Study of some of the physical variables of a metal-based system using the powder method

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Abstract. Some variables that in turn help improve the properties of copper, whether mechanical or physical, were studied. Copper was reinforced with carbide with excellent properties from WC and with different volumetric enhancement ratios (0,1.5,3,4.5,6) % . The powders were mixed and milled for a two-hour time, as the samples were pressed at (5) tons for a time of one minute, after which the prepared samples appeared at 950°C and for a time only two hours, various tests were conducted on the samples for the purpose of studying their physical and compositional properties and included a diffraction examination X-ray, real and apparent porosity, real and apparent density, compressive strength. The results were encouraging and gave the best values after sintering and at a 6% WC boost, if the minimum true porosity was 13.31%, while the apparent porosity was 9.22%, while the real density value was10.72g/cm³, and the highest apparent density was 11.22g/cm³. The radial compressive strength value is 132.7MPa.

Keywords: Mechanical Properties, XRD, Compressive strength, Powder method

1. Introduction :

Composite materials are defined as a mixture of two or more materials that give better specifications that are not available in either of the two materials separately, i.e. they have almost intermediate properties of the disparate materials included in their composition, so that the material then behaves as a single mass as it consists of two phases, the Reinforcement Phase. They are particles, fibers, whiskers, or plates surrounded by another phase, which is the ground or the so-called Matrix Phase [1,2]. Many modern technologies require a group of materials with distinct properties that cannot be obtained when using traditional alloys. Ceramic and polymeric materials have been used as engineering materials in space applications, underwater applications and some transport media applications. For example, aircraft engineers are looking for synthetic materials that have high resistance. It has low density and is resistant to impact, scratching and corrosion, and it is rare for these qualities to coexist. Therefore, the composite materials were the best solution to combine these contradictory characteristics. The composite materials received an abundant share of development research to meet the requirements of technical progress. One of the most important advantages of overlaying materials is the flexibility of design, as the engineer can add reinforcing materials with different shapes and shapes and design them so that he puts the fibers, for example, in the direction of the loads, which leads to the optimal use of the material and thus to a greater reduction in the weight of the final installation. Geometrically, on superimposed materials, it is weak in its ability to withstand dynamic shock loads, as this often causes a stratification of the material [3,4]. Powder metallurgy technology is one of the most important composite materials technologies, as it dates back to thousands of years B.C. It was called the lost art and was known during the early stages without sintering until it was known in Europe at the end of the eighteenth century when different methods of
producing platinum powder were recorded. Metal powders such as gold, copper, bronze and some oxides were known as materials for decorating ceramics and as a basis for paints, inks and cosmetics. Gold powder was also used in manuscript decoration [5]. The production of the powders was not known, but it could be obtained through granulation after melting the metal, as he preferred the property of low melting temperature and high oxidation resistance as is the case in gold powder due to the low potential available at that time. The use of powders for decorative purposes and dyes has become a thing of the past, as these powders are used in modern science to cement and harden solids by pressing and heating to temperatures lower than the melting temperature of the base metal [6,7]. The current work aims to improve the physical properties by adding copper strengthening materials, in other words that copper-based composites reinforced with carbide particles may have many and very distinct benefits such as: high mechanical properties, good compressive strength and low porosity, which can be greatly utilized in these systems. Manufacture of some internal combustion engines, gears, or aircraft parts.

2. Experimental Part

2.1 Raw Materials Used

Copper was used as the base material, with a grain size of 44µm and a purity of 99.5%, which was manufactured by the Indian company (CDH), while WC was the reinforcing material with a grain size of 74µm and purity of 99.8% and manufactured by (Changsha Santech Materials Co.).

2.2 Preparation of Samples for Measurement

The powders selected for both the base and the reinforcing materials must be dried in order to get rid of the moisture that negatively affects the physical and mechanical properties of the prepared samples. The materials were heated to (100°C) for half an hour in order to get rid of moisture and other volatile materials. Then, the weight of each component mixture was prepared by following the weight ratios; the copper percentage was the highest and it was considered the main material, and the WC was in percentages (0, 1.5, 3, 4.5, 6)%). Weighing was done using a Sartorius scale with an accuracy of (0.0001) grams and calibrated by the Central Agency for Standardization and Quality Control. After the completion of the grinding process within a time of two hours and mixing and obtaining a homogeneous powder, samples were formed by means of (Uniaxial) pressing technology in a hardened steel mold of (60HRC) hardness. The ground and mixture were 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. For this purpose, a hydraulic press of (HALIM USTA) Turkish origin with a press capacity of (20Ton) was used to obtain samples from cylindrical samples with a diameter (10) mm and a height (6) mm. After the pressing process, the samples were not ready for testing and had a weak resistance, green resistance, which required care when transporting and handling. The sintering process was carried out using a German-origin (CARBOLITE) furnace at a temperature of (950°C) and a time of only two hours.

3. Examinations and Measurements

3.1. X-ray Diffraction (XRD):

X-rays are known as monochromatic electromagnetic rays that are exactly similar to the nature of light, but with a very short wavelength ranging between (0.25-0.5), as they are produced in the X-ray tube by the collision of electrons with the target metal. The English scientist WL Bragg was able to find an important mathematical relationship to determine the distance between crystal levels using X-ray diffraction, as he relied on the fact that the atoms inside the crystal line up in distinct groups of levels, and when a beam of X-rays falls on these levels, they lie in all directions inside the crystal, from which the type of material and the phases formed inside the material are known by applying the following equation [8].

\[ 2d \sin \theta = n\lambda \]  

(1)
where: d: The distance between atomic planes, \( \varnothing \): diffraction angle (Bracke angle), \( \lambda \): wavelength.

n: An integer representing the order of the diffraction peak.

### 3.2. Density

Density is one of the most important properties of powder metallurgy technology products, as many applications require calculating and measuring the density of the body with high accuracy in order to identify the size of the pores inside the body and the size of the voids and gaps. In addition to determining the mechanical and chemical properties, it is involved in determining the thermal and electrical insulation properties of materials. [9,10,11]:

#### 1. Apparent Density

Represents the ratio between mass and apparent volume that includes only the actual material and the closed pores. The bulk density is calculated according to Archimedes' theory using the following relationship:

\[
A.D. = \frac{W_d}{W_d - W_i} \times \rho_w
\]

where: \( \rho_w \): The density of water (g/cm³), \( W_d \): The weight of the body when it is dry (g), \( W_i \): The weight of the body suspended in water (g).

#### 2. Bulk Density

It is defined as the ratio of the mass of a substance to its total volume, which includes the actual material and the open and closed pores. The volumetric density is calculated according to Archimedes’ theory using the following relationship:

\[
B.D. = \frac{W_d}{W_s - W_i} \times \rho_w
\]

where: \( W_s \): The weight of the body which is saturated with water (g).

### 3. Porosity

Porosity is expressed as the ratio of the volume of voids in the body to the total volume. The pores appear as open volumes inside the materials produced by powder metallurgy technology after the sintering process. The residual pores are inherent in powder metallurgy products and have undesirable effects on mechanical properties by becoming a focus of stress concentration, causing the product to fail when exposed to mechanical loads. At present, the size of the pores can be controlled and estimated in a way that serves the product and the nature of the work, as porosity may be required in some products such as self-lubricating mechanical filters and bearings and in the manufacture of vibration absorbing parts, silencers and other porous materials.

Likewise, the porosity can be divided in general into two types [12]:

#### 1. Apparent Porosity

It represents the ratio of open pores to the total volume of the body. The apparent porosity can be calculated according to Archimedes' theory from the following relationship:

\[
A.P. = \frac{W_s - W_d}{W_i} \times 100 \%
\]
The volume of closed and open pores represents the total volume of the body. The true porosity can be calculated from the following relationship [13,14]:

\[
T.P. = \frac{T.D. - B.D.}{T.D.} \times 100 \text{ %} \quad (5)
\]

T.P. : Total Porosity Ratio of Sintered Body, B.D. : Practical sintered body density (volumetric density) (g/cm^3), T.D. : Theoretical sintered body density (g/cm^3).

3.4. Compressive Strength:

The compressibility test is an opposite test for the tensile test, as the uniaxial impedent load is a compressive non-tensile load. This test is used to evaluate the fragile materials whose tensile stress value is much less than the compressive stress value \( \sigma_{\text{comp.}} > \sigma_{\text{tens.}} \). Such as metal parts manufactured by the method of powder metallurgy and many non-metallic materials such as ceramics, wood and bricks. Compression resistance is calculated by applying stress perpendicular to the section of the sample that is in a disk image. Compression resistance is calculated according to the following relationship [15]:

\[
\sigma_D = \frac{2F}{\pi dh} \quad (6)
\]

Since: \( \sigma_D \): compressive resistance (MPa), F: force (N), d: sample diameter (mm), h: the thickness of the specimen (mm).

4. Results and Discussion:

4.1. XRD Diffraction Analysis:

The study of X-ray diffraction is one of the important tests to know the type of material used within the superpositions, as well as observing the phase changes that occur with each increase in concentration or thermal sintering. It is also possible to know new phases that may be useful in improving the physical properties of the different composites, if Figure (1) shows X-ray diffraction results for superimposed (Cu-WC) and at different reinforcement values of WC are (a = 0%, b = 1.5%, c = 3%, d = 4.5%, e = 6%). Figure (1) the appearance of copper as a base material at the international card number (CardNO.96-901-2955), while the support material appeared at the card number (Card NO.96-150-1520), and what was noticed was the emergence of a new phase of metal oxide This can be attributed to the temperature that the samples were exposed to during the heat treatment, which gave them thermal energy that helped in the diffusion process between the grains of the materials forming the composites as well as increasing the effectiveness of the reaction The chemical among them that led to the formation of another phase is (WO_3), which has a high density of (7.16) g/cm^3 as well as An increase in the intensity of the other phases formed compared with the sintering process, and since these phases have high densities, an increase in their concentration in the composites after sintering means an increase in the density of the composites.
Figure 1. shows the X-ray diffraction of Cu-WC compositions at different support ratios and after sintering at 950°C.
4.2. Relationship of Reinforcement ratios with apparent porosity before and after sintering:

Through Figure (1) we notice the inverse relationship between the porosity and the change in the percentages of the hardener (WC) before sintering, as the apparent porosity decreased from (30.22%) to (17.99%), and in the same figure and after sintering at (950°C), we notice the decrease in the porosity as well. From (24.44%) to (9.22%), and all values before and after sintering are from a consolidation rate of (0%) to (6%). Therefore, the decrease in the porosity values of the compound was evident with an increase in the density and addition ratios, and this is consistent with the behavior [16]. And that the amount of the decrease in the porosity ratios may be due to the same reasons that led to the increase in density, and the reason for the decrease in porosity is also due to the fact that the thermal energy supplied to the atoms within the crystal pattern of the grains of the components of the complexes during the heating process increased their movement (vibration), which it was easy to allow the atoms to move between the corners of the crystalline pattern of grains, and this was reflected in the development of the diffusion process and the formation of new phases.

![Figure 2](image_url)

**Figure 2.** The relationship between reinforcement ratios and apparent porosity before and after sintering.

4.3. Relationship of Reinforcement ratios with True porosity before and after sintering:

Through Figure (3), we notice the inverse relationship between the true porosity and the change in the percentages of the hardener (WC) and that the amount of decrease in the porosity ratios is from (33.348%) to (19.255%) and the content of tungsten carbide from (0-6)% before sintering, while the decrease was from (25.290%) to (13.31%) and the content of tungsten carbide ranged from (0-6)% when sintering at a temperature of 950°C. This can be attributed to the temperature that the samples were exposed to during the heat treatment, which gave them thermal energy that helped in the diffusion process between the grains of the materials forming the complexes, which helped to fill the voids as well as increasing the effectiveness of the chemical reaction between the elements. As the thermal treatment had an effect on the decrease in the porosity ratios of the manufactured models, and the reason for the decrease in the porosity is due to the fact that the thermal energy supplied to the atoms within the crystal pattern of the grains of the components of the complexes during the heating process increased their movement (vibration), which facilitated the possibility of atoms moving between corners. The crystal pattern of the granules and this was reflected in the evolution of the diffusion process [17].
4.4. Relationship of Reinforcement ratios with Apparent Density before and after sintering:

Figure (4) shows the relationship between the bulk density and the change in the cementing ratios of tungsten carbide for (Cu-WC) composites before and after the sintering process at a temperature of (950°C) for a period of two hours only. Density and for all carbide ratios, for example, the density increases from (8.182 - 9.583) g/cm³ at the tungsten carbide content from (0%) to (6%), and after sintering the density increases from (8.945 - 11.22) g/cm³ when the tungsten carbide content is from (0). %) To (6%), and this increase can be attributed to the high density of tungsten carbide when compared with the density of copper [16], as well as the formation of phases resulting from the chemical reaction between the materials that make up the composites during the sintering process, as the increase in the cementation ratios of carbide has a high The high density and the sintering temperature in which the samples helped greatly increase the bulk density, which is an essential element in improving the physical and mechanical properties of the manufactured samples. Therefore, it is natural to increase the density by increasing the volumetric ratios of tungsten carbide [18].
4.5. Relationship of Reinforcement ratios with True Density before and after sintering:

Figure (5) shows the relationship of cementation ratios with tungsten carbide on the real density before and after sintering, as we note that the real density (green density) of the samples prepared before sintering increases from (8.082 g/cm$^3$) to (9.383 g/cm$^3$), while the density also increases. Actual after sintering from (8.545 g/cm$^3$) to (10.72 g/cm$^3$) at the content of tungsten carbide from (0-6)%. The reason for the increase in the density values can be attributed to the high density of tungsten carbide and heat treatment which helped to develop the gradual diffusion process between the components of the composite as well as the effect of the reaction on improving the properties of the interface between the tungsten carbide grains as the strengthening phase and the copper grains which represent the base phase. This increased the strength of the bonding between them and the formation of phases and oxides that may occupy the spaces between the grains of the combined materials [19]. From all of these reasons, it is natural to find the percentage increase in the density values after the sintering process than after the sintering process.

![Figure 5](image)

Figure 5. The relationship between reinforcement ratios and true density before and after sintering

4.6. Relationship of Reinforcement ratios with Compressive strength before and after sintering:

Figure (6) shows the relationship between the reinforcement ratio of WC and the compressive strength of a (Cu-WC) compound having different TCC ratios before and after sintering. The increase in the reinforcement ratios increases the compressive strength of the composite, regardless of the sintering in it, as the compressive strength increased from (51.33 MPa) to (91.21 MPa) before sintering, and it also increased from (80.11 MPa) to (132.7 MPa) after sintering, all of which are about the cementing content. Tungsten carbide from (0-6)%. This behavior is due to the same factors that led to the increase in the hardness values, as the increase in hardness is responsible for increasing the compressive strength by increasing the support content. As for the upward compressive strength, it takes the following order (pure copper <(1.5%) carbide <(3%) carbide <(4.5%) carbide <(6%) carbide. The reason for this is due to the work of tungsten carbide (WC) on the copper particles coating. Complete fusion and partial fusion are prevented, as the higher the percentage of tungsten carbide, the less the obstruction and the greater the bonding, and then the compression resistance increases [20].
Figure 5. The relationship between reinforcement ratios and compressive strength before and after sintering.

5. Conclusion:

The powder method is distinguished in the production of many systems used with different technological applications, and the current conclusion is the possibility of obtaining Cu-WC compositions using the method of powders where the identity of the materials used was known by X-ray diffraction, and the inverse relationship between the real and apparent porosity and the change of proportions was also observed. Stiffening material (WC) before and after sintering, as for the apparent and actual density results, it is noticed that the increase in the strengthened ratios of tungsten carbide is accompanied by an increase in the density and for all carbide ratios before and after sintering. We find that the best cementing ratio is 6%, and the thermal sintering is 950°C.

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