Compressive Strength, Wear, and Structure Characteristics as a Result of Silicon Carbide Addition on a Copper Base

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Abstract. The current research aims to study of the effect of the reinforced materials on the extent of failure or resistance of the metals. The powder method was used to manufacture models of copper-based composites, then copper was reinforced by silicon carbide at percentages of (0, 5, 10, 15, 20)%, and alumina was used as a fixed support at (10% Al₂O₃), Moreover, the mixture was ground by a steel mill for 2, 4, and 6 hours and then pressed with a press capacity of 20 tons. The homogeneous mixture was placed inside a steel mold and pressed at 5 tons for a time of one minute. After sintering at 900°C for two hours, the samples were prepared. The diagonal compressive strength tests, the wear test and examination of an atomic force microscope in three different grinding periods were carried out. The results of the examination showed that the highest compressive strength was obtained (53.3 Mpa) at a six-hour grinding time with a percentage of 20% SiC, while the wear rate showed a decrease in its value as it was less weary at a six-hour grinding time, and at a percentage of 20% SiC also (1.10368 * 10⁻⁷ g/cm). The images obtained from the atomic force microscope showed that the total surface topography and the morphology of the grains formed on the surface have a high degree of homogeneity and arrangement after the heat treatment. We observed the regularity in the growth of the superimposed layer and noted that the grains were arranged perpendicular to the axis. As the crystalline heights are approximately equal, the best characteristic parameters of the results were found at sintering of 900°C, grinding time of six hours, and cementing content of 20%.

Keywords: Failure Analysis, Reinforced materials, Minerals, Composite materials.

1. Introduction

The science of powder metallurgy is called the art of producing materials with high properties, unlike the production of other materials by means of smelting and casting. Powder production appeared in Europe at the end of the eighteenth century when platinum was atomized [1]. The industrial development and the increase in its requirements for the production of materials that cannot be produced by other methods led to the development of powder metallurgy technology, which can be summed up as combining metal powders and ceramic materials to obtain high properties. After mixing, it is pressed at high pressure and then sintered at temperatures below the melting point of the base material in order to complete the cohesion process between the particles of the matrix and the additives [2]. Powder metallurgy technology is of great importance compared to other technologies because of its high potential for producing composite materials. Such materials consist of a number of metals and while in a state of fusion, their alloys are not mixed with each other at all. For example contact cutters for electrical purposes can be manufactured from steel tungsten that resists corrosion and soft silver with high electrical conductivity. This technology is characterized by the production of complex shapes and it is less expensive than other technologies since there is no production waste and...
the best choice for the cleanliness of the environment, aerospace and even mathematical applications [1-3].

Thermal treatments play an important role in improving mechanical, thermal and physical properties. Heat treatment can be defined as the process of heating and cooling metals or alloys to obtain the required mechanical properties or restore properties lost during operations such as welding, forming, or removing the stresses generated on metals or alloys. In the product, whether from mechanical operation or production, the heating process is usually carried out in furnaces. As for the cooling process, it has several methods depending on the type of treatment that is conducted, such as cooling inside the oven or with air [4]. One of the most important points that distinguish the mechanical properties of the prepared samples is Vickers hardness test, which gives a well-defined value for the strength of the fabricated material [5]. The mineral powders used as a base in the composite materials are fortified with many reinforcing materials, which may be carbides such as TiC or SiC or ceramic materials such as Al₂O₃ [6]. The current study aims to determine the failure of samples manufactured under stress by compressive method and study the structural properties of the composites for the purpose of using them in many applications such as electric brushes and mechanical sliding bearings, among others, that require excellent mechanical and structural properties as well as low wear behavior.

2. The Practical Part

1. The Materials

Copper metal was used as the base material and manufactured by the Indian company (CDH), with grain size (44μm) and purity of 99.5%, while the first stable hardening material is alumina (Al₂O₃-α) manufactured by (Changsha Santech Co.) of Chinese origin with a granular size nm (30 ± 5) and a purity of 99.99%. The second variable reinforcement material is silicon carbide (SiC) manufactured by the German company (Merck) with a granular size (55μm) and a purity of 99.90%.

2. Sample Preparation Method

The used powders were dried at a temperature of (200°C) for a period of two hours in order to remove the moisture that would affect the properties of the prepared form. After that, the weights of the mixture of each component were prepared by following the weight ratios, so that the proportion of alumina is constant and in the amount of (10%) for all mixtures. Copper metal is the basis for all mixtures and both silicon oxide was in percentages of (0.5,10,15,20) %. Weighing was done by using a Japanese-origin Sartorius electron balance with an accuracy of (0.0001) grams. After the completion of the grinding and mixing process and obtaining a homogeneous powder for three different grinding times, samples were formed by means of uniaxial pressing technology in a hardened steel mold of (60HRC) hardness. The mixture was placed inside the press mold, which was carefully placed in the press to prevent any movement of the mold parts. Then, 5Ton pressure was applied for one minute to avoid the possibility of flexible return [7]. The hydraulic press used to prepare samples (HALIM USTA) type, of Turkish origin has a maximum pressure of (20Ton) in order to obtain samples from cylindrical samples with a diameter (10) mm and a height (6) mm. After the pressing process, since the samples were not ready for testing and had weak resistance, the green resistance, they required care when transporting and handling until the sintering process took place. The sintering process was carried out using a German-origin (CARBOLITE) furnace at a temperature of (900°C) for a time of only two hours, after which samples were extracted from the furnace to begin the examination process after preparing the surface of the samples.
Tests and Measurements

1. Compressive Strength Test

The compressive strength test was performed by using the Universal Testing Machine (HOYTOM) of Chinese origin, and the sample was placed on the examination platform. The load was then assigned to the sample diameter until the failure occurred and the maximum load was read from the digital screen of the device; the device could store the maximum value of the load before failure. The compressive strength is calculated from the relationship (1) [8],

\[ \sigma_D = \frac{2F}{\pi dh} \]  

where: \( \sigma_D \): compressive fracture resistance (MPa).

F: Impressive force (N), d: Diameter of the sample (mm), h: Thickness of the sample (mm).

2. Wear Rate Test

Wear is one of the important characteristics of material surfaces defined as the amount of material loss from the surface of the metal due to the friction of the moving parts. The impressed load was fixed at (10N), using constant slip velocity (r.p.m950), and the load incidence time for each test was (10 min). The wear rate test was performed using a device that works in the way of a screw on the disk (Pin - on - Disc). This method was employed because it was easy and gave the value of wear effectively by means of the difference in weight of the sample before and after operation: [10, 9].

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

where: \( W = \) wear rate (\text{gm/cm}), \( \Delta W = \) lost weight (gm), and the difference is represented by weight of the sample before and after operation.

\( SD = \) the slip distance (cm) and is equal to:

\[ SD = t \cdot V \]  

where: \( t = \) test time (min), while slip velocity (V) is:

\[ V = D \cdot \frac{n \cdot \pi}{60} \]  

\( n = \) rotational velocity of the disc (r.m.p), \( D = \) slip diameter (cm).

Thus, the wear value can be found using the following equation (5) [11].

\[ \text{Wear rate} = \frac{\Delta W}{2\pi t \cdot n \cdot 60} \]  

3. Atomic Force Microscopy (AFM).

Atomic force microscopy (AFM) is used to study the topography of the surface and the surface crystal structure of coating layers. This way, it is possible to calculate the grain size (Grain size), the average surface roughness rate, and the average square root value (Root Mean Square). The superpositions are important in knowing how their atoms are distributed and arranged on surfaces, and to identify differences or homogeneities in the properties or features related to each atom separately.
Results and Discussion:

1. The effect of additive content and grinding time on compressive strength.

Figure (1) shows the relationship between the content of SiC addition and the milling time on the compressive strength of composites with different SiC ratios. Regardless of the proportion of silicon carbide particles, increasing the content and grinding time increases the compressive strength of the compound, from (10.6-28.8) MPa for a grinding time of only two hours, from (15.2-40.5) MPa for a grinding time of only four hours and from (22.4-53.3) MPa for a grinding time of only six hours, and for all cases, at a silicon carbide content of (0-20%). This is attributed to the high resistance of the hardening particles, which leads to an increase in the hardness of the composites by increasing the silicon carbide content, in addition to resisting local deformations with high efficiency and thus forming coherent samples with high compressive strength. The high sintering temperature for a period of two hours has an important role in increasing the bonding strength between the particles. It also plays a significant part in the components of the composites through good diffusion and distribution, as well as the increase in density and decrease in the porosity ratios after sintering, which leads to support and armament of the superposed mass, and this is consistent with [12].

![Graph showing relationship between SiC content and compressive strength](image)

Figure 1. The relationship between the change in the size ratios of silicon carbide particles and the grinding time with the diagonal compressive strength after the sintering process.

2. The effect of adding and grinding content on the wear rate

Figure (2) shows the relationship between the change in the size ratios of the silicon carbide particles and the grinding time with the wear rate after performing the sintering process at a temperature of 900°C for a period of two hours. The wear rate decreased from (3.53036 * 10^{-7} – 1.81377 * 10^{-7}) g/cm at a grinding time of two hours, while the decrease rate at a grinding time of four hours was from (2.42915 * 10^{-7} – 1.54899 * 10^{-7}) g/cm and at a grinding time of six hours was from (1.94332 * 10^{-7} - 1.10368* 10^{-7}) g / cm at the silicon carbide content from (0%) to (20%). The decrease in the wear rate when increasing the content of the hardening and grinding particles is due to the fact that the composites are stiffer when the SiC particles are added. Therefore, there is less weight loss due to the strengthening of the foundation or the floor with the ceramic particles that impede the progression of the dislocations and the stresses in which the hardened
particles (SiC) resist are generated. Later, an inversion density is generated, and the difference in the thermal expansion coefficient has a major role in this process, which results in an increase in the hardness by increasing the content of the strengthening particles. Moreover, the wear rate decreases when adding SiC particles and in turn increases the hardness [13]. The rate of wear is inversely proportional to the hardness according to the following relationship [14].

\[ V = K \frac{W \cdot X}{H} \] (6)

Since: \( V \) = size of wear, \( K \) = coefficient (constant) of wear, \( W \) = vertical load, \( X \) = slip distance, \( H \) = material hardness.

![Figure 2](image.png)

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

3. Results of Atomic Force Microscope

Electron microscopy of samples were taken before and after heat treatment at 900°C for two hours. Figure (3) shows AFM microscopic images of the prepared samples before the sintering process in two and three dimensions, at different size fractions of silicon carbide, and at a milling time of six hours, which is the best milling time that gave encouraging results in physical and mechanical tests. It was found that the average square root (Root-mean-square height) for all proportions were as follows: (0% SiC = 48nm), (5% SiC = 47nm), (10% SiC = 43nm), (15% SiC = 35nm), (20% SiC = 31nm). The surface homogeneity of the models can be observed with the increase in the reinforcement ratios. The grinding process has a great effect on the homogeneity of the superpositions, and the smoothing process is due to the occurrence of cold formation of the particles. With the increase in grinding time, the forming percentage increases and subsequently the thickness of the inversion and the reactive solidity increase along with it. The ductility of the metal, however, decreases until the metal becomes brittle at the end up to an extent that no additional plastic formation can be accommodated. As for Figure (4), the AFM microscope image in two dimensions is 2D and in three dimensions 3D of the models after performing the sintering process at 900 °C for a time of only two hours. It was found that the average square root (Root-mean-square height) for each proportions were as follows (0% SiC = 56nm), (5% SiC = 53), (10% SiC = 48nm), (15% SiC = 37nm), (20% SiC = 26nm). It was also noted that the mean square root values after sintering increased from their values before sintering due to the increase in the bond strength between copper and silicon carbide due to the sintering temperature 900°C for two hours. Therefore, it helps to improve the interface of superpositions and improve the bonding between particles, regardless of the fact that the cold compression process itself results in superpositions with a green density that is much less than the
theoretical density. Thus it is logical that the bulk density is higher than the green density. The bulk density approaches the theoretical density as a result of the merger between the particles of the superposition during the sintering process. As noted, the total surface topography and the morphology of the grains formed on the surface have a high degree of homogeneity and arrangement after the heat treatment. The regularity in the growth of the superposed layer are observed and the grains are perpendicular to the crystal axis and the heights are approximately equal. silicon carbide particles are considered to be the centers of porosity polarization, whether before or after sintering [15,16. Less particles attract more porosity than particles with a larger grain size.
Conclusions:
The copper-based material is characterized by high durability if it is strengthened with materials of high strength and hardness such as alumina and silicon carbide, these materials gave a high diagonal compressive resistance that contributes to increasing the hardness of the base material, as also, the wear rate showed a decrease in its value, reaching \((1.10368 \times 10^{-7} \, \text{g/cm})\) at 20% reinforcement and after sintering, while atomic force microscopy showed that there is homogeneity of the surface of the models with high support ratios and in the two-dimensional and three-dimensional images.

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