Preparing and Studying Some Mechanical Properties of Aluminum Matrix Composite Materials Reinforced by Al_2O_3 particles

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Abstract

The aim of this work is preparing and studying some of mechanical properties [Brinell hardness (BHN) and compression strength] of aluminum matrix composite material that reinforced by (3, 6 , 9 , and 12 wt.%) Al_2O_3 particles. Powder technology technique is used in samples preparing. Samples were compacted by using single action pressing then followed directly by sintering process at 500°C under the effect of inert gas conditions

Results were showed an advancing in the Brinell hardness (BHN) and compression strength especially at 12 wt.% α- Al_2O_3. The development in the Brinell hardness (BHN) and compression strength were found to reach 89% and 54% respectively from the initial properties of unreinforced aluminum samples.

Key words: MMCS, Composite, Powder metallurgy, Aluminum, Mechanical properties.

تحضير ودراسة بعض الخواص الميكانيكية لمادة مركبة ذات أساس ألمنيوم مدعم بدقائق Al_2O_3

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يهدف البحث الحالي إلى تحضير ودراسة بعض الخواص الميكانيكية (صلادة برينل ومقاومة الانضغاط) لمادة مركبة ذات أساس من الألمنيوم مقوى بدقائق الألومينا وبنسب وزنيه (3, 6, 9, 12wt.%). استخدمت تكنولوجيا المساحيق في تحضير النماذج حيث تم كبس النماذج بأسلوب أحادي الاتجاه و تلى ذلك تلبيدها بدرجة حرارة 500°C في جو خامل.

أظهرت النتائج إن تقوية الألمنيوم بدقائق الألومينا يظهر تحسنا في صلادة برينل ومقاومة الانضغاط وخاصة عند نسبة تقوية 12 wt.%. حيث بلغ مقدار التحسن في صلادة برينل ومقاومة الانضغاط للمادة المركبة 89% و 54% على التوالي بالمقارنة مع الألمنيوم غير المقوى.

الكلمات الرئيسية: MMCS, المواد المركبة, ميتالورجيا المساحيق, ألمنيوم, الخواص الميكانيكية.

1.**Introduction:**

An increased interest is observed in last years in metal matrix composite, mostly light metal based, which have found their applications in many industry branches, among others in the aircraft industry , automotive, and armaments ones, as well as in electrical engineering and electronics, etc.(Vukcevic and Delijic, 2002).

The metal matrix composite can be reinforced with particles, dispersoids or fibers. However , the biggest interest in composites materials is observed for those reinforced with hard ceramic particles due to the possibility of controlling their tribological, heat or mechanical properties by selection of the volume fraction, size, and distribution of the reinforcing particles in the matrix (Mrowka- Nowotnik et. al.,2007). They are used more often, compared with the composite materials of other metals, due to the broad range of their properties, and also due to the possibility of replacing the costly and heavy elements made from the traditionally used materials (Dobrzanski et. al.,2006).

Particle reinforced metal matrix composite represent a group of materials where the hardness, resistance of the reinforcement are combined with the ductility and toughness of a matrix materials. Aluminum is the most frequently use matrix material due to its low density. Because of its extreme hardness and temperature resistant properties, Al_2O_3 ceramic particles are often used as a reinforcement within the aluminum matrix. This type of composite is more frequently used in the automotive industry today, particularly in various engine components as well as brake an rotors (Muller and Monaghan, 2001).

Two main development directions of manufacturing metal matrix composite materials technology are observed: Casting method and powder metallurgy. The casting process is the most economical process. However, it has some restrictions due to the matrix alloy and density of the reinforced phases. Therefore, the volume fraction and the size of the reinforcements that can be added are very limited. It is also possible that some defects (e.g. voids because of shrinkage) can form in the cast(Yilmaz and Buytoz, 2001).

The powder metallurgy route is more widely used for the manufactured of metal matrix composite system because it offers some advantages compare to other methods. One of the main advantages of this process is the lower temperatures, hence decreased possibility of chemical reaction between the matrix and reinforcement phases. Other advantages include the possibility of incorporating many types of matrices and reinforcement phases in the same composite system. In addition, a higher fraction of reinforcement particles may be included in the composite when compared against the rheological limitations of casting process (Gheorghe and Rack, 2000).

A good example is aluminum-aluminum oxide composites, for which the presence of the ceramic increases substantially the elastic modulus of the metal without greatly affecting its density. However, the level of improvement depends on the shape and alignment of the aluminum oxide. Also, it depends on the processing of the reinforcement. Other properties, such as the strength of metal matrix composites, depend in a much more complex manner on composite microstructure. The strength of particles reinforced composite, for example, is determined by fracture processes, themselves governed by a combination of micro structural phenomena and features.

These include plastic deformation of the matrix, the presence of brittle phases in the matrix, the strength of the interface, the distribution of flaws in the reinforcement, and the distribution of the reinforcement within the composite. Consequently, predicting the strength of the composite from that of its constituent phases is generally difficult (Johnson et. al., 1994).

Aluminum based composite materials are leading ones in this area, they are fabricated using many methods, including powder metallurgy processes, and then formed, e.g., by hot extrusion. Powder metallurgy makes materials properties relatively easy to control by mixing materials with different properties in various proportion (Chen et. al., 1998).

The combined attributes of metal matrix composites, together with the costs of fabrication, vary widely with the nature of the material, the processing methods, and the quality of the product. In engineering, the type of composite used and its application vary significantly, as do the attributes that drive the choice of metal matrix composites in design. For example, high specific modulus, low cost, and high weld ability of extruded aluminum oxide particle-reinforced aluminum are the properties desirable for bicycle frames. High wear resistance, low weight, low cost, improved high temperature properties, and the possibility for incorporation in a large part of unreinforced aluminum are the considerations for design engine pistons (Ranjbaran, 2010) (Kozma, 2003).

The goal of this work is to prepare and study the mechanical properties (Brinell hardness (BHN) and compression strength) of aluminum matrix composite material reinforced by (3 , 6 , 9 , and 12 wt.%) α-Al_2O_3 by using powder metallurgy method.

2. Experimental work

Laboratory high purity materials were used in this work consisted of aluminum powder (50-150 μm in particle size) (Riedel-de Haen AG-Germany), α-alumina powder (70-210 μm in particle size) (BDH Chemicals LTD Poole England), and Paraffin oil as moulding release. Tables 1 and 2 illustrate some mechanical properties of aluminum and α-alumina powders respectively. Initially, α-alumina particles were added to aluminum powder in different weight ratios (3, 6, 9, and 12 wt. %) using Sartorius electronic balance with an accuracy of ± 0.1 mg. The powders were mixed thoroughly in a ball mill at 300 rpm for 180 min. with the addition of n-hexane (n-C_6H_{14}) in order to prevent powders oxidation due to frictional heat. The mixed powders were then dried at 75 °C for 10 h.

Mixed powders according to the above weight percentages were pressed at (250 kg/ cm^2) in a special mould to get the compression strength test samples according to (ASTM- D 618) using hydraulic press type (Leybold Harris No. 36110). Die wall lubrication was applied by brushing a thin layer of graphite powder over die cavity and the top punch. Sintering was carried out at 600 °C for 3 hrs. In the furnace and slow cooling until reached room temperature in an argon atmosphere.

Microstructure analysis was carried out under light optical microscopy. The sintered density was determined by weighing the samples in both air and water. Hardness values and compression strength was determined by using Universal testing machine.

3. Results and Discussion

Fig. 1 shows the diffractograms from the surface of α-(Al_2O_3) particles. Whereas Fig. 2 shows the standard diffractograms of α-Al_2O_3.

The microstructures of as polished aluminum reinforced by 6 and 12 wt.% α-Al_2O_3 particles composite are shown in Figure 3 and Figure 4 respectively. Alumina particles appear darker than the aluminum matrix. Clustering of the alumina reinforcements is pronounced in the lower weight fraction composite (6 wt. % α-Al_2O_3) and can be described as islands surrounded by the aluminum matrix with much more lower density of the reinforcement (Figure 3). The reinforcements, on the other hand, appear homogeneously distributed in the 12 wt. % α-Al_2O_3 composite (Figure 4). However, porosity can be viewed. Porosity may be due to improper compaction or particles pull out during grinding and polishing.

In the processing of powder materials using powder metallurgy route, green compact was sintered to decrease the porosity and increase the density. In general, the change in density depends on the kind of powder materials and the sintering conditions such as temperature and time. However, for a green compact made from mixed composite powders (Al and α-Al_2O_3 powder), the density change is affected not only by sintering conditions but also influence by the combination and weight fraction of the composite powders. The density of composite increases with the increasing amount of α-Al_2O_3. This is because density of Al_2O_3 powder (3.72 g/cm^3) is higher compared to the density of aluminum powder (2.7 g/cm^3) (Ahmad et. al., 2007).

Table 3 showed true density, apparent density , porosity ratio, and water absorption ratio before and after sintering process for aluminum reinforced by (9 wt.%) of α- Al_2O_3. All these values were measured according to ASTM- C-329/1988.

Fig. 5 show the Brinell hardness values versus the increasing weight fraction of α-Al_2O_3. The hardness value increases with weight fraction of α-Al_2O_3 particles. Unreinforced aluminum has the lowest Brinell hardness value (105) whereas aluminum composite reinforced with 12 wt.% of α-Al_2O_3 particles has the highest Brinell hardness value (199). This explains that, with the increasing number of hard alumina particles, the hardness of the aluminum matrix will increase. This is belongs to the high hardness values of α-alumina particles in comparison to Al hardness and to the good bonding between the reinforcement and matrix phases.

The presence of α-alumina particles in the microstructures can impede the movement of dislocations since these particles are stronger than the matrix. The degree of strengthening produced also depends on the size of particles, their distance apart and the tenacity of the bond between particles and matrix. Since that the particles are stronger than the matrix, the dislocation cannot pass through them, but if the stress is high enough, the dislocation can by-pass them leaving a dislocation loop around each particle. This will make the passage of a second dislocation much more difficult, particularly since dislocations have greater difficulty in passing between particles which are near to each other (Higgins R. A.,2006)

Results showed in Fig. 6 that the increasing in compression strength values of aluminum composite continuously with the increasing of α-alumina particles until reaches maximum value (276 MPa) at 12 wt.%. α-alumina particles. This behavior related to the role of reinforced particles in resist the growth and propagation of cracks and also the increasing of material resistance to deformation(Smallman and Ngan,2007).

Rodriguez et. al. (Rodriguez et. al., 2006) explain that, microstructure and mechanical response of the matrix is modified due to the reinforcement the grain size of the matrices is reduced respect to the unreinforced alloys, it is observed a higher dislocation density in the matrices and the nucleation of incoherent precipitates is favored by the presence of reinforcements due to the higher defects density. For these reasons the matrices are expected to be harder than the unreinforced alloy.

4.Conclusions

1. The production of aluminum reinforced by α-Al_2O_3 particles composite in the form net shape component can be achieved by use of conventional powder technology route cold uniaxial pressing and sintering processing technology.
2. Results showed that adding 12 wt. % of α-alumina particles to aluminum as a metal matrix improves Brinell hardness (BHN) by 89%, and compression strength by 54%.
3. These composite materials appear to be promising materials for industrial purposes.

5.References

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Table. 1: Some mechanical properties of aluminum powder (Callister, 2003)(McColm,1983)

Density(kg/m^3)	Modulus of Elasticity (GPa)	Tensile Strength (MPa)	Thermal Conductivity(W/m. °C)
2700	71	60	247

Table. 2: Some mechanical properties of aluminum oxide powder (Callister, 2003)(McColm,1983).

Density(kg/m^3)	Modulus of Elasticity (GPa)	Tensile Strength (MPa)	Fracture Toughness (MPa. $m^{0.5}$)	Thermal Conductivity(W/m. °C)
3720	304	282.55	4.2- 5.9	39

Table. 3: True density, apparent density, porosity, and water absorption of Al-composites reinforced by 12 wt.% of α-Al_2O3 particles.

Parameters	Units	Before Sintering	After Sintering
True density	g/ cm^3	2.67	2.87
Apparent density	g/ cm^3	2.28	2.62
Porosity	%	23.48	8.59
Water absorption	%	10.25	3.27

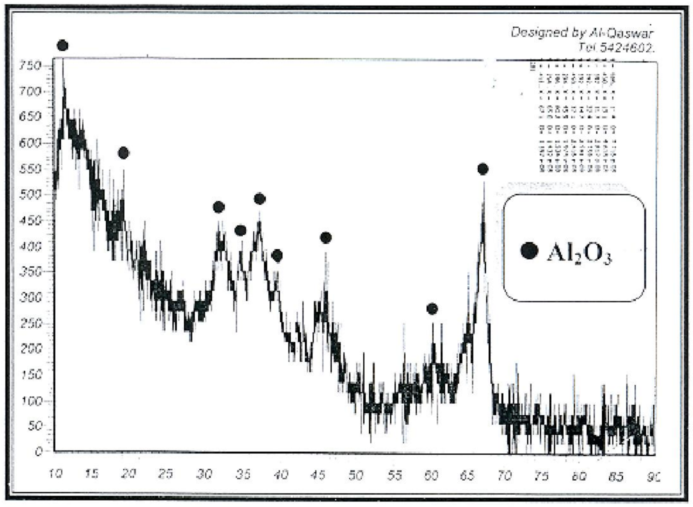

Fig. 1: **Diffractograms from the surface of α-(Al_2O_3) particles.**

Fig. 2: Standard Diffractograms of α-Al_2O_3

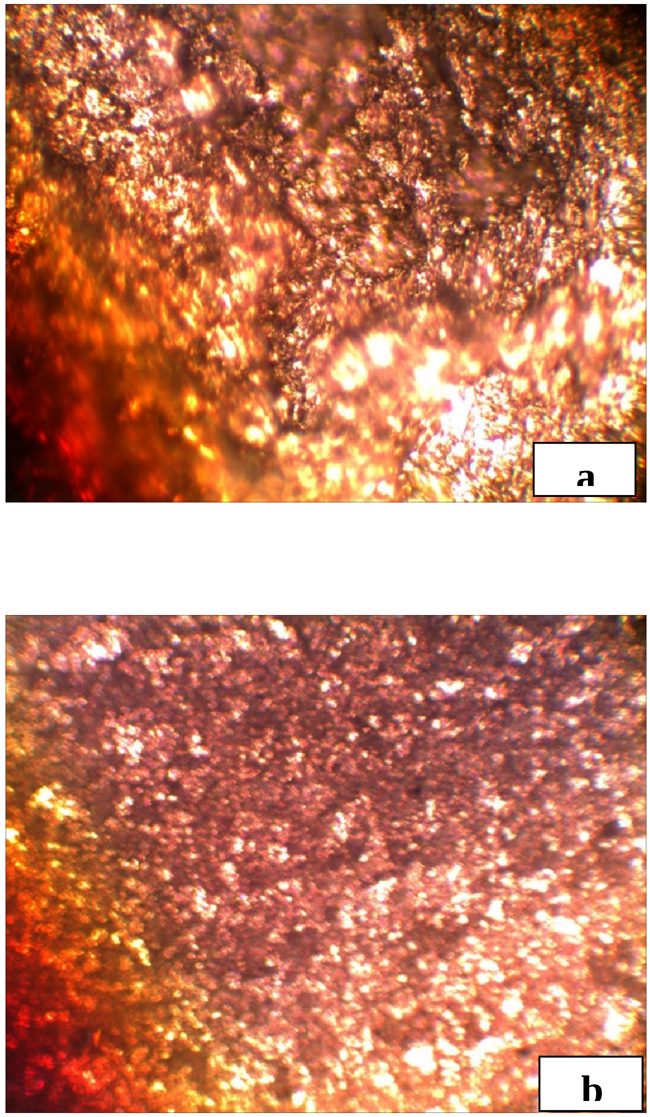

Fig. 3: light optical micrograph for as polished aluminum reinforced by 6 wt.% α-Al_2O_3 particles (a) before sintering process, (b) after sintering process Alumina particles appear darker than the aluminum matrix.

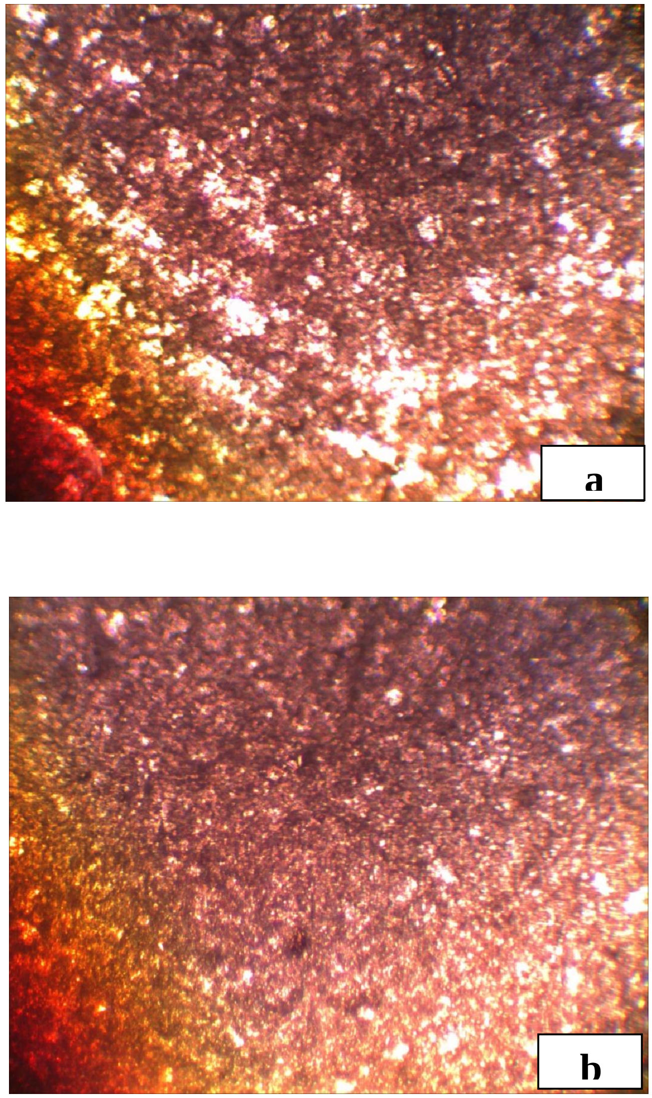

Fig. 4: light optical micrograph for as polished aluminum reinforced by 12wt.% α-Al_2O_3 particles (a) before sintering process, (b) after sintering process Alumina particles appear darker than the aluminum matrix.

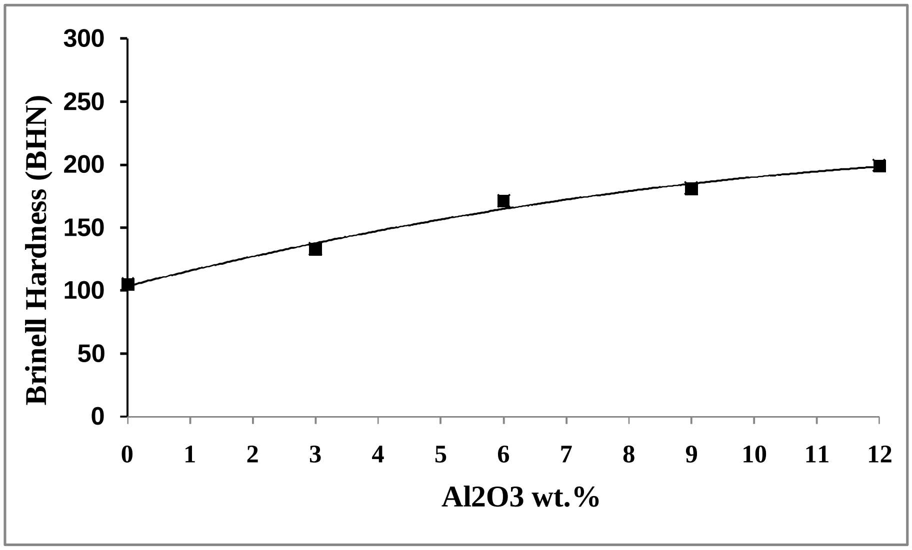

Fig. 5:Illustrate the relation between concentration of α-alumina particles and Brinell hardness (BHN).

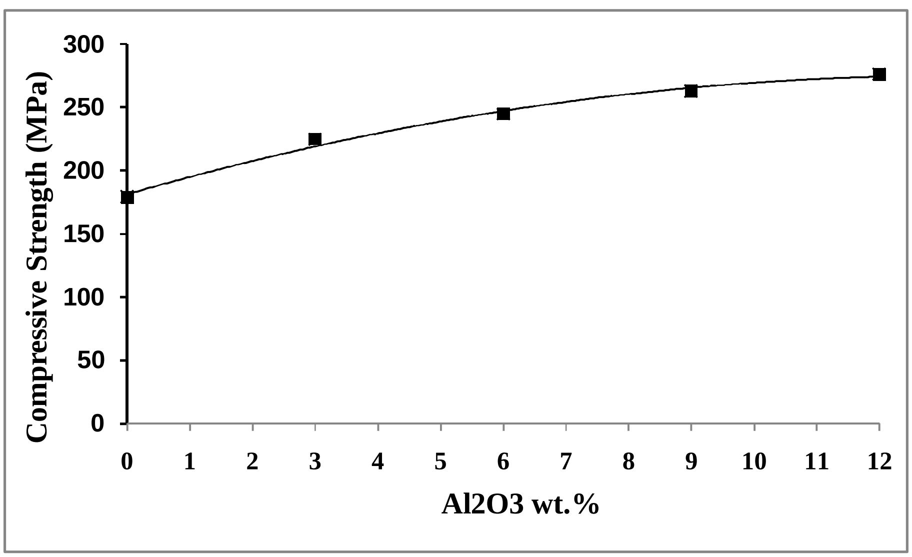

Fig. 6:Illustrate the relation between concentration of α-alumina particles and Compression strength (MPa).