Enhancement The Properties of Aluminum by Adding Boron Carbide by the Powder method

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Abstract: Powder technology can be used in many different applications that require strength in durability and lightness in weight such as aircraft parts and internal combustion engines, the current work includes this technology to produce models from a mineral base of (Al) aluminum and reinforced with Al₂O₃ with a fixed rate of 5%, and with different proportions of boron carbide. B₄C is (0,5,10,15,20) %. The preparation process was done by mixing the powders for three consecutive times (2,4,6) hours using of a homemade mill containing steel powder and steel balls, a hydraulic press was used for the purpose of the formation of samples at a pressure of (100 bar) and for a time of one minute, and the sintering process was carried out at 560°C and for a time of two hours by means of an English furnace of origin. Included (true density and porosity), the results showed that the X-ray diffraction between the identity of the materials used is clearly observed, noting that the intensity of the phases increases with each grinding time and that the true density decreases with the increase of the support ratios while the real porosity is the one that increases with Each increase in cementing ratios, as for the hardness, was increased with the increase in cementing ratios, and it was thus found that the best grinding time gave good physical, mechanical and structural properties was six hours, and the best reinforcement percentage wear 20% B₄C when sintering at 560°C.

Keywords: Mechanical properties, Physical properties, Reinforcement, Structural properties

1-Introduction:

The alloys obtained from metal powders are called pressing and then sintering without smelting powdery alloys, and the Russian scientist b. Sobolyevsky preceded the use of powdery alloys industrially. In the year 1827 AD, a method was used to obtain coins (coins) from platinum powder by pressing, then sintering and forging [1].

Powder metallurgy is the technology of mineral preparation processes through which parts are produced with different shapes from metal powders, as the powders are pressed to obtain the desired shapes and then these parts are heated through a process called sintering in order to cause the bonding between the particles to obtain a coherent mass (Rigid Mass) The compression process is carried out at certain pressure levels by using a press machine with a number designed and manufactured for this purpose, namely the mold and the press, and the subsequent sintering process is performed at a temperature lower than the melting temperature of the base material, and this method is used either because of the difficulty of producing these alloys by the casting process because its components are not mixed. In the liquid state or the difficulty of melting it, the interest in the type of each of the base materials and the reinforced materials and their specifications and knowledge of their characteristics make us determine the type of material required to be produced and the field in which it can be used, for example in the field of space has created composite materials of low density that bear high
temperatures, and in the field of Medicine and for the purpose of compensation for the human body parts made of composite materials with high specifications and techniques against corrosion and shattering [2,3]. Metal-based composite materials reinforced with ceramic materials were used to improve the mechanical properties of the new material. The use of an aluminum-based composite material shortened distances in the development of engineering materials as it showed more advanced properties than traditional aluminum alloys, and with the development of modern cheap forming methods and the adoption of modern materials significantly and largely in modern industries [4]. The development of the industry 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 [5]. Powder metallurgy technology is of great importance when compared to other technologies because of its high potential for producing composite materials that consist of a number of metals and their alloys that are not alloyed at all with each other while in a state of fusion, for example contact cutters for electrical purposes can be manufactured from tungsten steel that resists corrosion and soft silver with high electrical conductivity. This technology has the advantage of producing complex shapes as well as being less expensive than other technologies because there is no production waste and it is even better for the cleanliness of the environment [6]. The aim of our study is to improve the properties of aluminum through the joint reinforcement of aluminum with two ceramic materials, namely alumina and boron carbide, by fixing the weight ratio of alumina and changing the addition of weight ratios to boron carbide, and studying the effect of changing the weight ratios on the structural and physical properties of the composite material.

2- Raw Material:

The matrix material was used from aluminum (Al) with a grain size 53≤μm of German origin from the company (Riedel-de Haën) with a purity of 99% and also a fixed percentage of alumina Al2O3 with a grain size 63≤μm of German origin was used from the company (Fluka) with a purity of 99.99%. As for boron carbide, it has a purity of 99.8%, with a grain size of 25µm, and is manufactured by the Chinese company, Changsha Santech Materials Co.

3- Experimental procedure:

The weights of the raw materials were prepared using a sensitive scale (Sartorius) of Japanese origin with accuracy (0.0001) grams, and the preparation of the raw materials includes homogeneity of mixing the powders, which is one of the necessary and important processes to ensure homogeneity and good distribution between the powders from which the composites are formed, and the mixing process was carried out for all proportions. The gravity of the powders using a homemade milling device that contains a steel powder that rotates by a small motor and rotates at a rate of 500 revolutions per minute, if the powders are ground at three different times it is (2,4,6) hours in order to know the effect of the milling times on the properties of the prepared samples, after the completion of Homogenizing the powders with the mixing process, the samples were pressed into a steel mold of (13mm) hardened hardness in one direction (60HRC) and in one direction (uniaxial), where the mold was hardened by and then rapid cooling with 850°C placing it in an electric oven for about an hour at a temperature of water with constant stirring. The molds are one of the basic elements in the pressing process because through them we can obtain presses according to the required shapes and dimensions, and the powder mixture was placed inside the pressing mold and then applied pressure of 100 bar for a period of time. Attention to avoid the possibility of soft return [7,8]. The pressing process was carried out by using a hydraulic press (HALIM USTA) type of Turkish origin with a press capacity of (20Ton), after the pressing process was completed, the presses are ready for the sintering process, and the sintering process of the compressed is carried out by the use of an electric oven (Electric Muffle Furnace) type [CARBOLITE] English origin with a temperature range up to 1100°C, the samples were placed inside a special powder for sintering and the samples were immersed inside the sand to prevent oxidation during the sintering process, and the furnace temperature was raised to (560 °C), which is the
sintering temperature at a rate of (5 °C/Min) and keep the pies inside the containers inside the oven for two hours, then turn off the oven and cool the pies inside the oven slowly to room temperature [10,9]. After that, the samples were cleaned well and prepared for physical and mechanical tests.

4- Structural and Physical tests:

1- X-Ray Diffraction Test

X-rays are a type of electromagnetic energy or electromagnetic radiation and are monochromatic, these rays are characterized by their penetration into human skin and reaching the bone and have a very short wavelength of up to (0.5-0.25) Angstrom, where the X-rays are produced in the X-ray tube by the collision of electrons. With target metal. The English scientist W.L.Bragg found a mathematical relationship to find the distance between the crystal levels using X-ray diffraction, and this relationship depends on the fact that the atoms inside the crystal line up in distinct groups of planes, so when a beam of X-rays falls on these levels, they lie in all directions inside the crystal, where it is possible to know the type of material and the phases formed inside the material using the following equation [11,12].

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

As: \( d \): The distance between atomic levels, \( \theta \): Diffraction angle, \( \lambda \): wavelength, \( n \): Integer number representing the order of the peak of the diffraction.

2- Density and Porosity:

One of the most important metallurgical tests for composites produced by powder metallurgy technology are density and porosity tests due to their importance. Green density is one of the important properties of powders and it has a great effect on densification, and that improving green density helps in obtaining smooth and regular compressions that can be determined through the relationship (2) [11]:

\[ \rho = \frac{M}{V} \]

As: \( \rho \): represents the green density (g/cm³), \( M \): represents the mass of the compressed (gm), \( V \): the compressed volume (cm³).

But the green density was determined in our current study based on Archimedes Principle's theory, and the physical examinations and tests represented by green density, volumetric density and true porosity were performed based on following Archimedes' rule method based on the international standard (ASTM C373 -88). A sensitive, accurate electrical balance (0.0001g) according to the following:

1. The presses were dried for one hour at a temperature of (150°C) using a Memmert electric oven. It was left to cool in the oven, and the press was weighed after it was removed from the oven to obtain a dry weight (Wd).
2. Distilled water was brought and treated in four stages, and distilled water was boiled for 5 hours and the compressed inside it, and after that, the compressed water was transferred to containers containing distilled water and kept for 24 hours at room temperature, then the garnets were removed and the water remaining on the surface was carefully removed. Then weigh the depressions to obtain the saturated weight (Ws).
3. The pellets were weighed while suspended and immersed in distilled water by means of a sensitive suspension scale located in the Metallurgical Laboratory of the Mechanical Engineering Department at Tikrit University, to obtain the suspended weight (Wi).

Below are the mathematical relationships of the aforementioned tests, [15-13].
Theoretical Density:
\[ \rho_{th} = \sum \rho_i \cdot X_i \]  
(3)

As: \( \rho_{th} \) = the theoretical density (g/cm\(^3\)), \( \rho_i \) = The theoretical density of the elements composing a single compressed (g/cm\(^3\)), \( X_i \) = The weight ratio of each component in the compressed.

Bulk Density:
\[ \rho = \frac{W_d}{W_s - W_i} \cdot \rho_w \]  
(4)

As: \( \rho \) = Volumetric density (g/cm\(^3\)), \( \rho_w \) = density of used liquid (water) (1g/cm\(^3\)), \( W_d \) = The dry weight of the pressed in grams, \( W_i \) = The suspended weight of the pressed in grams, \( W_s \) = The saturated weight of the pressed in grams.

True Porosity:
\[ T.P\% = \frac{\rho_{th} - \rho}{\rho_{th}} \cdot 100 \]  
(5)

Since: T.P\% = Percentage of true porosity, \( \rho_{th} \) = Theoretical density, \( \rho \) = Volumetric density.

3-Hardness Test:

The method adopted in this study is the Brinell method, which is used to measure the hardness of minerals that have relatively high porosity because it gives a larger area of the body whose hardness is to be measured compared to other methods. The Brinell device consists of a cylinder from which a cone hangs from which a cone is fixed with a ball called the Brinell ball. This ball shall be made of hardened steel with different diameters (1, 2, 5, 10) millimeters. As a result of the effect of the specified standard load on the ball, it penetrates into the body whose hardness is to be measured, leaving a semi-spherical effect whose diameter \( d_b \) can be measured. Knowing the measurement of the diameter of the ball used in the measurement \( D \) with the impacted load \( F \), we can find the amount of hardness by the following equation [16]:

\[ HB = \frac{2F}{\pi \cdot D \cdot (D - \sqrt{D^2 - d_b^2})} \]  
(6)

5- Result and Discussion:

1- X-ray diffraction analysis:

The study of the samples prepared by the X-ray diffraction method is one of the very important elements of the examination in order to benefit from them to know the identity of the materials used in the work as well as to follow the changes that occur with the increase in the milling time on the initiator and the effect of the sintering process on the overlays. In figure (1) it gives the x-rays diffraction after mixing and grinding the powders in two hours, then pressing and sintering at 560 ° C for a time of two hours, while figure (2) represents the diffraction of X-rays after mixing and grinding the powders in a time of four hours and then pressing and sintering them, while figure (3) represents the diffraction of X-rays after mixing and grinding the powders in six hours, then pressing and sintering them, while figure (4) gives X-rays diffraction with a support rate of 20% and for three different grinding times (2,4,6) hours, that all the shapes in each of them are at strengthening concentrations With boron carbide \( (B_4C)\% \) (a = 0, b = 5, c = 10, d = 15, e = 20), then we notice in all shapes the appearance of the aluminum base material \( Al \) in the cubic system according to the
international card (96-431-3215), as for the first support material alpha-alumina \( \alpha-Al_2O_3 \) in the hexagonal crystal system and with the international card (96-900-7497), while the second support material is boron carbide B4C with a Trigonal crystal system. Little phase changes, but all the compositions were stable and regular, with a crystal growth observed with increasing milling time and at all different concentrations.
Figure 1. X-ray diffraction of different concentrations and at a milling time of two hours after sintering.
Figure 2. X-ray diffraction of different concentrations and at a milling time of two four after sintering.
Figure 3. X-ray diffraction of different concentrations and at a milling time of two six after sintering.
Figure 4. X-ray diffraction with a support rate of 20% for three different grinding times (2, 4, 6) hours.
2-Effect of Milling Time and boron carbide content on bulk density:

Figure (5) shows the relationship between grinding time, boron carbide content and volumetric density of different percentages of boron carbide before and after the sintering process and at a milling time of only two hours, as the density before sintering decreases from (2.129-1.960) g/cm$^3$ and after sintering by 560°C from (2.314-1.964) g/cm$^3$, as also in Figure (6), after a four-hour milling time, the density before sintering decreases from (2.276-1.883), g/cm$^3$ and after sintering by 560°C, it decreases from (2.406-2.007) g/cm$^3$. Also, according to Figure (7), after a six-hour milling time, the density before sintering decreases from (2.391-1.986) g/cm$^3$ and after sintering by 560°C, it decreases from (2.674-2.128) g/cm$^3$ and at all milling times, the percentage of cementing with boron carbide is reduced at all milling times. From (0%) to (20%) of B$_4$C, and it is noticed through the figures that the increase in the grinding time has led to a decrease in the bulk density and for all the proportions of boron carbide in the composites and this may be attributed to the increase in the percentage of cold forming by increasing the milling time and the accompanying increase in hardness And flow stress and a decrease in ductility, which is a standard for plastic formation, and this leads to an increase in the powder's resistance to compression and plastic formation with an increase in the milling time. Accordingly, the density of the compressed compound decreases, and both [17] and [18] have reached a similar result for materials of the mineral base. The smoothing of the aluminum particles also plays an important role in the decrease in the bulk density by increasing the milling time, and clumps form during grinding, as the decrease in particle sizes leads to an increase in the number and percentage of pores and then reduces the density, and the weak density of boron carbide also leads to a decrease in the density of the composites (2.52 g/cm$^3$) and increasing its content will necessarily lead to a decrease in the density of the composite.

![Figure 5](image.png)

**Figure 5.** Shows the relationship between milling time boron carbide content and volumetric density of different percentages of boron carbide before and after the sintering process.
3. The effect of Milling time and content of boron carbide on true porosity:

The true porosity (closed porosity and open porosity) increases with increasing grinding time and boron carbide content, as Figure (8) shows the relationship between boron carbide content and true porosity and at a two hour grinding time, if it is noticed through the shape and before sintering that the porosity increases from (36.27-28.41)% After sintering it also increases from (34.15-26.02)%%, while figure (9) shows the relationship after a four-hour grinding time, if it is noticed through the shape and before sintering that the porosity increases from (32.59-22.20)% and after sintering it also increases from% (28.44-20.37), and figure (10) shows the relationship of cementing ratios with porosity and at the milling time six hours through the shape and before sintering that the porosity increases from (27.01-15.34)% and after sintering it also increases from (20.25-9.98%), and at all times Grinding of the fortification of boron carbide from (0%) to (20%) of B$_4$C. This behavior is attributed to the same reasons that were mentioned in the above two items. What attracts attention when comparing these shapes with the bulk density shapes is the very large effect of the boron carbide content on both true porosity and bulk density when compared to the effect of milling time. This result suggests that boron carbide is the dominant factor controlling the percentage of true porosity and thus the bulk density and has a clear action in covering, encapsulating and isolating aluminum particles from each other, hindering partial fusion and preventing complete fusion between particles during the sintering process in addition to hindering or preventing volumetric contraction. As for the smoothing
of aluminum particles and forming clumps from them, and increasing their resistance to the plastic formation and compression by increasing the milling time, it is a reinforcing factor in determining these two properties and is not controlled or controlled. [19,20,21] have reached similar results for a metal-based compound after the sintering process.

**Figure 8.** The relationship of boron carbide percentage and two hours grinding time to true porosity before and after sintering.

**Figure 9.** The relationship of boron carbide percentage and four hours grinding time to true porosity before and after sintering.

**Figure 10.** The relationship of boron carbide percentage and two hours grinding time to true porosity before and after sintering.
4-Effect of milling time and boron carbide content on hardness:

Figure (11) describes the relationship of boron carbide content with Brinell hardness and at a two-hour milling time before and after sintering, as we notice an increase in hardness with an increase in boron carbide reinforcement rates, as before sintering it increased from (62-95) while after sintering at a degree of 560°C for a time only two hours increased from (77-118), while figure (12) gives the relationship of boron carbide content with hardness and at the time of milling is only four hours, and before sintering the hardness increases from (78-122), while after sintering it increases from (90-130). As Figure (13) shows the relationship of boron carbide content with hardness, and at the time of milling is only six hours, and before sintering the hardness increases from (92-137), while after sintering it increases from (129-182), and at all milling times the ratios were from (0%) to (20%) of boron carbide. This behavior can be attributed to increasing the perivitelline hardness to several factors that reinforce each other in achieving this large increase, on top of which is the smoothing of aluminum-alumina-carbide particles during grinding and agglomeration of aluminum base particles as a result of cold welding. With the effect of the methods shed by the steel grinding balls, as both smoothing and agglomeration increase both the surface area and the contact area of the particles and improve the bonding between them as a result of solid state spread during the sintering process at a temperature of 560°C and achieve the state of fusion because sintering is a basic and very important factor in the convergence and homogeneity of powders. Mineral and ceramic. The increase in milling time also increases the percentage of cold forming and increases the involution density. During the sintering process, re-crystallization occurs within these particles, and the higher the cold forming ratio, the smoother the structure resulting from recrystallization, and with it the surface area of the crystalline boundary increases and the higher values hardness and this is consistent with what he went to [6] when using metal-based materials. The increased grinding time also leads to a uniform distribution of boron carbide particles in the compound, which leads to better bonding between the composites and higher hardness values.

Figure 11. The relationship of the percentage of boron carbide and the milling time two hours to the Brinell hardness before and after sintering.
Figure 12. The relationship of the percentage of boron carbide and the milling time four hours to the Brinell hardness before and after sintering.

Figure 13. The relationship of the percentage of boron carbide and the milling time six hours to the Brinell hardness before and after sintering.

Conclusion:

The important conclusion of the compresses from the (Al-Al₂O₃-B₄C) system is that they can be manufactured with different support from boron carbide, thus helping the carbide to improve the properties of aluminum, as the structural properties represented by the X-ray diffraction of the prepared samples were studied and with three different grinding times (2, 4, 6) hours, and during that examination, we notice that there are no significant phase changes, but all the compositions were stable and regular, noting the presence of crystalline growth with an increase in milling time and at all different concentrations, and as the real density was studied and for three grinding times also, it was found that at all milling times there is a decrease with the values of the volumetric density, as for the results of the real porosity, there was a gradual increase in the values of porosity with the increase of the reinforcement with boron carbide, as for the value of Brinell hardness, it was taking an increase from the beginning of the reinforcement to the last percentage of the reinforcement, which was 20%. Conduct a thermal sintering process.

Authors' declaration:

-Conflicts of Interest: None.

-We hereby confirm that all the Figures and Tables in the manuscript are ours.
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