]. Zhou and co-workers studied Zr2Al3C4 reinforced Cu matrix composites and investigated its properties. The results showed that bulk density is almost similar with theoretical density when the reinforcement content 5vol. % and the value dramatically decreased. Brinell hardness increased with increasing Zr2Al3C4. By increasing Zr2Al3C4 electrical conductivity decreased and down to around 50% IACS with 20 vol. % reinforcement [20]. Shu and Tu studied microstructure and the thermal expansion characteristics of Cu-SiC composites. They observed that the bulk density of the Cu-SiC composites decreased when the content of SiC increased and as the particle size increased. When summarizing the finding in literature regarding the properties of Cu matrix composites, as increase in reinforcement content bulk density and electrical conductivity decrease, hardness increased. These results are coincided with the findings [21].

Microstructural characterization of composite contact materials

When optical microscope microstructure images of copper matrix composite specimens containing SiC reinforcements at different ratios are examined, it is seen that SiC grains are homogeneously dispersed in 0,5% SiC, 1% and 2% structure and not undergoing any agglomeration (Figure-9a,b,c,). Figure-9 shows that SiC particles vary in size from 10 to 70 µm and it is also seen that there are some voids originating from grains pull out at some points.

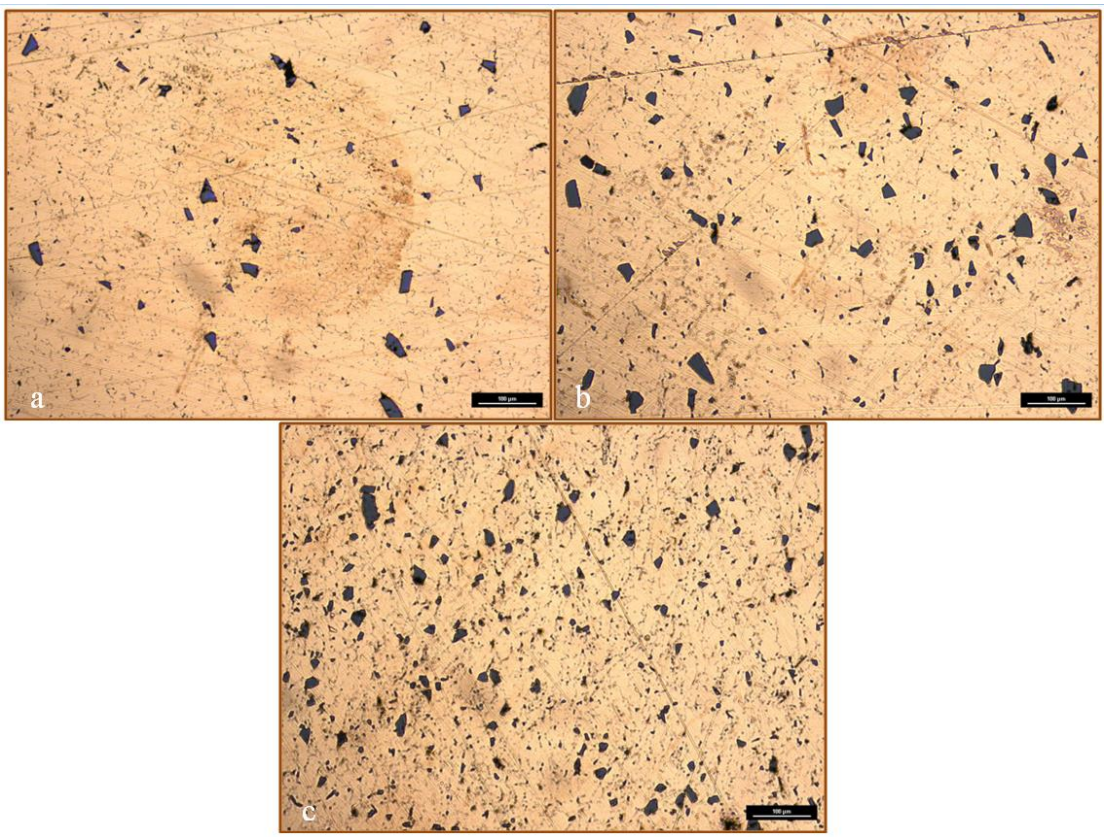

Fig-9: Optical microsscopy images of composite samples at 100x, a) S1, b) S2, c) S3

CONCLUSIONS

- The powder sizes of copper and SiC powders are 50-100 μm and 1-40 μm, respectively. The copper grains have a spherical structure, and the SiC has a spherical and sharp-edged structure.
- A small amount of graphite phase is found in the SiC powder.
- With increasing SiC reinforcements, the hardness values were found to be higher than the pure one.
- With increasing SiC reinforcements, the bulk density values decreased with the exception of S1, which was in line with the pure one. This is probably because S1 has a better packing density.
- With increasing SiC reinforcements, the electrical conductivity value was 32% lower than the IACS value of pure copper. This is probably due to the production process. For this reason the comparison was made with pure copper we prepared. it was determined that the decrease in conductivity with increasing reinforcement was ~ 9%, 17% and 31%, respectively in S1, S2, S3 codes.
- In future work it will be aimed to increase the bulk density values of copper contacts, to reduce the amount of process-induced impurities and to improve the sintering conditions and to obtain optimum conductivity and mechanical property values.

REFERENCES

1. Braunovic, M., Myshkin, N. K., & Konchits, V. V. (2017). *Electrical contacts: fundamentals, applications and technology*. CRC press.
2. http://www.pepbrainin.com/products-solutions/electrical-contacts/[10.12.2017]
3. Timsit, R. S. 2013). Electrical Contact Materials. InEncyclopedia of Tribology; (pp. 901-903). Springer US.
4. Leung, C. H. (2013). Contact materials, silver graphite, silver-refractory-graphite. In *Encyclopedia of Tribology* (pp. 468-470). Springer US.
5. Jeannot, D., Pinard, J., Ramoni, P., & Jost, E. M. (1994). Physical and chemical properties of metal oxide additions to Ag-SnO/sub 2/contact materials and predictions of electrical performance. *IEEE Transactions on Components, Packaging, and Manufacturing Technology: Part A*, *17*(1), 17-23.
6. Karadag, M., & Zeytin, S. (2017). B_4C Takviye Oraninin Bakir Matrisli Kompozitlerin Mekanik ve Elektriksel Özelliklerine Etkisi. Metal Dünyası.
7. Karadag, M., Acikbas, G., Cilliyuz, Y., & Acikbas, C. N. (2017). Bakir Matrisli Kompozit Özellikleri Üzerine TiC Takviye Miktarinin Etkisi, International Engineering Research Symposium, 11-13 Sept. 2017 Düzce, Turkey.(TiC)

8. Olgun, U., Gülfen, M., Göçmez, H., & Tuncer, M. (2017). Synthesis and room temperature coating of nano ZrB 2 on copper using mechanical roll-milling. Advanced Powder Technology.
9. Biyik, S., & Aydin, M. (2016). Investigation of the Effect of Different Current Loads on the Arc-Erosion Performance of Electrical Contacts. *Acta Physica Polonica, A.*, *129*(4).
10. Gök, M. G., & Kaplan, M. (2011). Toz Metalurjisi Yöntemiyle Elektrik Kontak Malzemesi Üretimi ve Kontak Performansının Araştırılması.
11. Efe, G. C., Altinsoy, I., Ipek, M., Zeytin, S., & Bindal, C. (2011). Some properties of Cu–SiC composites produced by powder metallurgy method. *Kovove Mater*, *49*(2), 131.
12. Akhtar, F., Askari, S. J., Shah, K. A., Du, X., & Guo, S. (2009). Microstructure, mechanical properties, electrical conductivity and wear behavior of high volume TiC reinforced Cu-matrix composites. *Materials characterization*, *60*(4), 327-336.
13. Güler, Ö., & Evin, E. (2009). The investigation of contact performance of oxide reinforced copper composite via mechanical alloying. *journal of materials processing technology*, *209*(3), 1286-1290.
14. Zhu, J., Liu, L., Zhao, H., Shen, B., & Hu, W. (2007). Microstructure and performance of electroformed Cu/nano-SiC composite. *Materials & design*, *28*(6), 1958-1962.
15. Xing, H., Cao, X., Hu, W., Zhao, L., & Zhang, J. (2005). Interfacial reactions in 3D-SiC network reinforced Cu-matrix composites prepared by squeeze casting. *Materials Letters*, *59*(12), 1563-1566.
16. Schubert, T., Brendel, A., Schmid, K., Koeck, T., Zieliński, W., Weißgärber, T., & Kieback, B. (2007). Interfacial design of Cu/SiC composites prepared by powder metallurgy for heat sink applications. *Composites Part A: Applied Science and Manufacturing*, *38*(12), 2398-2403.
17. Harris, B. (1999). Engineering composite materials. London: Institute of metarials.
18. Gupta, K. M., & Gupta, N. (2015). *Advanced electrical and electronics materials: processes and applications*. John Wiley & Sons. UK.
19. Kwon, D., Nguyen, T. D., Huynh, K. X., Choi, P., Chang, M., Yum, Y., ... & Kwon, Y. (2006). Mechanical, electrical and wear properties of Cu-TiB~ 2 nanocomposites fabricated by MA-SHS and SPS. *Journal of Ceramic Processing Research*, *7*(3), 275.
20. Zhang, J., He, L., & Zhou, Y. (2009). Highly conductive and strengthened copper matrix composite reinforced by Zr2Al3C4 particulates. *Scripta Materialia*, *60*(11), 976-979.
21. Shu, K. M., & Tu, G. C. (2003). The microstructure and the thermal expansion characteristics of Cu/SiCp composites. *Materials Science and Engineering: A*, *349*(1-2), 236-247.