The Effect of Adding SiC on Some of the Mechanical Properties of the Cu-Al$_2$O$_3$ System Using Powder Metallurgy

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Abstract. Powder metallurgy is one of the simple ways employed to produce alloys that are used in many technological applications. In the recent work, different contents (0, 5, 10, 15 and 20%) of silicon carbide ($\geq 63$ $\mu$m) were used as a reinforcement material on matrix ((90, 85, 80, 75 and 70) % Cu-10% Nano-Al$_2$O$_3$). The mixture was milled by a locally made mill for three consecutive times (2, 4 and 6) hours. After that, a compressor with the highest compaction capacity (20 tons) was used to compact the mixture. The mixture was compacted in a steel die through applying pressure of 5 tons for one minute. After sintering samples at 900°C for two hours, mechanical tests including Vickers hardness, diametric compressive strength and wear were applied as a function of the grinding time. The results showed that the best hardness (119.4 Hv) is reached for the grinding time of six hours and the reinforcement of (20% SiC), while the highest compressive strength was obtained for same time of grinding with a reinforcement of (53.3 Mpa). Concerning the rate of wear, its value decreased to the lowest value at the same conditions above (1.10368*10$^{-7}$ g/cm). Accordingly, the best characteristic parameters of the results appeared at 900°C, the grinding time of six hours, and reinforcement content of 20%.

1. Introduction
Powder metallurgy is the process of producing metal materials whereby parts are produced in different forms of metal powders. Powders are compacted to obtain the required shapes, and then these resulting parts are heated with a process called sintering in order to create the interconnection between particles to obtain a rigid mass. The process of compaction is performed at certain compaction levels using a compressor with tools designed and manufactured for this purpose, which are die and compressor. The subsequent sintering process is performed at a temperature below the melting point of the matrix. This method is used either because of the difficulty of producing these alloys by casting process because their components are not mixed in the liquid state or because it is difficult to melt them [1]. The composite is a mixture of two or more materials that are strongly correlated with each other based on which the material acts as a single mass, so that it possesses intermediate properties of the component. This means that the composite material consists of two phases: matrix and reinforcement. The phases used are metal, ceramic or polymeric materials and the reinforcement phase is particles, fibers, whisker or sheets [2-4]. Copper-based composites produced with powder metallurgy technology are ranked third after iron, steel and aluminum-based products. The use of copper in powder metallurgy dates back to the 1920s [5]. Due to the high electrical and thermal connectivity, copper and its alloys have been widely used in thermal
and electronic applications such as the packaging of electronics, contactors and resistance welding poles. However, the relatively low mechanical properties in both high temperature and room temperature have limited or reduced the wide applications of pure copper. The mechanical properties can be improved by adding reinforcement materials for copper and its alloys. In other words, the copper-based and particle-reinforced composites may have many distinct benefits such as high mechanical, conductive properties and wear resistance [6]. The current study aims to improve the behavior of wear and reduce rubbing as well as mechanical properties by preparing a metal-based composite, which is copper, and reinforcing it by silicon carbide with different volumetric sizes using powder metallurgy. Thus, it can be used in many applications such as electric brushes, sliding mechanical bearings and other applications that require excellent thermal and electrical conductivity with low wear behavior.

Experimental Part

Raw Materials
The matrix used is copper manufactured by the Indian company (CDH) with grain size (44μm) and purity 99.5%. The first reinforcement material is Alumina α-Al₂O₃, manufactured by Changsha Santech Co., of Chinese origin with grain size (30±5) nm and a purity of ≥99.99%. The second reinforcement material is silicon carbide (SiC) manufactured by Merck the German company with grain size (53μm) and a purity of 99.90%.

2. Sample Preparation Method For Measurement

Powders were dried at a temperature of (200°C) for 2 hours to get rid of wetness and other volatile materials. The weights of each component mix were then created by following the weight ratios so that the alumina ratio was constant by (10%) for all mixtures. Silicon oxide percentages were (0, 5, 10, 15 and 20) % and copper was the matrix (90, 85, 80, 75 and 70)% The weight was done using a Japanese-origin Sartorius electric balance with accuracy of (0.0001 g). After completing the grinding and stirring processes and obtaining a homogenous powder for three different grinding times, the samples were formed using uniaxial compaction in a steel die with a hardness of (60HRC). The stirred mixture was carefully placed inside the compaction die to avoid any movement of its parts. A pressure of (5 ton) was then applied for one minute to avoid the possibility of elasticity [7]. For this purpose, a Turkish-origin computerized hydraulic compaction of (HALIM USTA) type with a capacity of 20 ton was used to obtain cylindrical samples of (10) mm in diameter and 6 mm height. After compaction, the samples were not ready to perform tests and had weak resistance, which is green resistance. This requires care when transporting and handling until performing the sintering process. The sintering process was performed using a German-origin CARBOLITE oven at 900 °C for two hours. After that, the samples were removed from the oven for the examination process after the preparation of the sample surfaces.

3. Examinations and Measurements

3.1. Vickers Hardness (Hv)

Hardness is an important mechanical feature. It is known to be resistant to surface indentation [8]. It was examined using Vickers method by inserting the tool (a square-based diamond pyramid) by forcing a load of 500 g for (10 Sec). By calculating the diameters of the resulting indentation, Vickers hardness could be defined for the compacted sample by applying equation (1) [9]:

\[ Hv = \frac{1.8544 P}{D_v^2} \text{ g/mm}^2 \] …… (1)

where P is the force applied (g) and D_v is the average diameter of the pyramidal indent resulting from forcing a load on the surface.

3.2. Diametric Compressive Strength

Compressive strength was tested using Universal Testing Machine of (HOYTOM) type of Chinese origin. The sample was placed on the test platform. After that, a load was then applied to the diameter
of the sample until the failure occurred. The maximum load was recorded from the digital screen of the machine, knowing that the machine has the possibility to store the maximum value of the load before failure. Compressive strength was calculated using Eq. 2 [10]:

$$\sigma_D = \frac{2F}{\pi dh}$$

where $\sigma_D$ is the compressive strength of crushing (MPa), F is the applied load (N), d is the sample diameter (mm), h is the sample thickness (mm).

3.3. Wear Rate Test

Wear is an important characteristic of the material surface, which is defined as the loss of material from the metal surface due to the friction of moving parts. From the initial trials, the amount of applied load was determined by (10N), using a fixed sliding speed (480 r.p.m). The period of applied load per test was 10 min. Wear test was carried out using a Pin-on-Disc device of Chinese origin found in the laboratories of the Department of Mechanical Engineering at Tikrit University. Table (1) shows the conditions of wear. A vertical load was applied by a (Pin) through a holder. The compacted sample was placed on a rotary disk. The reading was taken by a top sensor tied vertically on the arm holding the compacted sample. The reading was then moved to a digital scale fixed at the front of the device. The required loads were fixed at the top of the device as required. Wear rate was calculated using the weight method, which included calculating the amount of weight loss for each sample through weighing the sample before connecting it to the device and after the completion of the device operation using a digital balance by applying the following relation [11,12,13,14] :

$$W = \frac{\Delta W}{SD} \text{ (gm/cm)}$$

where $W$ is wear rate (g/cm), $\Delta W$ is the lost weight (g) which represents the difference in weight for the sample before and after operation, SD is the sliding distance (cm) which equals:

$$SD = \pi D n t$$

where D is the disc diameter (cm), n is the rotational velocity of the disk (rpm), t is the test time (min).

| The rotational velocity of the disc | 480 r.p.m |
|-----------------------------------|----------|
| Test time                         | 10 min   |

| Vertical load applied             | (10) N   |
|-----------------------------------|----------|
| The diameter of the test disc     | 60 mm    |
| Disc hardness                     | 62 HRC   |

Table 1. Conditions of wear rate test

Step of the Test Method

The compacted samples of diameter (10) mm and height (5) mm were prepared.
The samples were ground using sandpaper (400, 600, 800, 1200).
The sample was weighed before the test using a sensitive digital balance.
The rotational disc of the device was cleaned before starting the test.
The sample was fixed in its position using a holder designed according to the heights and diameter of the compacted sample. More than one sample was manufactured in the mechanical workshops in the General Company for the manufacture of medicines and medical supplies in Samarra.
Loads were fixed and a load of (15, 20, 25) Newton was applied vertically each time to the samples at a rotational velocity of the disk of (480 r.p.m).
The device was switched on after adjusting and resetting the test time.
The device was switched off after (20) minutes from the start of operation.
The sample was removed and weighed using the balance after the test.
The amount of weight loss was defined.
The relationship (3) was applied to extract wear rate for each sample.
The above-mentioned processes were reapplied to all samples. Wear rate was calculated for each sample by calculating the average wear rate for the upper and lower surface of each sample.
4. Results and Discussion

4.1. The Effect of the Added Content and Grinding Time on Vickers Hardness

Figure (1) shows the relationship between the change in the size ratios of silicon carbide particles and the grinding time on Vickers hardness after sintering at 900°C for two hours. It is observed that the hardness increases with increasing the content of silicon carbide and grinding time. Hardness increased after sintering from (38.1-84.2) at the grinding time of two hours. Then, it increased from (54.4-102.8) at a grinding time of four hours. After that, it increased from (74.6-119.4) at the grinding time of six hours for all cases at silicon carbide content (0-20%).

The increase in hardness as a result of adding silicon carbide particles and grinding is due to the high hardness of silicon carbide particles located within the range of (2500-3300) kgf/mm². In addition to the large number of interfaces formed as a result of adding reinforcement particles (SiC); as well as increased resistance to plastic deformation and increased residual internal stress due to the difference in coefficient of thermal expansion between matrix and reinforcement particles that produce a lot of dislocations. This leads to increase the hardness of the composites because silicon carbide particles of high hardness act as barriers to the deformation of the matrix and thus hinder the movement of dislocations. This makes stress greater in order for the dislocation to pass through the particles and thus requires an increase in the applied load. This in itself means an increase in the hardness values, and that the homogeneous distribution between matrix and reinforcement particles also has a major role in increasing the hardness. This is consistent with the results published in [15,16].

![Figure 1. The relationship between the change in the size ratios of silicon carbide particles and grinding time with hardness after the sintering process.](image)

4.2. The Effect of the Added Content and Grinding Time on Diametric Compressive Strength

Figure (2) shows the relationship between the content of silicon carbide and grinding time on the compressive strength of the composites with different silicon carbide ratios. Increased content and grinding time result in increasing the compression strength of the composite regardless the ratio of silicon carbide particles. The compressive strength increased from (10.6-28.8 MPa) for a grinding time of two hours, then it increased from (15.2-40.5 MPa) for a grinding time of four hours. After that, it increased from (22.4-53.3 MPa) for a grinding time of six hours for all cases at a silicon carbide content of (0-20%).

This is due to the high resistance of the reinforcement particles, which increased the composite hardness by increasing the content of silicon carbide. In addition, it is also related to the resistance of on-site deformations with high efficiency and then the formation of coherent samples with high compression strength. The high sintering temperature for two hours plays an important role in increasing the strength of the correlation between component particles of composites through good propagation and distribution, as well as increasing density and decreasing the ratios of porosity after sintering, which
leads to support and reinforce the composite mass. This is consistent with the results of the study in ref. [15].

![Figure 2](image)

**Figure 2.** The relationship between the change in the size ratios of silicon carbide particles and grinding time with diametric compressive strength after the sintering process

### 4.3. The Effect of the Added Content and Grinding Time on Wear Rate

Figure (3) shows the relationship between the change in the size ratios of silicon carbide particles and grinding time with wear rate after sintering at 900°C for two hours. It is observed that increasing the size ratios added to silicon carbide and grinding time has reduced wear rate from \((3.53036 \times 10^{-7} - 1.81377 \times 10^{-7})\) g/cm at a grinding time of two hours. Then, it decreased from \((2.42915 \times 10^{-7} - 1.54899 \times 10^{-7})\) g/cm at a four-hour grinding time. After that, it decreased from \((1.94332 \times 10^{-7} - 1.10368 \times 10^{-7})\) g/cm at grinding time of six hours for all cases at silicon carbide content (0-20%).

The low wear rate when increasing the content of reinforcement particles and grinding is attributed to the high hardness of composites when adding silicon carbide particles. Hence, the weight loss is low as a result of reinforcement of surface or ground with ceramic particles that hinder the progress of the dislocations. Therefore, stresses that are resisted by hard particles (SiC) would be generated and thus generating a dislocation density. The difference in the coefficient of thermal expansion has a significant role in this process that results in increasing the hardness by increasing the content of reinforcement particles. Moreover, wear rate decreases when adding SiC particles that cause increased hardness [17].

Wear rate is inversely proportional to the hardness according to the following relationship[18]:

\[
V = K \times \frac{Wx}{H} \quad (5)
\]

where \(V\) is wear size, \(K\) is the coefficient of wear, \(W\) is the vertical load, \(X\) is the sliding distance, \(H\) is the material hardness.
5. Conclusions
The important conclusion of the current research is the possibility of manufacturing models of copper-based composites reinforced by two materials of Nano-alumina by 10% and micro silicon carbide in different contents. After sintering at 900°C for two hours, mechanical tests were conducted. The obtained results showed that the best hardness was (119.4 Hv) at a grinding time of six hours and reinforcement (20%SiC). While the highest compression strength obtained at the same grinding time and reinforcement rate was (53.3 Mpa). As for wear rate, its value decreased as it was lower in the same conditions mentioned above (1.10368*10^-7 g/cm).

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