



## The Role of Nano-SiC on Microstructure and Tribological Properties of SiC/Cu Nano-Composite

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### Authors' contributions

*This work was carried out in collaboration among all authors. Author MAM designed the study, performed the analyses, wrote the protocol and wrote the first draft of the manuscript. Authors MMS, MG and IGEB managed the analyses of the study. All authors read and approved the final manuscript.*

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### ABSTRACT

The present study has investigated the role of nano-SiC on microstructure and tribological properties of SiC/Cu nano-composite. The nano-composite powders have been cold compacted under a constant pressure of 480 MPa and sintered at 860<sup>o</sup> C under argon gas for 2 h. SEM-EDS and XRD diffraction were performed for microstructure examinations. Pin-on-disk experiments were carried out under wet conditions (3.5 wt. % NaCl solution). All samples have been investigated against abrasives of different sizes (from 7, 13, 20 and 26 μm), at different applied loads (10, 15, 20 and 25 N), and sliding speed (0.25, 0.5, 0.75 and 1.0 m/s). The results revealed that the grain structure of the copper matrix was reduced with increasing SiC nano-particles. Furthermore, it was found that the wet wear resistance was improved as a function of nano-SiC content.

*Keywords: Powder metallurgy; composites; grain size; wet wear resistance.*

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## 1. INTRODUCTION

Copper is one of the most common metals used for engineering applications owing to excellent electrical and thermal conductivity, good ductility and corrosion resistance, [1-3]. However, the low mechanical strength and wear resistance of pure Cu is a serious problem limiting copper to be used in many fields [4]. Addition of ceramic particles to copper matrix could increase the strength, hardness, and the wear resistance of the copper matrix [5]. The uses of metal matrix composites in engineering applications such as electrical sliding contact are in continuous growing, as high thermal /electrical conductivity and good wear resistance are required [6]. SiC particles have been commonly chosen as a reinforcement material owing to its low cost, availability, high strength and high wear resistance. Furthermore, SiC particles do not react with the Cu-matrix at high temperatures to form new phases [7,8].

The common techniques used for producing Cu matrix composites are powder metallurgy and casting [9]. Powder metallurgy route is preferred more than casting due to low cost, good wettability and low agglomeration [7,9]. Efe et al. [10] found that the SiC content effects on the physical and mechanical properties of SiC/Cu composites. It was noted that the hardness increased while the relative density and electrical conductivity of composite decreased with growing the SiC content. Prosviryakov [11] reported that increasing SiC content above 25 wt. %, the hardness decreases due to the increase of the porosity and reducing the microstructural homogeneity of SiC/Cu composites. Akbarpour et al. [12] documented that the size of SiC particles effects on the

physical and mechanical properties of SiC/Cu composites. It was found that hybrid particles (micro and nano particles) exhibited a higher wear resistance and improved the compressive strength of SiC/Cu composites in comparison to the micro-composite. The effect of nano SiC particles with high volume fraction on the physical and tribological properties of SiC/Cu composite fabricated by powder technique has attracted many authors for different applications [2,11]. Therefore, a systematic research has been directed on fabrication of nano-Cu with different volume fractions of nano-SiC ranged from 5 to 20 nano-SiC (vol. %) and investigation of their effects on microstructure, dislocation density and tribological properties of SiC/Cu nano-composite in wet conditions (3.5 wt. % NaCl solution).

## 2. MATERIALS AND METHODS

### 2.1 Materials

SiC and Cu nano powders with average particle size of 40 and 50 nano respectively were used in this study. Fig. 1 shows the TEM of the nano powder materials. The xSiC/Cu nano-composites were fabricated by powder metallurgy (x=5, 10, 15 and 20 vol%). The nano Cu and SiC particles were mixed together using a mixer with 10 cm diameter and speed of 950 rpm for 3 h to obtain composites with uniform distribution of nano-SiC particles into the matrix. The nano Cu and SiC/Cu nano-composites powders were cold compacted using universal testing machine. A constant pressure of 480 MPa was applied on a disc steel die having a diameter of 12 mm and a thickness of 10 mm. The green compacted samples were sintered in electric tube furnace at 850°C in presence of argon gas for 2 h.

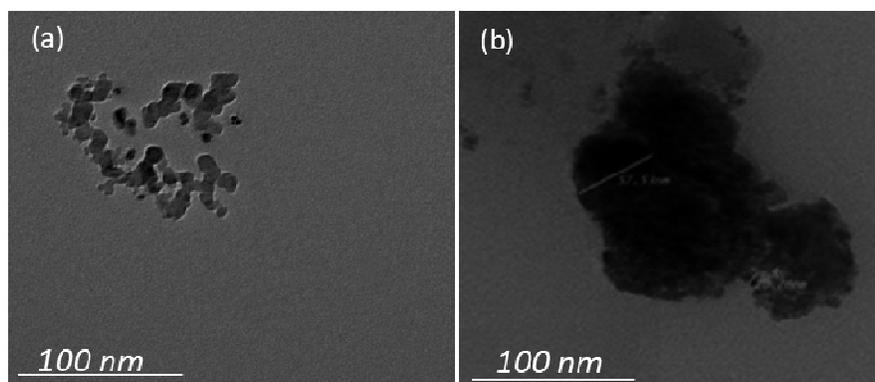
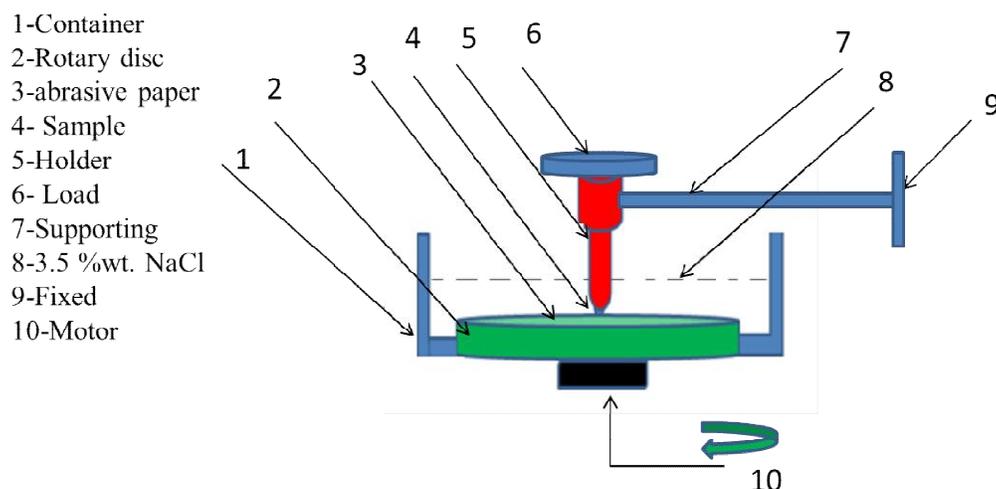


Fig. 1. TEM image of nano-SiC (a) and nano-Cu (b) powders



**Fig. 2. A schematic sketch of wet pin on the disc**

## 2.2 Microstructural Evaluation

The microstructure of Cu and SiC/Cu nano-composites was determined using scanning electron microscope (SEM), model JEOL JSM-6330F at voltage of 30 keV. All specimens were prepared by grinding with SiC paper having grit size of 360, 600, 800, 1000, 1200 and 1500. After that, these samples were polished using 6, 3 and 1  $\mu\text{m}$  diamond paste. The surfaces of samples were cleaned using acetone and dried in air. Finally, the samples were etched in solution of 5g FeCl<sub>3</sub>+25 mL HCl+50 mL H<sub>2</sub>O.

## 2.3 XRD

X-ray diffraction analysis was performed using Philips Machine for determining the different phases and the grain size of Cu and SiC/Cu nano-composite. A monochromatic Cu-K radiation with  $\lambda = 0.154 \text{ nm}$  has been used. The scanning range was 5–90 ( $2\theta$ ) with a step size of 0.01° ( $2\theta$ )/Sec.

## 2.4 Hardness

The hardness of Cu and SiC/Cu nano-composites was measured by Vicker hardness tester using a load of 5 kg. The average hardness value of 10 indentations was reported for each sample.

## 2.5 Wet Abrasive Wear Testing

The wet abrasive wear tests were carried out using a pin-on-disc machine (Fig. 2) in sea water

environment. The speed varied from 0.25, 0.5, 0.75 and 1.0 m/s, the applied loads were in the range of 10, 15, 20 and 25 N at a fixed time of 30 minutes. The load was applied on the specimen through a cantilever and the specimen was in contact with the rotating disc having a diameter of 140 mm. the size of abrasive material varied from 7, 13, 20 and 26  $\mu\text{m}$  fixed on an aluminum wheel covered with rubber.

The specimens after each test were dried, cleaned with a soft brush and weighed with a micro-balance. The abrasion wear rates were calculated using Archard equation [13]:

$$\Delta V = K \frac{PL}{H} \quad (1)$$

where ( $\Delta V$ ) is loss volume during sliding wet wear distance (L) under applied normal load (P), K and H are dimensionless wear coefficient and hardness of material, respectively.

Three separate experiments were carried out for each test to ensure the reproducibility of results. The standard deviation values were calculated to assess the statistical error for all tests.

## 3. RESULTS AND DISCUSSION

### 3.1 Microstructure

Fig. 3 shows the SEM photographs of Cu and SiC/Cu nano-composites with different SiC contents sintered at 860°C. It can be seen that the nano-SiC particles are homogeneously dispersed inside the matrix. Increasing the

addition of SiC particles, the SiC particles move and concentrate at the grain boundaries, forming a homogenous network and uniformly dispersed inside the matrix as well. Like this behavior was obtained by Efe, et al. [10]. Moreover, Fig. 3 shows that the grain size of Cu obviously is refined with increasing SiC content. This is attributed to the pinning effect of SiC that restricts the grains growth of the matrix.

### 3.2 XRD Analysis

The XRD of nano Cu/SiC(p) composite with different SiC contents is shown in Fig. 4.

According to the JCPDS X-ray diffraction files, the reflection planes of (111), (200) and (220), assuring the formation of Cu face center cubic. The reflection planes of (100), (002), (101), (102), (110), confirming the formation of hexagonal SiC. On the other hand, Fig. 4 shows that increasing SiC particles, the intensity of Cu peaks are reduced. The reducing in intensity according to Akbarpour et al. [12] is attributed to the difference in thermal expansion between Cu matrix and SiC particles, leading to formation of lattice micro-strain in the matrix. Also the behavior can be attributed to the decreasing in grain size of the matrix.

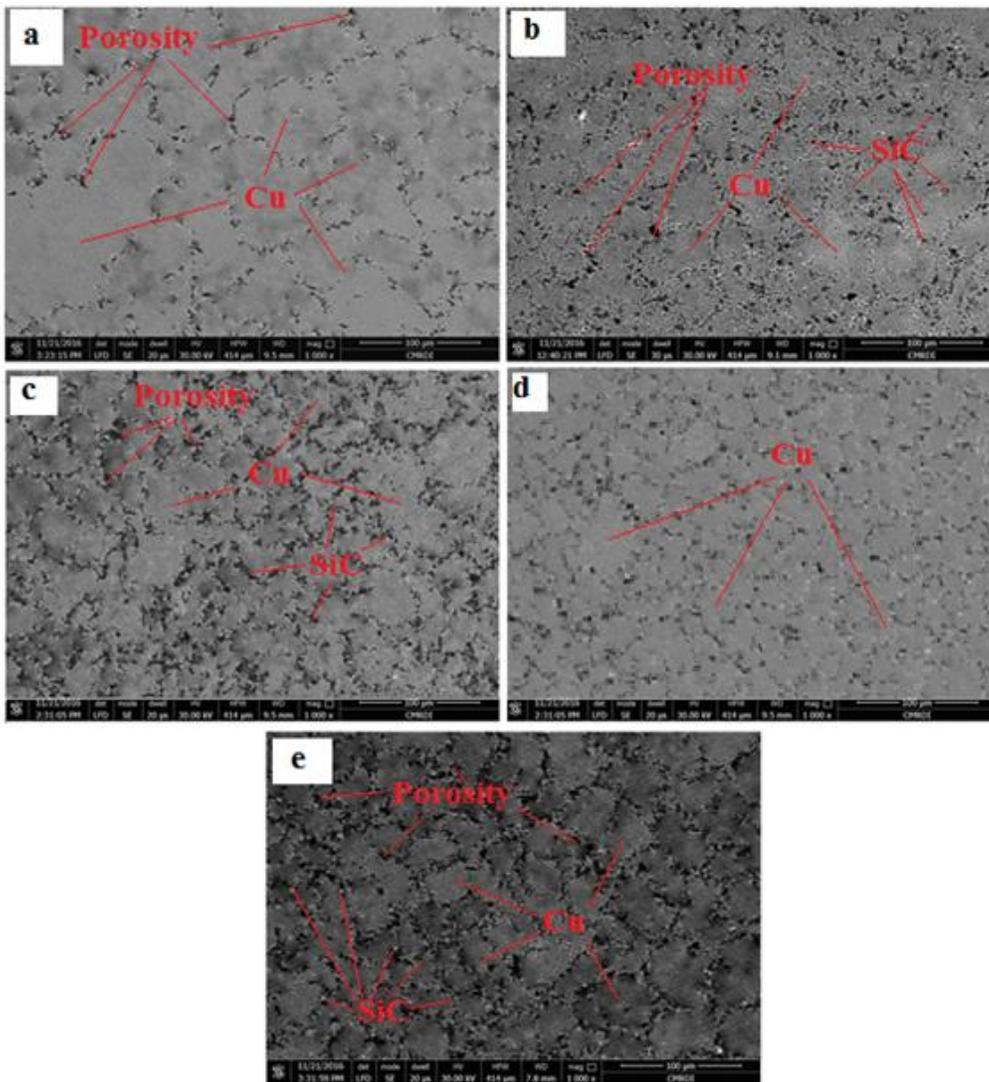
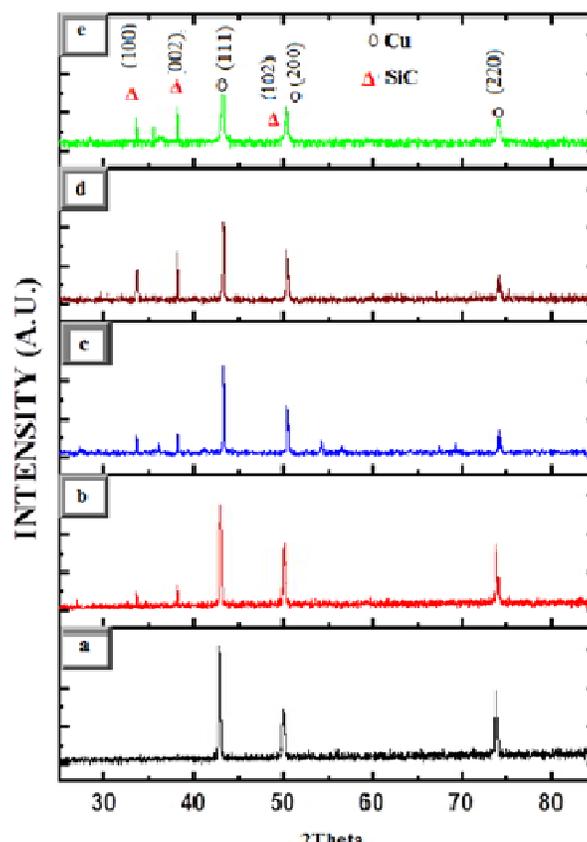


Fig. 3. Microstructure of SiC/Cu nano-composites with different SiC contents sin-tered at 860<sup>0</sup> C. (a) 0.0 vol. % SiC, (b) 5 vol. % SiC, (c) 10 vol. % SiC, (d) 15vol. % SiC and (e) 20 vol. % SiC



**Fig. 4. The XRD of SiC/Cu nano-composites with different SiC contents sintered at 860°C. (a) 0.0 vol. % SiC, (b) 5 vol. % SiC, (c) 10 vol. % SiC, (d) 15 vol. % SiC and (e) 20 vol. % SiC**

### 3.3 Hardness Measurements

The hardness value of nano-Cu alloy as a function of nano-SiC content is shown also in Fig. 5. It is clear that all Cu-SiC nanocomposite samples exhibit higher hardness comparing to Cu sample. Similar results have been documented by different authors using micron and nano-particles [5,10]. Shabani et al. [9] obtained more than 2 times increase in the hardness of Cu by addition of 60% vol SiC micron particles. Alizadeh and Nassaj [14] found that addition of 4% B<sub>4</sub>C (Wt.%) nanoparticles inside the Al-2%Cu alloy increases the hardness about four times. The behavior is due to the existence of nano particles inside the matrix which work as a load-supporting component in the nanocomposites and hence increase the hardness [15]. However, the improvement in the hardness depends on the SiC content. It can be revealed that the hardness increases by 11, 24, 40 and 53 % with increasing nano-SiC content to 5, 10, 15 and 20 vol%, respectively. The

behavior is attributed to the differential thermal contraction [16] at the interface of SiC-Cu. This difference in the thermal expansion coefficient leads to creating a strain field which increases the dislocations and hence decreasing the plastic deformation of the composite. Furthermore, the uniform distribution of the SiC into the matrix increases the strengthening. According to Gül et al. [15] incorporating fine particles less than 1  $\mu\text{m}$  in the matrix leads to carrying the load by the matrix and hindering the dislocation motion by the fine particles. Therefore, a further improvement in hardness is obtained.

### 3.4 Tribological Behavior

#### 3.4.1 Effect of sliding speed

The effect of sliding speed on the wet wear rate of SiC/Cu nanocomposite with different SiC content is shown in Fig. 6. It is clear that increasing the sliding speed from 0.25 to 1.0 m/s, the wear rate increases due to growing the plastic deformation by increasing the sliding

speed. However, the results presented in Fig. 6 shows that the wear rate decreases with increasing nano-SiC content to 20 vol %. The behavior is attributed to nano-SiC particles which work as a load carrier and protect the Cu-matrix from damage. Additionally Fig. 6 indicates that the gradient of increasing the wear slows down with increasing the sliding speeds for SiC/Cu nanocomposite. The behavior is attributed to the plastic deformation which forms a tribo-layer

containing silicon oxide. This layer acts as a self-lubricant and hence protects the matrix of SiC/Cu nanocomposite from further damage. On the other hand, Fig. 6 indicates that the wear rate of the base Cu sample grows linearly with increasing the sliding velocity because the interface between the surface of sample and abrasive material does not contain like this layer as well as the base sample has low hardness value compared with SiC/Cu nanocomposite.

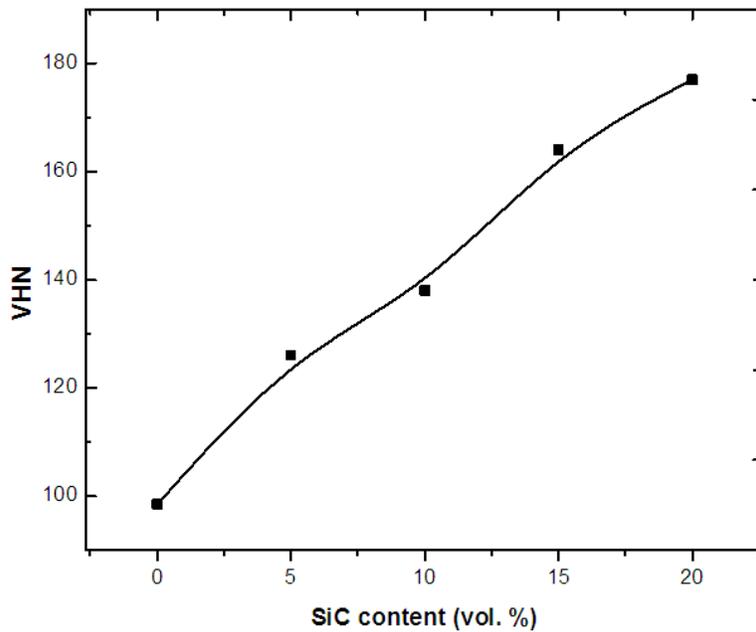


Fig. 5. Effect of SiC content on the hardness of Cu/SiC nano-composites

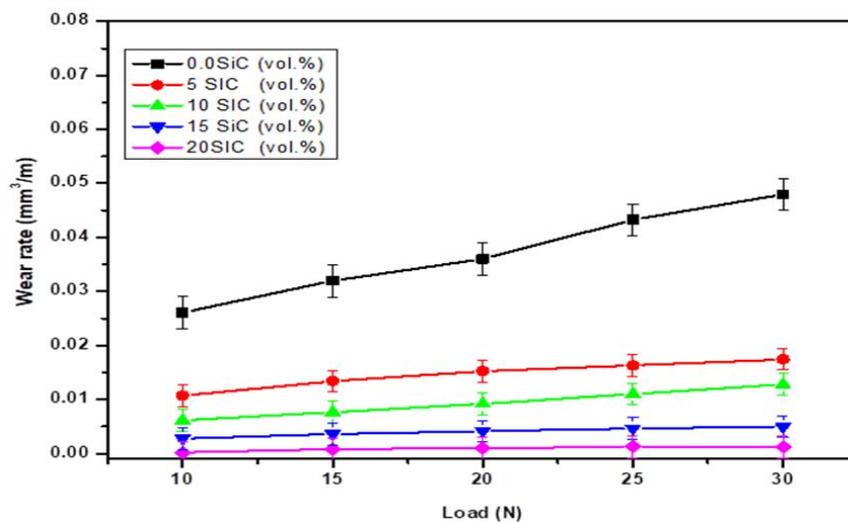


Fig. 6. Effect of sliding speed on the wet wear rate of SiC/Cu nano-composite

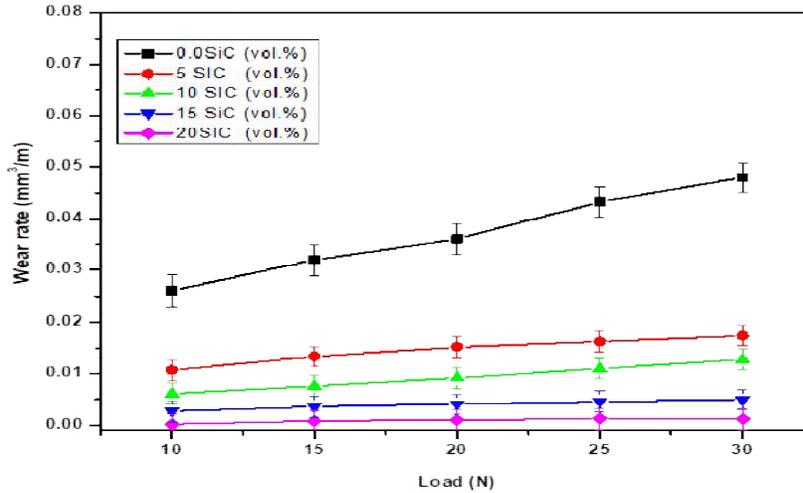


Fig. 7. Effect of applied load on the wear rate of SiC/Cu nano-composite

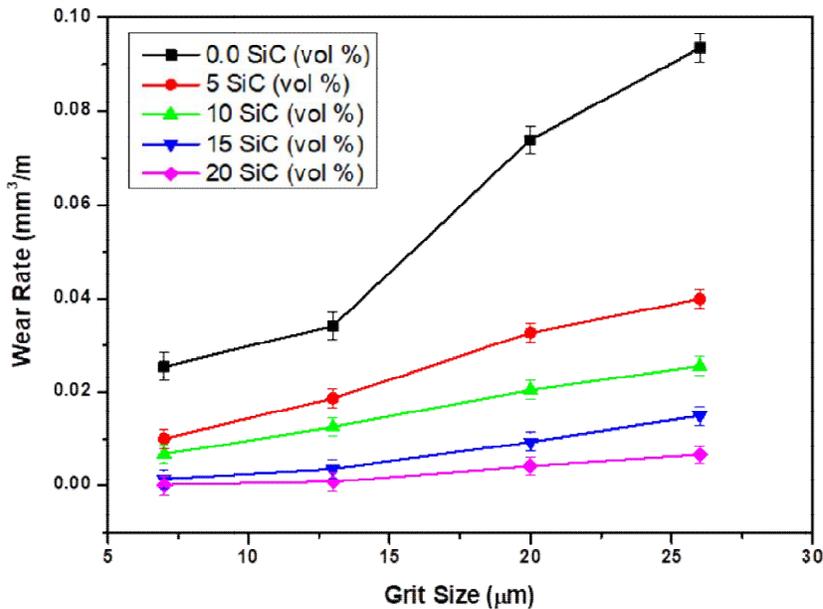


Fig. 8. Effect of abrasive particle size on the wear rate of SiC/Cu nano-composite

### 3.4.2 Effect of load

The effect of load on the wear rate of SiC/Cu nano-composite with different percentages of SiC is shown in Fig. 7. It is clear that the wear rate increases with increasing the applied load for all percentages. However, the wear resistance at all percentages increases when compared with the base Cu.

This enhancement in wear resistance is attributed to presence of hard SiC nano-particles in the Cu-matrix. Furthermore, Fig. 7 illustrates

that the wear resistance increases with an increase in volume fraction of nano-SiC. This behavior may be due to growing the load bearing capacity of nano-SiC particles with the increase in the volume fraction of the reinforcement and increasing the hardness according to Archard law [13].

### 3.4.3 Effect of abrasive particle size

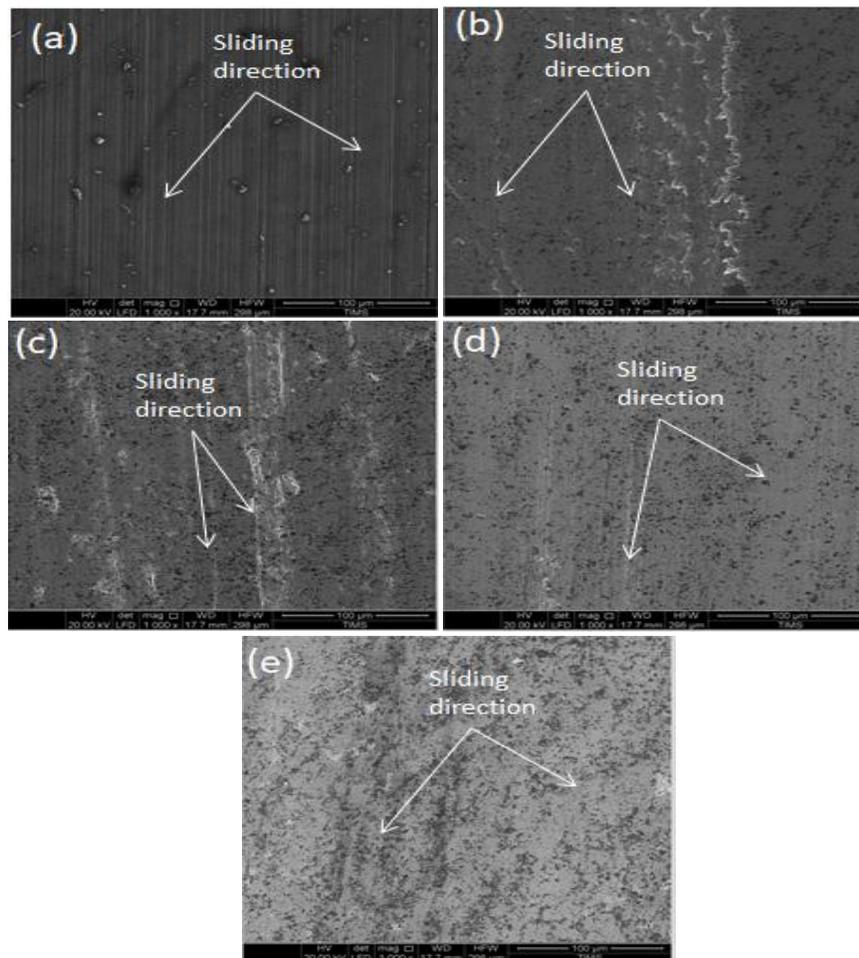
Fig. 8 indicates the influence of abrasive particle size on the wear rate of Cu-SiC nano-composite with different volume fraction of SiC at a load

of 15 N and a sliding speed of 0.5 m/s. It is clear that the wear rate increase with growing the abrasive particle size for all samples. This behavior is owing to the plastic deformation which increase significantly when the wear is occurred under coarser abrasive particle size [12]. However, the results show that the wear rate more quickly increases with growing abrasive particle size for the base Cu matrix while the gradient of increasing slowdowns with increasing SiC percentage. These results are also in a good agreement with hardness values.

### 3.5 Worn Surface Morphological Analysis of the Surface after Wear Test

SEM micrographs have been taken for worn surfaces of the investigated samples at applied

load of 15 N, sliding velocity of 0.5 m/s and abrasive particle size of 13  $\mu\text{m}$ , as shown in Fig 9. It can be clearly seen that the nano-Cu sample indicates continuous parallel grooves (Fig. 9 (a)). This behavior means that the dominant wear mechanism in nano-Cu sample belongs to the abrasive wear mechanism. Fig. 9 (a) shows also that the grooves are wider and deeper suggesting an augmented metallic contact and a higher co-efficient of friction value. Fig 9 (b & c) shows that SiC/Cu nano-composites with 5 and 10 SiC (vol %) suffer from plastic deformation and adhesive wear in several places. In-cresing the SiC to 15 and 20 SiC (vol %), both the plastic deformation and adhesive wear decreased greatly. This behavior may be attributed to many reasons: firstly, a tribo film covers the entire surface and therefore, it



**Fig. 9. SEM micrographs of worn surfaces of of SiC/Cu nano-composites with dif-ferent SiC contents sintered at 860°C. (a) 0.0 vol. % SiC, (b) 5 vol. % SiC, (c) 10 vol. % SiC, (d) 15 vol. % SiC and (e) 20 vol. % SiC**

decreases the adhesive wear. Secondly, the uniform distribution of nano-SiC in the matrix (see Fig. 3). These two factors decrease the adhesive wear.

#### 4. CONCLUSIONS

SiC/Cu nano-composites with the different volume fractions have been successfully produced using powder technique. The microstructure and tribological behavior have been investigated and the conclusions are as follows:

1. The grain structure of the copper matrix was refined with increasing SiC nano-particles owing to Zener pinning effect.
2. The wet wear resistance was improved as a function of nano-SiC content.
3. The dominant wear mechanism in nano-Cu sample was the abrasive wear mechanism while the adhesive wear mechanism was the predominant in SiC/Cu nano-composites with 5 and 10 SiC (vol.%) which in turn reduced greatly with increasing SiC to 15 and 20 (vol.%) due to a uniform distribution of nano-SiC and forming tribo film covered the entire surface.

#### COMPETING INTERESTS

Authors have declared that no competing interests exist.

#### REFERENCES

1. Zohdy KM, Sadawy MM, Ghanem M. Corrosion behavior of leaded-bronze alloys in sea water. *Materials Chemistry and Physics*. 2014;147:878-883.
2. Ming H, Yunlong Z, Lili T, Lin S, Jing G, Peiling D. Surface modifying of SiC particles and performance analysis of SiCp/Cu composites, *Applied Surface Science*. 2015;332:720–725.
3. Sadawy MM, Ghanem M. Grain refinement of bronze alloy by equal-channel angular pressing (ECAP) and its effect on corrosion behavior, *Defence Technology*. 2016;12:316–323.
4. Alaneme KK, Odoni BU. Mechanical properties, wear and corrosion behavior of copper matrix composites reinforced with steel machining chips, *Engineering Science and Technology, an International Journal*. 2016;19:1593–1599.
5. El-Kady O, Fathy A. Effect of SiC particle size on the physical and mechanical properties of extruded Al matrix nanocomposites, *Materials and Design*. 2014;54:348–353.
6. Tjong SC, Lau KC. Tribological behaviour of SiC particle-reinforced copper matrix composites. *Materials Letters*. 2000;43:274–280.
7. Abd-Elmonem M., Metwally MM, Sadawy M, Ghanem I, EL-Batanony G. Effect of SiC(p) content on the corrosion behavior of Nano SiC(p)/Cu Composites. *The Egyptian International Journal of Engineering Sciences and Technology*. 2018;26:22–28.
8. Khadem SA, Nategh S, Yoozbashizadeh H. Structural and morphological evaluation of Al-5vol. % SiC nanocomposite powder produced by mechanical milling. *Journal of Alloys and Compounds*. 2011;509:2221–2226.
9. Shabani M, Paydar MH, Zamiri R, Goodarzi M, Moshksar MM. Microstructural and sliding wear behavior of SiC-particle reinforced copper matrix composites fabricated by sintering and sinter-forging processes, *Journal of Material Research and Technology*. 2016;5(1):5–12.
10. Celebi Efe G, Yener T, Altinsoy I. Ipek M, Zeytin S, Bindal C. The effect of sintering temperature on some properties of Cu–SiC composite. *Journal of Alloys and Compounds*. 2011;509:6036–6042.
11. Prosviryakov AS. SiC content effect on the properties of Cu–SiC composites produced by mechanical alloying. *Journal of Alloys and Compounds*. 2015;632:707–710.
12. Akbarpour MR, Mousa Mirabad H, Alipour S. Microstructural and mechanical characteristics of hybrid SiC/Cu composites with nano- and micro-sized SiC particles, *Ceramics International*. 2019;45:3276–3283.
13. Agunsoyey JO, Ayen AA. Effect of heat treatment on the abrasive wear behavior of high chromium iron under dry sliding condition, *Tribology in Industry*. 2012;34(2):82-91.
14. Alizadeh A, Taheri-nassaj E. Mechanical properties and wear behavior of Al–2 wt.% Cu alloy composites reinforced by B4C nanoparticles and fabricated by mechanical milling and hot extrusion. *Materials Characterization*. 2012;67:119–128.

15. Gül H, Alp A, Akbulu H. Preparation and characterization of bronze/SiCp composites produced via current activated sintering method. *Materials Science in Semiconductor Processing*. 2015;38:413–419.
16. Abd-Elmonem Metwally M, Fattah HA, Ghanem M, EL-Batanony IG. Effect of SiC content on dry sliding wear behavior of nanosized SiC(P)/Cu composites. 2018; 13(49):1260-1267.

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