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EFFECT OF SIC CONTENT ON DRY SLIDING WEAR BEHAVIOR OF NANOSIZED $SIC_{(P)}$/CU COMPOSITES

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ABSTRACT
In this study, the wear behavior of nano Cu and $SiC_{(p)}$/Cu composites powders with different weight percentages of SiC particles was investigated under pin on disc equipment at 8–20 N load and 0.83-3.25 sliding speed. The composites were produced via powder metallurgy (PM) route. The results revealed that the wear resistance of $SiC_{(p)}$/Cu composites increased with increasing SiC content to 20 vol %. Beyond this value the wear resistance decreased but still more than the unreinforced sample. Moreover, the investigation on worn surfaces was done to understand wear mechanism.

Keywords: Cu alloys, Composite materials, SiC , Wear, Worn morphology

1. INTRODUCTIONS
Many applications within the electronic and manufacturing industries require components to be made with materials possessing high electrical and thermal conductivity, high corrosion and wear resistance as well as good mechanical properties. This is in addition to maintaining microstructural stability and high temperature resistance [1-3].At present, copper alloys became one of the major groups of commercial metals and they were widely used because of their excellent electrical and thermal conductivity, outstanding resistance to corrosion and good strength and fatigue resistance [3]. Specifically, copper matrix composites have been used for the design of radiators, electronic contact devices, casing of jet engines and in recent years as substitute materials for the design of cylinder heads, liners and brake discolor in automotive industry [2]. The development of copper matrix composites has relied on the use of ceramic reinforcements with alumina and silicon carbide the most commonly utilized. The choice of both ceramic materials is largely influenced by their high hardness and wear resistances, refractory nature, and relative availability and cost advantage [4].Powder metallurgy is considered as an efficient technique in producing metal-matrix composites. An important advantage of this method is its low processing temperature compared to melting techniques. In addition, powder metallurgy allows good distribution of the reinforcing particles in the matrix. Another advantage of powder metallurgy technique is its ability to manufacture near net shape product with low cost [5-8].
The abrasive wear of materials is of technical and economic importance . It has been already recognized as one of the most potentially serious tribological problems facing the operators of many types of plants and machinery; several industrial surveys have indicated that wear by abrasion can be responsible for more than 50 % of unscheduled machine and plant stoppages [9].

Therefore, in the present work, this paper focused on the effect of ultra-fine SiC particles on wear behavior of Cu metal matrix composite prepared by powder metallurgy technique.

2. Materials and experimental methods

2.1. Materials

Cu powder alloy of 80 nano particle size reinforced with silicon carbide particles with average particle size of 90 nano (Fig. 1) were fabricated by powder metallurgy. Three different volume percentages (10 - 30 vol. %) of reinforcement particles were used. The powder was weighed to the required percentages using an electronic balance with an accuracy ± 0.01 mg. The powder mixtures were vigorously shaken in a completely sealed container to obtain uniform dispersion of reinforcement particles within matrix material particles. Then, the powders mixture was pressed in a high carbon steel compaction die with a diameter of 10 mm and a length of 2 cm. Universal testing machine at pressure of 400 MPa was used. The green compacts were placed in oxygen free closed die and sintered at 850 ^{0}C for 2 hours.

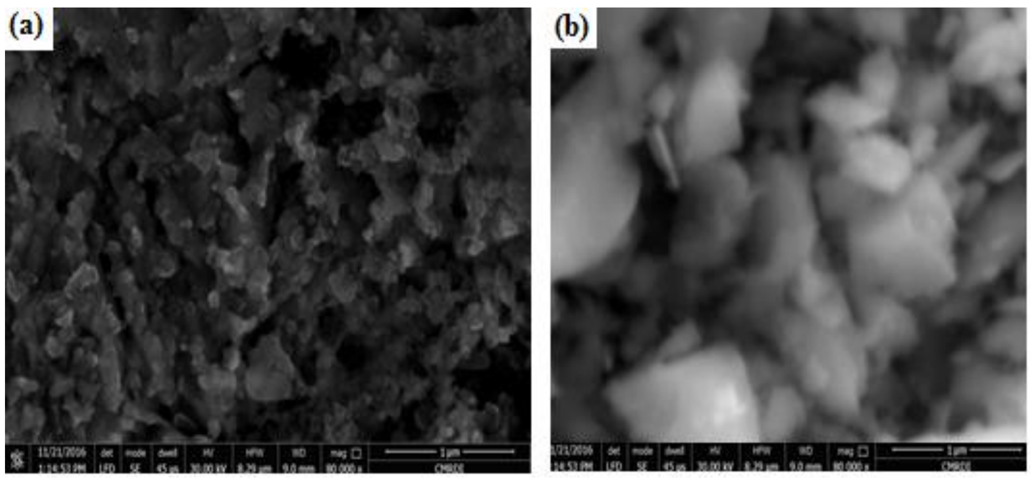

Fig.1. SEM photomicrograph of morphology of (a) Cu and (b) SiC powders

2.2. Microstructural evaluation

The microstructure of Cu alloy reinforced with silicon carbide particles were analyzed by scanning electron microscope (SEM), model JEOL JSM-6330F at voltage of 20 keV. All samples were prepared by grinding with 350, 600,1000 and 1200 grid SiC paper respectively. After that, these samples were polished using 6,3 and 1μ m diamond paste. The surfaces of samples were cleaned using acetone and dried in air. After that all heat treated samples at different conditions were etched in solution of 5g $FeC1_3$+25 mL HC1+50 mL H_20.

2.3. Hardness

The hardness of the heat treated alloy at different conditions was measured in a Vickers hardness tester using a load of 5 kg. The samples were polished as mentioned before. In each sample, 10 indentations were taken and the average hardness value along with standard deviations was reported.

2.4. Sliding Wear Test

A pin-on-disc wear testing machnie was used in carrying out wear tests, varying the speed 0.83, 1.67, 2.51 and 3.25 m/s, and the applied loads of 8, 12, 15, and 20 N, at a fixed time limit of 10 minutes. Fig.3 shows the schematic sketch of wear testing of a sample pin in front view.

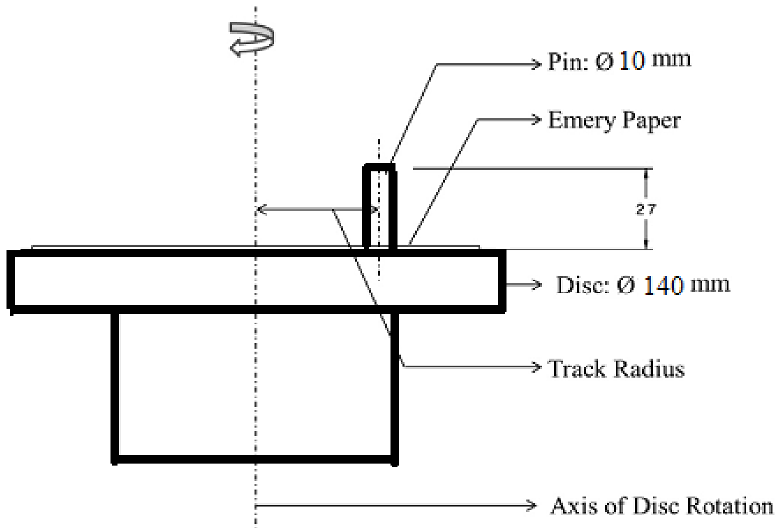

Fig. 3. A schematic sketch of pin over the disc (elevation view)

In order to ensure that there is an effective abrasion of the surface of the specimens, each of the specimens was subjected to sliding on emery paper (600 grit size) fixed on an aluminum wheel on the pin-on-disc machine. During sliding, the load was applied on the specimen through a cantilever mechanism and the specimen brought in intimated contact with a rotating disc with a diameter of 140 mm.

The specimens were cleaned with a soft brush after each test and they weighed with a micro-balance. Wear rates were obtained from the volume lost after sliding wear tests and the use of Archard equation [10]:

$$Q = \frac{KW}{H} \qquad \textbf{(1)}$$

where Q is the volume loss of the abraded material per unit sliding distance, K is the wear coefficient, W is the applied normal load and H is the hardness of the abraded material.

Finally, worn surfaces were observed in optical microscope to determine the wear mechanism present in the tribosystem.

2.3. Temperature measurement

Temperature measurements of wear pin during the sliding were carried out with chromel–alumel thermocouple. Thermocouples were placed into a hole of 2 mm diameter at 1.5 mm away from sliding surface drilled up at axis of cylindrical pin. Temperature was recorded with help of digital temperature indicator after 60 min of sliding.

3. Results and Discussions

3.1. Microstructure evolution

Fig. 4 shows the SEM photographs of SiC_p/Cu composites with different SiC contents. The microstructure shows color contrast (dark and bright fields) in the copper matrix with visible dispersion of the reinforcing particulates (Fig. 4(a-d)). The light phase is the copper matrix while the dark phase shows SiC particles. It can be observed that The SiC particles were uniformly distributed inside the matrix and around copper grains when the SiC content was 20%, while SiC particles became aggregate as SiC content reached at 30%.

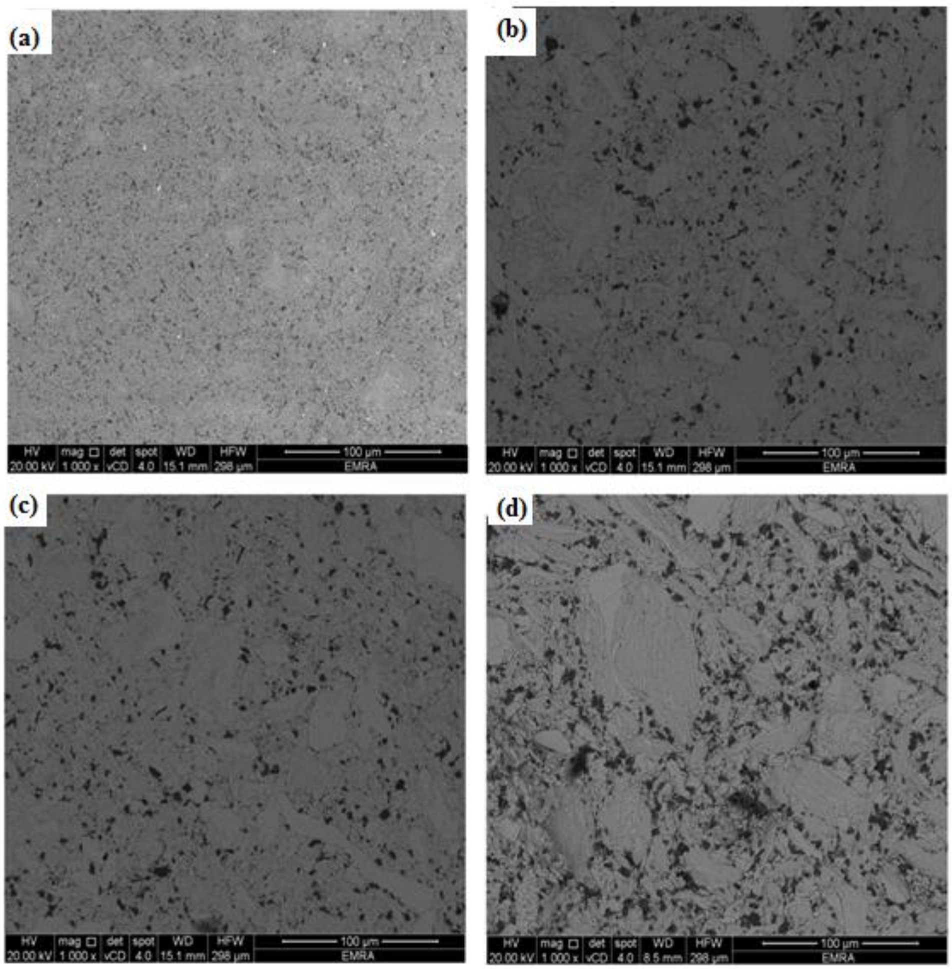

Fig. 4. Microstructure of Cu/$SiC_{(p)}$ composite with different SiC contents sintered at 850 ^{o}C . (a) 0.0 vol. % $SiC_{(p)}$, (b) 10 vol. % $SiC_{(p)}$, (c) 20 vol. % $SiC_{(p)}$ and (d) 30 vol. % $SiC_{(p)}$,

3.2 Hardness measurements

The variation of Vickers hardness of Cu alloy as a function of SiC content is shown in Fig. 5 It is obvious that with increasing SiC content the hardness of Cu alloy increases.
Increase in hardness could be due to the effects of differences in thermal expansions between the SiC particles and the copper alloy. Thermal expansion coefficient differences would lead to the creation of strain field and eventually dislocations pile up. All these would help in the increase of mechanical properties of the composite. However, the hardness dropped with the addition of 30 vol % SiC. This is thought to be due to the particulate-to-particulate interaction which marred the properties of the alloy. The results are in agreement with microstructure results.

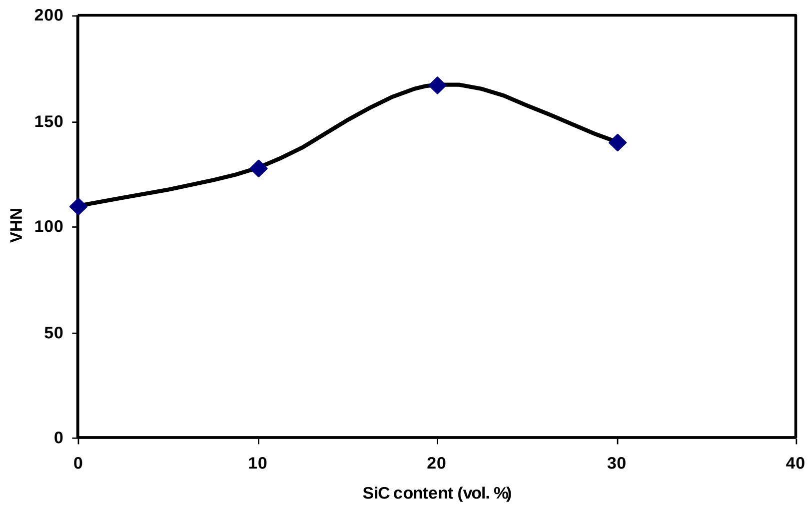

Fig.5. Effect of SiC content on hardness of nanosized $SiC_{(p)}$/Cu composites

3.3. Effect of sliding speed

Fig. 6 gives the variations of wear rate of both reinforced and unreinforced alloy with sliding speed at a normal load of 8 N. It can be seen that wear rate of Cu alloy decreases with increase in the SiC content to 20 vol % SiC. The hard ceramic reinforcements act as load carriers and protect the base alloy from wear realizations. Further it can be observed from Fig. 6 that wear rate of the unreinforced alloy specimen increases linearly with significant increase in sliding velocity. However in the case of composites the wear rate decreases initially and increase with increasingin sliding speed. Any increase in sliding velocity increases the temperature at the interface sections resulting in formation of silicon oxide rich tribo-layer [8]. The developed layer protects the material from further wear and as an outcome the wear rate decreases. But further increase in sliding velocity increases the temperature at the interface and certainly material softening occurs. At this stage, tribo layer detaches from the surface and so the softened MMC gets exposed to the counterpart, consequently increasing the wear rate of MMC. However, the results indicate that beyond 20 vol % SiC the wear rate increases. This is due to the particulate-to-particulate interaction which weakens the mechanical properties of the alloy.

3.4. Effect of load

Fig. 7 gives the variations of wear rate of both reinforced and unreinforced alloy with applied load at constant speed of 2.51m/s. It is clear that the wear rate of both the unreinforced alloy and the composite specimens increased with increasing the applied load. However, the gradient of that increase is not the same for the different alloys. The wear rate of the composites is lower than that of the unreinforced alloy. The behavior is due to the hard ceramic reinforcements which act as load carriers and protect the base alloy from wear. Furthermore, Fig. 7 illustrates that the wear rate decreases with increasing the SiC content to 20 vol % SiC, beyond this value the wear rate increases. This is due to the particulate-to-particulate interaction which weakens the mechanical properties of the alloy.

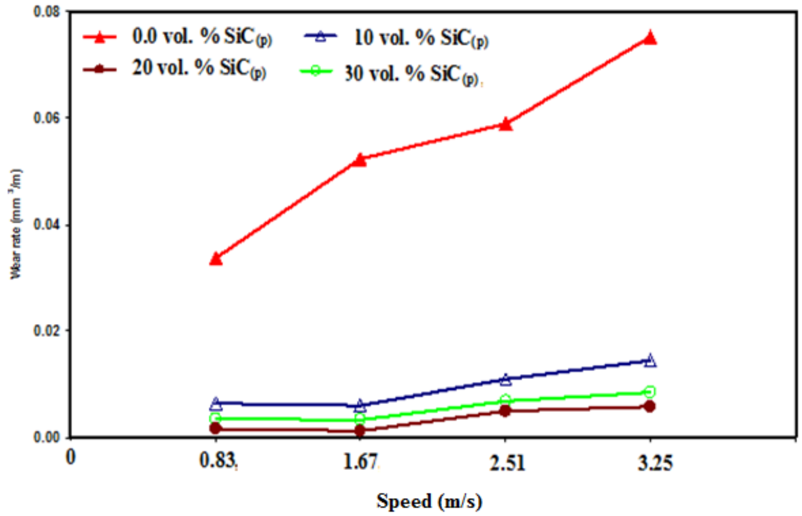

Fig. 6. The wear rate of composite SiC/Cu with different SiC content as a function of sliding speed at a normal load of 8N

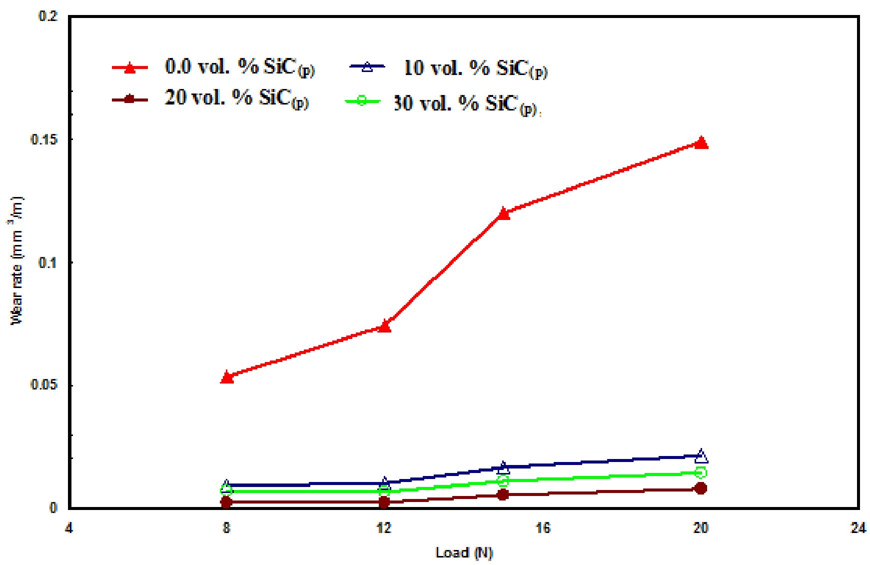

Fig. 7. **The wear rate of composite SiC/Cu with different SiC content as a function of normal load at sliding speed of 2.51 m/s**

3.5. Effect of SiC content on temperature rise

Fig. 8 shows the temperature as a function of SiC content at an applied load of 15 N and a sliding speed of 4.35 m/s. It can be seen that at the initial stage of wear tests the temperature increases with increasing the time of wear for all sample due to the high hardness of the oxide layer on the surfaces of alloys. After that the temperature rise tends to reach a steady value. Also Fig 8 indicates that the temperature rise decreases with increasing SiC to 20 vol.% SiC. This behavior is due to decreasing the coefficient of friction. Beyond this value temperature increases due to increasing of coefficient of friction. This result is in agreement with results obtained in other sections.

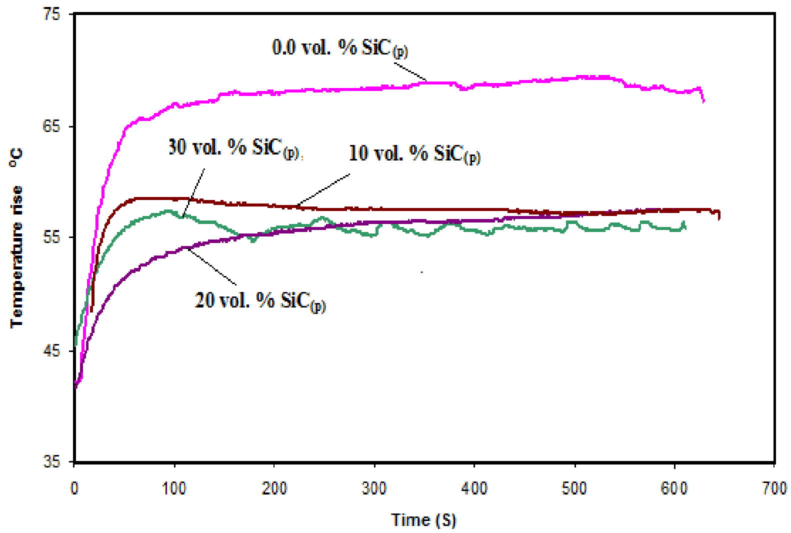

Fig.8. The temperature as a function of SiC content at an applied load of 15 N and a sliding speed of 4.35 m/s

3.6. Worn surface

To correlate the wear test results with the worn surface of the test pins, optical micrograph has been taken for worn surfaces at an applied load of 15 N and a sliding speed of 4.35 m/s. Fig. 9 shows worn surface of both reinforced and unreinforced alloys. It can be seen that unreinforced alloy indicates continuous wear groves (Fig. 9 (a)). The wider and deeper grooves suggest increased metallic contact and a higher coefficient of friction value. Dawes and Thomas [9] observed that the thickness of oxide layers increases with increase in temperature in rise. On the other hand, the worn surfaces of reinforced alloy with different content of SiC (Fig. 9(b-d)) shows smaller grooves with a slight plastic deformation at the edges of the grooves. The depth of grooves decrease with increasing SiC to 20 vol %. Beyond this value it increases again.

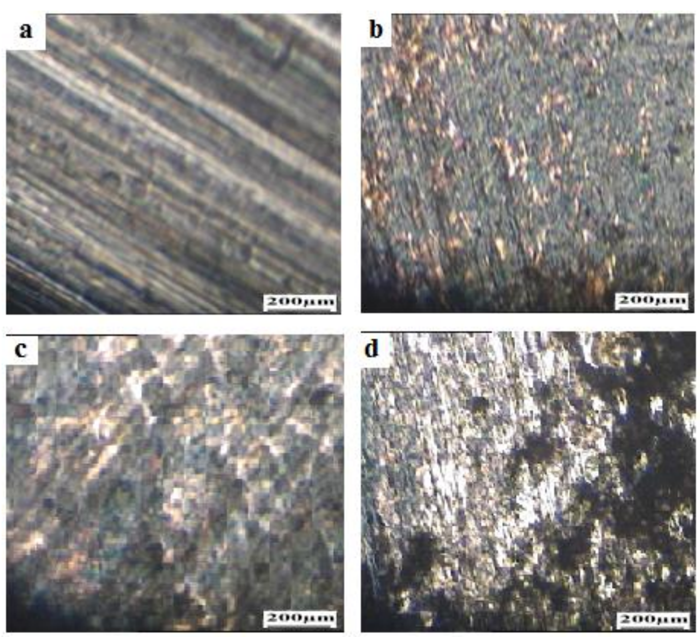

Fig. 9 Optical micrographs of worn surfaces of of $Cu/SiC_{(p)}$ composite with different SiC contents sintered at 850 ^{o}C . (a) 0.0 vol. % $SiC_{(p)}$, (b) 10 vol. % $SiC_{(p)}$, (c) 20 vol. % $SiC_{(p)}$ and (d) 30 vol. % $SiC_{(p)}$

4. CONCLUSIONS

The effects of nanosized SiC content on the hardness and dry sliding wear behavior of Cu/SiC nanocomposites synthesized by mechanical milling is investigated. It is demonstrated that the increased SiC content results in increased hardness of the nanocomposites. The Cu/SiC nanocomposites, as compared with the base metal, exhibited higher wear resistance and lower temperature rise. Optical micrographs studies of the worn surfaces revealed that in the unreinforced alloy, the prominent wear mechanism was abrasive wear. However, in the Cu/SiC nanocomposites, the wear mechanism changed from abrasive to adhesive.

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