

PROCESSING AND PROPERTIES OF SiC PARTICLES- REINFORCED COPPER ALLOY MATRIX

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Abstract

Metal matrix composites are an attractive choice for aerospace and automotive application because of their stiffness -to- weight ratio. Composites with aluminum and magnesium matrices have been investigated extensively, while less work has been carried out on copper matrix composites. In the present study powder metallurgy technique was used to prepare specimens of copper and copper alloy matrix (Cu-Sn- Pb-Zn) reinforced with SiC particulate. The effect of sintering temperature and volume fraction of SiC_p particles on densification was investigated. Also, the effect of particle characteristic of SiC_p reinforcement on mechanical properties and wear behavior under varying contact pressure and sliding speed by using pin -disc was carried out.

Introduction

Metal matrix composites are well known for their attractive physical and mechanical, properties, such as, high specific modulus, strength; wear resistance and thermal stability [1-3]. One of the most useful properties of copper is its high electrical conductivity. However, because of its poor tensile and creep strengths, even at modest temperatures design problems arise when copper is used in electrical applications.

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The mechanical strength of copper can be increased dramatically either by age hardening or by introducing dispersed particles in its matrix. Dispersed particles such as oxides, carbides and borides are insoluble in the copper matrix, and are thermally stable at high temperatures. Cu-TiO₂ particles have been prepared from copper-coated titania particles by the powder metallurgy route [4]. Zirconium diboride (ZrB₂) is used for special high temperature aircraft and electrical discharge machining (EDM) [5]. Various methods have been used to produce MMCs, such as, squeeze casting [6], liquid metal infiltration [7], centrifugal casting technique [8], and powder metallurgy [9-10]. Among these processes, PM is considered to be the most suitable process to produce particulate reinforced copper matrix composites. The PM route consists of several processes like blending, compacting, and sintering. Blending is one of crucial processes in PM where the metallic powders are mixed with the ceramic reinforced particles. Good blending produces no agglomeration of both the metallic and ceramic particle powders, which may be obtained in casting process due to the difference in the densities.

Relationship between compacting pressure, green density, and green strength of copper powder compacts was investigated [11]. It was found that, the breaking strength of the pressed Cu compact increases with green density and also with compacting pressure. A theoretical equation for the relationship between green density and contact area between powder particles was derived from a geometrical consideration and agreed well with experimental findings. The disperse morphology of second phase and microstructural evolution metal-ceramic composites prepared by a multi-billet coextrusion process have been examined. The microstructural observations reveal that the microstructure of metal-ceramic composites is primarily related to the mixing proportion and particle size ratio of two components. The disperse morphology of second phase in a matrix depends to a large extent on the particle size ratio between the matrix and second phase [12]. Tribological behavior of SiC particle – reinforced copper matrix composites fabricated by means of the HIP process was investigated [13]. The tests indicated that the composite with 20 vol. % SiC_p exhibits a lower wear loss.

In the present investigation copper alloy matrix was used to prepare Cu alloy – SiC_p composites by powder metallurgy. The effect of SiC particulate on densification of pure and copper alloy (Cu-Pb-Sn-Zn) was investigated. The influence of volume fraction and grain size of SiC particulate on UTS, hardness and the wear characteristics was studied. Pin on disk was used to carry out the wear behavior under variable contact pressure and sliding speed of the composites with different volume fraction and particles size.

Experimental procedure

Specimens were prepared from atomized Cu powder of purity 99.8 % with 5, 10, 15 and 20 vol. % SiC_p (group I). The fabricated composites were prepared by PM method. The mixing of copper and SiC particles was carried out in a laboratory mixer with 4wt % ethanol to prevent segregation of the lower density of SiC particles for 3 hours. The mixtures were then cold compacted at 600 MPa. The obtained pellets were then sintered at 950 °C in the course of four hours in hydrogen atmosphere. The density of pressed (ρ_p) and sintered (ρ_s) samples is presented in table 1. The green and sintered density was determined according to Archimedes, method [14]. In this technique density is determined by measuring the difference between the specimen's weight in air and when it was suspended in distilled water at room temperature. Other specimens (group II) were prepared from the same copper, 5wt%Sn, 5wt%Pb, 5wt%Zn and SiC particles with 5, 10, 15 and 20 vol. % and different particles size 1, 10, 30 and 60 μm . The mixtures were cold compacted at 400 MPa to form compacts of standard tensile test shown in Fig. 1. and cylindrical specimens of 13 mm diameter and 18mm length. The compacted specimens were sintered at 850, 875, 900 and 940 °C for 2 hours in hydrogen atmosphere. The sintered composites were re-pressed at 500 MPa, finally re-sintered at 900 °C and held for two hours in the same atmosphere. B scale Rockwell hardness was measured 6 times on a specimen's surface ground by 800 emery papers. The ultimate tensile strength (UTS) was applied by using computerized universal testing machine. The wear rate was

determined by using pin – disc [15]. For testing wear rate, several test specimens from copper and copper alloys composites were prepared (6mm Dia. and 10mm height). The procedure of the test was such that each specimen was thoroughly cleaned with acton, then dried and weighed just prior the wear test. After that, the test was carried out for dry contacts at the desired speed and load conditions. Then the specimens was weighed after testing at ambient temperature and the wear was expressed as a loss of weight per Km. The loss of weight is measured on a sensitive digital balance with accuracy of ± 0.1 mg. The effect of particle size and volume fraction of SiC particulate on wear rate and coefficient of friction was studied. The worn surfaces of the composites were investigated using optical microscope.

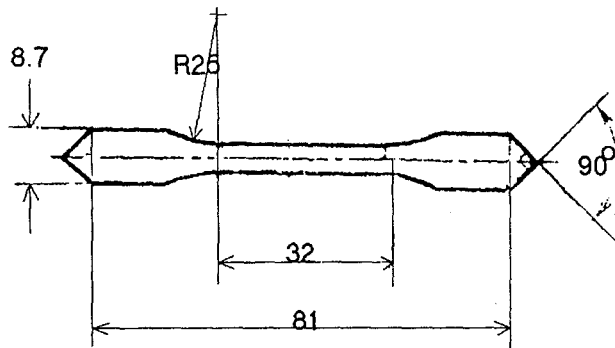


Fig.1. Shape of standard tensile test (Dimensions in mm)

Results and Discussion

To show the effect of SiC_p contents on the density of pressed (ρ_p) and sintered (ρ_s) copper samples of composites with 5, 10, 15 and 20 vol.% SiC_p (samples in group I). The obtained density relative to the theoretical density (TD) is given in table1.

Table .1: Density of samples of Cu- SiC_p

SiC _p (vol %)	ρ_p (g/cm ³)	ρ_p (% TD)	ρ_s (g/cm ³)	ρ_s (% TD)	ρ_s/ρ_p
0	7.760	0.866	8.160	0.912	1.052
5	6.470	0.784	6.600	0.800	1.022
10	5.560	0.728	5.640	0.738	1.014
15	4.860	0.682	4.900	0.701	1.008
20	4.240	0.636	4.250	0.640	1.003

The results indicate that the density of sintered composites (ρ_s) decreases with increasing the volume fraction of SiC_p which inhibit the sintering mechanism, Fig2. Moreover, this is due to the low density of SiC particles (3.3 g/cm³) compared with that of copper matrix (8.96 g/cm³).

Figure 3 shows the variation of the measured density with sintering temperature of re-pressed and re-sintering composites of various SiC_p contents group (II). As shown from the figure the density decreases by increasing the temperatures to 900 °C then increased by increasing the temperature. It is attributed to the interaction between Cu and Pb which is important in the present system because of the formation of liquid phase which, in, general, contributes considerably to the densification of the compact, according to the Cu-Pb phase diagram [16]. The Pb – Cu melt of less than 3.5 mass % below the monotectic temperature of 954 ° C increases to about 10mass% above this temperature. Such an increase of the melt content is expected to cause a remarkable change in densification behavior. Moreover, it is reasonable to attribute this to a large number of sweat beads observed on the surface of the sintered composites. This formation of sweat beads could be a result of the liquid phase being pulled by a capillary force to the specimen's surface. This liquid flow led to the formation of residual pores in the original areas of melting which could be filled with the excess liquid phase at 940 C° and exhibited highest densities. At the same time the density of pure copper increases by increasing the sintering temperature.

Fig 4. shows influence the reinforcement volume fraction and particle size of SiC on the tensile strength and the hardness of copper alloy composites. As can be seen, the incorporation of SiC particulate decreases the strength and increasing the hardness of the composites. This behavior is contrast to the results reported for aluminum and magnesium matrix composites, where an increased strength was reported compared with of un-reinforced alloy [17]. At the same time this trend is agreement with the results reported for copper when 5wt% uncoated titania powder was added, the strength of the composites was reduced to 20% below that of copper matrix [4]. The increase in composites hardness with increasing SiC_p content is an obvious result of the higher hardness of SiC particles.

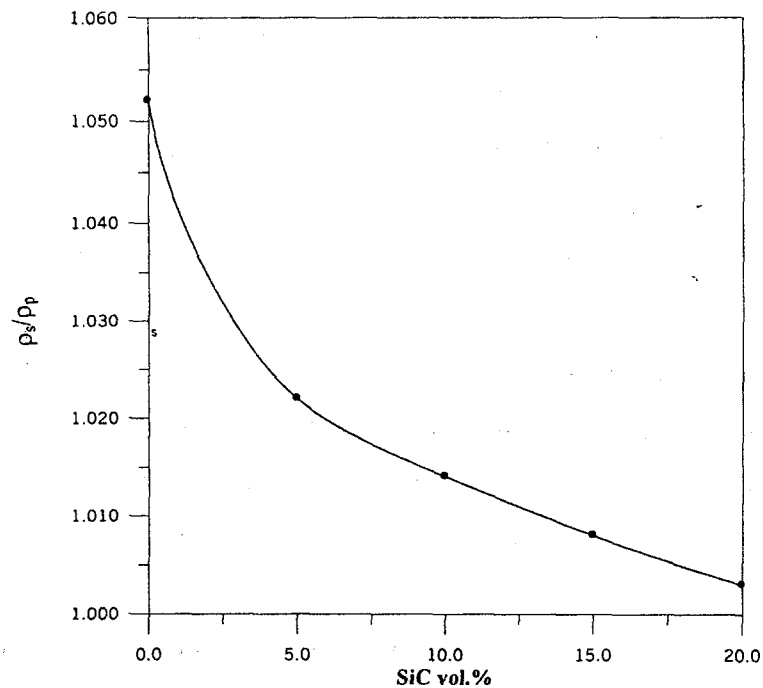


Fig 2 Effect of SiC particles on densification of pure copper.

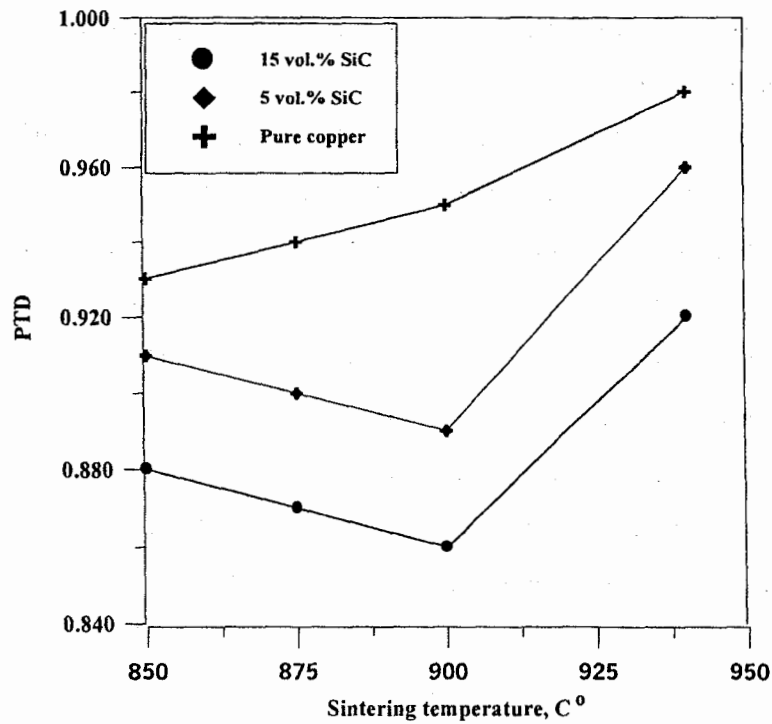


Fig.3 Effect of sintering temperatures and volume fractions of SiCp on percentage theoretical density (PTD).

There was no direct relationship between particle size and hardness however, it should be noted that hardness is determined by the material near the surface of the specimens while U.T.S. and failure originated near the center of the cylindrical specimens. It is quite that variations in density between the outer surface and the center of the specimens resulted from the compaction process, and this may have been responsible for the different relationships between mechanical properties and particles size .

The composites reinforced with 10-30 μm of SiC particles have higher strength and hardness. It appears that fine particles ($1\mu\text{m}$) tend to form higher agglomerations and this affects the hardness and tensile strength behavior of the composite. In regions of local reinforcement clusters the matrix probably does not have sufficient internal ductility to redistribute the very high- localized stress, therefore the composite fails before being able to reach stable plastic flow and normal ultimate strength .As the particle size is increased, the surface area for bonding between the particle and the matrix is decreased; i.e. the strength

decreased, owing to the tendency of the particles to agglomerate, thereby creating zones of weakness.

Fig.5. shows the variation of wear rate of un-reinforced Cu alloys- SiC_p composites with the contact pressures at a sliding speed of 1.5ms^{-1} . For the composites, the observed wear rates did not vary in a simple manner with volume fraction of SiC particles. It is evident from the figure that there is a sudden acceleration in the wear rate at contact pressure 1.0 MPa for the un-reinforced alloy and above 1.75 MPa for composite with 20 vol. % SiC_p respectively. This transition marks the onsets of severe wear rate regime. The wear resistance of the composites increased with volume fraction at contact pressure below 1.75 MPa. However, the wear resistance of Cu alloy-20 vol. % SiC_p composites decreases considerably at contact pressure above 1.75 MPa. The lowest wear rate moves gradually towards the composites with 15 vol. % SiC_p with further increasing contact pressure, which indicates that the wear rate of the composites depends on the volume fraction and contact pressure simultaneously. For the composites investigated, in the case of un-reinforced copper alloy, the asperities of counter part steel disc can deform, penetrate and cut into the copper alloy surface during dry sliding wear. This results in plastic strain localization in the subsurface region, leading to the formation of delaminating crack as shown in Fig.6.a. The excessive delaminating of surface layers of copper alloy matrix leads to a high wear loss, which increases with increasing the contact pressure. In the case of composites, the sliding wear imposes a substantial tangential force on the SiC particles in contact with the counter part steel disc which results in shear stress at the particles-matrix interface. Generally, increasing the contact pressure tends to increase the shear stress. At low contact pressure, the shear stress was too small to debond or pullout the SiC particles from the copper alloy matrix. Therefore, increasing the volume fraction of SiC particulate at low contact pressure tends to increase the wear resistance of the composites.

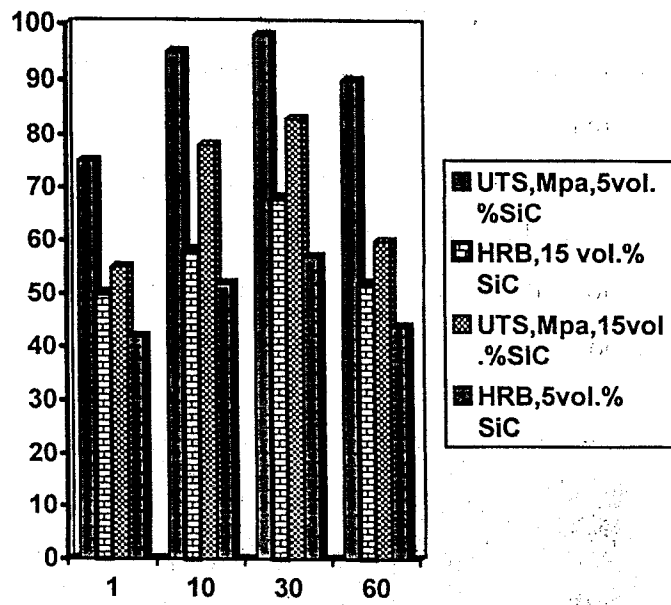


Fig.4. Effect of particles size and volume fraction of SiC_p on tensile strength and hardness of the composites

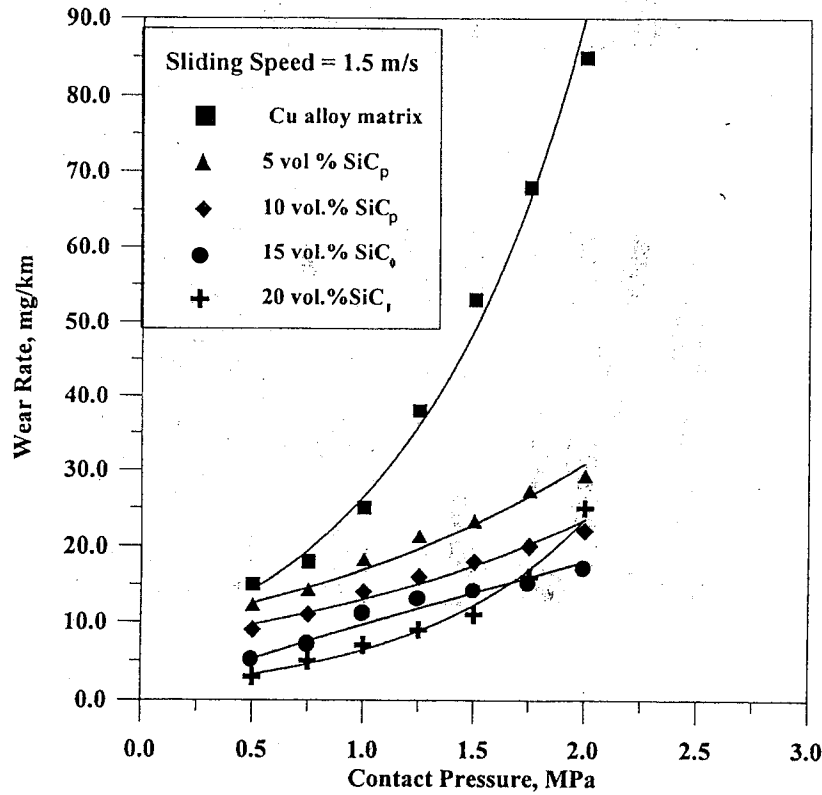


Fig.5 Variation of wear rates of un-reinforced Cu-matrix and Cu alloy - SiC_p matrix with the contact pressure.

Increasing the wear contact pressure tends to cause high plastic deformation of the matrix interface which can cause particle decohesion. Thus, the wear rates of the composites were mainly dependent on the level of the contact pressure.

Fig.6.b. shows that the worn surface of copper alloy-15 vol.% SiC_p which is characterized by fairly long continuous grooves, which form as the abrasive particles plough along the surface removing or pushing material into ridges to the sides of the grooves.



Fig.6.a The formation of delaminating surface cracks in un-reinforced copper alloy at contact pressure 1.5 MPa and sliding speed 1.5m/s

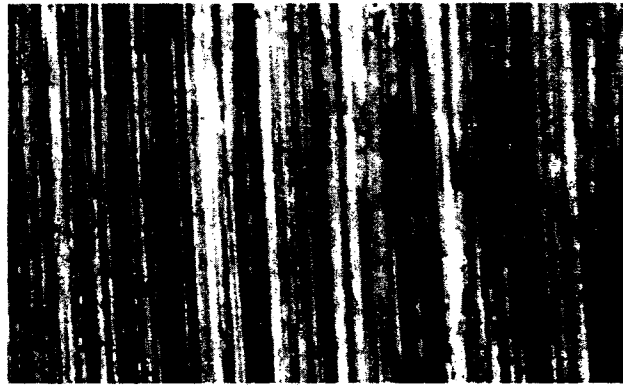


Fig.6.b Optical micrograph of Cu alloy- 15 vol. % SiC_p worn surface at contact pressure 1.5 MPa and sliding speed 1.5m/s.

The effect of volume fraction and grain size of the SiC particles on wear rate of copper alloy matrix composites are showed in Fig. (7). The figure demonstrates, that the addition of ceramic particulate reinforcements significantly decreases the abrasive wear loss of the copper alloy. The wear losses decrease with increasing the reinforcement volume fraction because extensive ploughing and cutting of the matrix by the abrasive particles is reduced by the presence of the harder ceramic particles. On the other hand, the results of the figure show that the composites with 1 μ m SiC particulate exhibit the lowest wear resistance while increasing the hard particle size to 10-30 μ m in PMMC significantly improves the wear resistance of the composite material .The explanation for these phenomena is that for the same fraction of SiC particles the particle-matrix interfacial area in the case of a small particle size was larger. These results in increasing the chance for the small particles of SiC to leave the matrix alloy with a small depth of metal removed. For relatively small particle sizes, an increase in particle size caused more of the contact load to be carried by the hard particles, and this lowered the wear of the softer matrix. This result is in agreement with those reported in [18]. As the particle size is increased further, the surface area for bonding between the particle and the matrix is decreased as long as the total volume of particles remains constant. This factor serves to weaken the particles-matrix interface for larger particles. In addition, the number of particles per unit area would be smaller for larger particles, resulting in the likelihood of greater contact force per particle. As a result, the PMMC wear would increase as the particle size increases. This trend is agreement with reference [19].

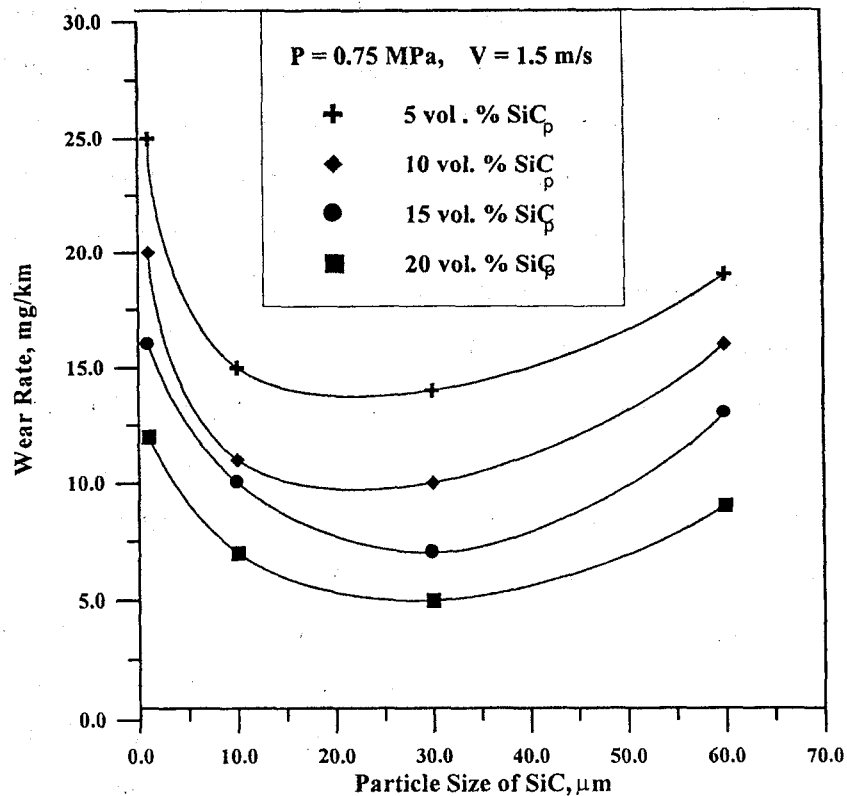


Fig.7 Effects of volume fractions and particle sizes of SiC_p on wear rate of the composites.

The effect of sliding speed on the friction and wear behavior of a Cu alloy – SiC_p composites was studied by varying speed in the range of 0.5ms⁻¹ to 3ms⁻¹ at contact pressure 0.75 MPa. The variation of wear rate and coefficient of friction of the composites with sliding speed for steady state sliding against steel counter face is plotted in Fig. 8.a and Fig.8.b. In this investigation, the variation of coefficient of friction with sliding speed was not significant. The coefficient of friction for the composite with higher volume fraction of SiC particles was slightly lower than that for the composite with lower volume fraction. The wear rates of the composites decreases with increasing sliding speed and were considerably larger at speed of 0.5 ms⁻¹. The proposed reason for this behavior is the temperature rise due to the increasing speed increased the oxidation film thickness enough to prevent direct metallic contact between the composite and the steel counter face and thereby reduced the wear rate. A similar trend was reported in references [20-21].

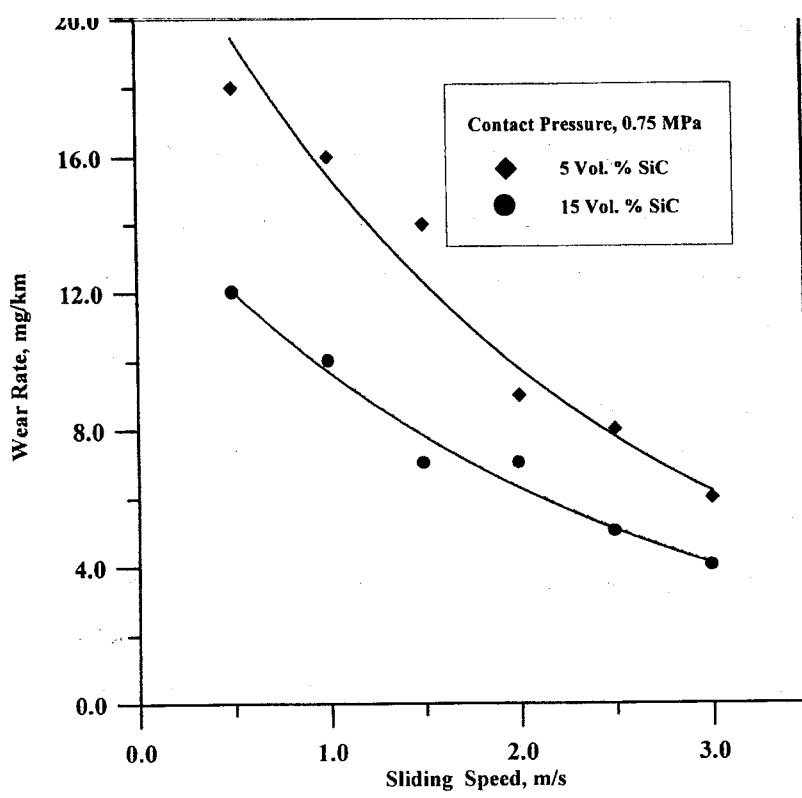


Fig.8a. Effect of sliding speed and volume fraction of SiC_p on the wear rate.

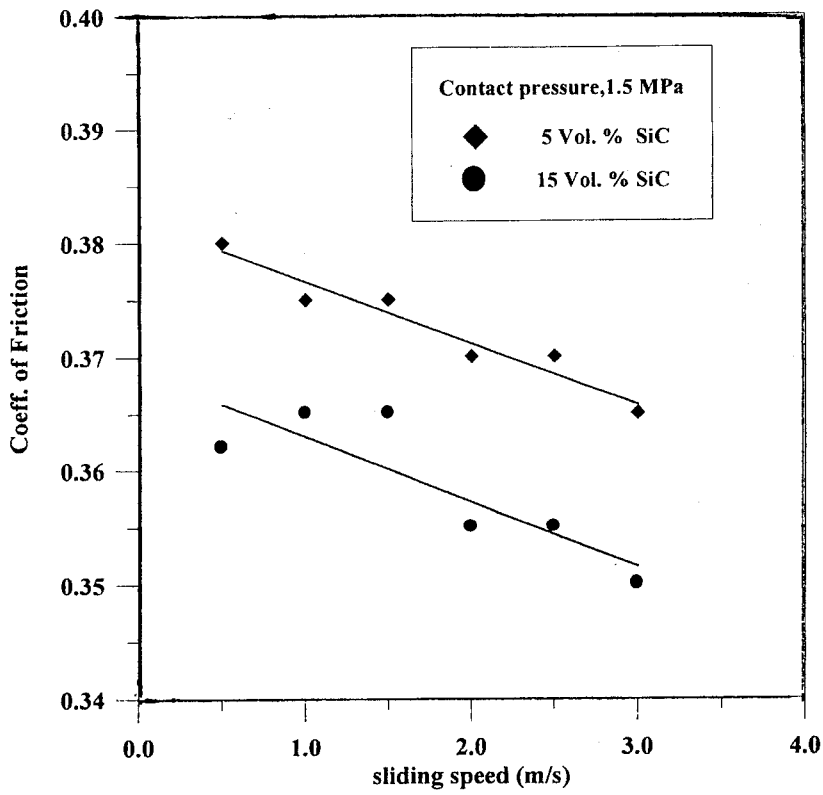


Fig.8b. Effect of sliding speed and volume fraction of SiC_p on the coefficient of friction.

CONCLUSIONS

The main conclusions of the present study are as follows:

- 1- The densification of pure copper and copper alloy matrix decreases by increasing the volume fraction of SiC particles due to the poor sintering in presence of particles.
- 2- Re-pressed and re-sintering for copper alloy matrix at 940 °C sintering temperature exhibits the highest density than 850,875 and 900 °C sintering temperature.
- 3- Tensile strength of un-reinforced of copper alloy matrix decrease after the incorporation of SiC particulates. While, the hardness increases by increasing volume fraction of SiC particles. The use of 10-30 μ m particle size exhibits the highest tensile strength, hardness and wears resistance.
- 4- There was no direct relationship between particles size and hardness.
- 5- The wear rate of the copper alloy/ SiC particulate composites investigated in this work decreases with increasing volume fraction of the reinforcing particulates. At low contact pressure, wear resistance of the composites increased with volume fraction of SiC particulate. At contact pressures above 1.75 MPa the wear rate increases by increasing volume fraction of SiC_p, due to poor interfacial bonding between the particles and the matrix.
- 6- The variation of the coefficient of friction with sliding speed was not significant. The coefficient of friction for composite with higher volume fraction of SiC particles was slightly lower than that for the composite with lower volume fraction and the wear rate decreases with increasing sliding speed and was considerably larger at speed 0.5ms⁻¹.

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خواص وتصنيع سبيكة النحاس المدعم بحبيبات كربيد السيلكون

صلاح عبدالوهاب أصيله

قسم هندسة الانتاج والتصميم الميكانيكى - كلية الهندسة بشبين الكوم / جامعة المنوفيه

ملخص البحث:

يتم اختيار واستخدام المواد المؤتلفة في كثير من التطبيقات العملية في مجال الفضاء والمحركات وذلك لمكانتها بالنسبة لوزنها.

وفي مجال المواد المؤتلفة نالت سبائك الالمونيوم ماغنسيوم إهتماما كبيرا في مجال البحث والدراسة بينما لاتزال الدراسة للمواد المؤتلفة التى أساسها النحاس محدوده وغير كافية.

وفي هذه الدراسة إستخدمت تكنولوجيا المساحيق للحصول على عينات من النحاس النقى - كربيد السيلكون - وسبيكة النحاس - $(Cu-Zn-Pb-Zn)$ والمدعم بحبيبات من كربيد السيلكون (SiC) - حيث تم دراسة تأثير درجة حرارة التلييد وكمية كربيد السيلكون المضافة على الكثافة قبل وبعد التلييد. تم كذلك دراسة تأثير حجم حبيبات كربيد السيلكون وكميتها على الخواص الميكانيكية وخصائص الاحتكاك والتآكل تحت تأثير أحمال وسرعات مختلفة.