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# Evaluation of Mechanical Properties of Particulate Composites

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## Abstract

A series of experiments have been taken out to test the validity of the effect of Aluminum hydrate on its interaction with Aluminum during sintering of aluminum metal matrix. The approach has been shown to be valid and several compositions have been fabricated. The alumina hydrate particle size and the amount of alumina hydrate in the composites are also shown to have an influence on the extent of densification.

The densities for all sintered specimens were measured. It was found that density increases as compaction pressure increases, the density decreases as particles size increases. At 400 MPa there is an optimum particles size which is (90-125) µm to reach maximum density and the density decreases as volume fraction increases from 2% to 20%.

The microstructure enhances as compaction pressure increases, agglomeration of alumina hydrate particles increases with increasing of volume fraction and cavities increases especially at low compaction pressure more than at high compaction pressure.

The mechanical properties (compression test and Vickers hardness) of sintered specimens compacted at 100 MPa accomplished for three volume fractions 2%, 10% and 20% and three particles size (45-90) µm, (90-125) µm and (125-150) µm. Young's modulus in compression decreases as volume fraction increases. Also it decreases as particles size increases and Vickers hardness decreases as volume fraction increases. Also decreases as particles size increases.

***Keyword:*** *Properties, particular, composites.*

## 1. Introduction

The special properties of metal-matrix composites can sometimes offset extremely high material cost. For example a significant weight reduction in an aircraft engine shaft can have many cumulative engineering effects. Use of the lower-weight metal composite can increase load-bearing capabilities, reduces wear and lubrication needs, and also increase output speed, all of which result in cost saving. The success of these products could make metal composite standard materials for many industrial applications [1].

These composites generally contain equiaxed ceramic reinforcements with an aspect ratio less than about five. Ceramic reinforcements are generally oxides or carbides or borides ($Al_2O_3$ or SiC or $TiB_2$) and present in volume fraction less than 30% when used for structural and wear resistance application. However, in electronic packaging applications reinforcement volume fraction could de as high as 70% [2, 3].

In general, PMMCs are manufactured either by solid state (PM process) or liquid state (stir casting, infiltration and in-situ) processes.

PMMCs are less expensive compared to CFMMCs. Mechanical properties of PMMCs are inferior compared to whisker/ short fiber/ continuous fiber MMCs but far superior compared to unreinforced metal alloys. These composites are isotropic in natural and can be subjected to variety of secondary forming operations including extrusion, rolling and forging[2].

The particulate composite are designed to produce unusual combination of properties rather than to improve strength. In this type of composites the matrix and the particles share the applied load [4].

The metal powders just after production may not posses favorable physical or chemical characteristics for subsequent processes. The maintenance of such properties is of importance from the viewpoint of both manufacturer and user[5, 6].

Powder conditioning which involves mechanical, thermal or chemical treatments or alloying of the powders is very important processing step of PM like their production, pressing and sintering operations. In general, the user is interested in receiving dry powder which is free from impurities and has uniform properties in different shipments favorable for compaction and sintering in accordance with the specifications mutually agreed upon with the manufacturer. The strict enforcement of the specifications by the user as well as producers lead to reduction and, in many cases elimination of variation in the properties of the individual shipment of powders.

Impure, wet, or deflective powder may be washed, dried or softened and purified by annealing in a reducing atmosphere, particularly hydrogen or its size, size distribution and shape may be varied by sieving, mixing or milling [5, 6].

In this work preparation of particulate composite from aluminum as matrix and alumina hydrate as reinforcement and to investigate effect on density by a) Compaction pressure b) Particles size and c) Volume fraction.

And to evaluate the mechanical properties (compression test properties and Vickers hardness) for specimens compacted at 100 MPa.

## 2. Experimental Work

The alumina hydrate powder used in these experiments as commercial material (gibbsite: Al2(OH)3) from (India)Ltd, contains (68.21% Al2O3 and 0.006 TiO).the aluminum was 98.55% Al with 0.4% Si, table (1) shows the properties of Aluminum and alumina hydrate.

**Table 1,**
**The Raw Materials and its Properties.**

| Material | Average particles size µm | Density g/cm$^3$ | Content |
|---|---|---|---|
| Aluminum | 40-50 | 2.65 | 98.55%AL, 0.4%Si |
| Alumina hydrate | (45-90),(90-125)and (125-150) | 2.34 | 68.21%$Al_2O_3$, <.006TiO |

The material were supplied in the form of powder with range of 40-50 µm for metal and 45-150 µm for ceramic by sieve fraction.

The aluminum and alumina hydrate powders were wet mixed in isopropanol and dried before pressing into the cylindrical samples 10 mm diameter x 15 mm.

The pallets were pressure less sintered at temperature 600 °C. The composite were analyzed by density measurements. X-ray diffraction and standard microscopy for the following discussion of the materials behavior.

## 3. Results and Discussion

From the experimental work, the values of densities obtained according to the parameters made with it (Compaction pressure, Particles size and Volume fraction), microstructure, X-ray diffraction and mechanical properties (compression test properties and Vickers hardness) for specimens compacted at 100 MPa. (fig. 1 & 2).

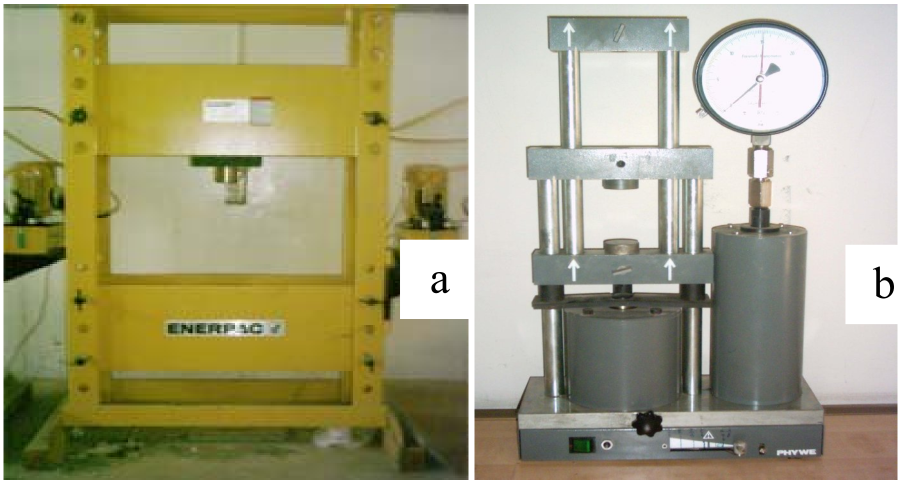

**Fig.1. a) 100 Ton Press. b) 30 kN Compression Test Divice.**

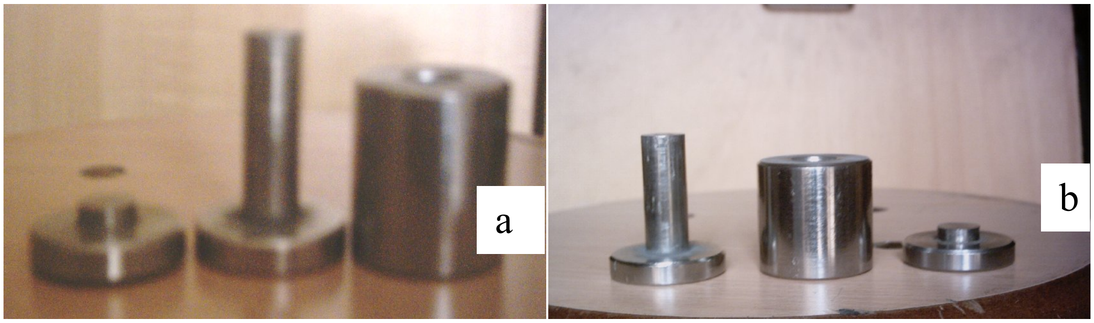

**Fig.2. Cylindrical die; a) D=25mm. b) D=15mm.**

## 3.1. Density Calculation

### 3.1.1. The Effect of Compaction Pressure

It is evident from Figs. 3 to 5 that the density increases with increasing pressure with nonuniform distribution and that because in earlier stages of compaction (100 MPa and 150 MPa) a little increase in pressure leads to increase the density of powder which reached 1.655 g/cm$^3$ (62.9% from theoretical density) at 100 MPa for 10% vol. for (125-150) µm of particles size. On the contrary at the next stages the pressure increased to (400 MPa) leads to little increase in density which reached to 2.533 g/cm$^3$ (95.7% from theoretical density) at 400 MPa for 2% vol. for (90-125) µm of particles size. This is because at the beginning, the density increases according to partial displacement between the particles and this displacement distributes for the body of the specimen with nonuniform distribution. Therefore the particles which exist in good position will be displaced in pores and cavity beside it with unnoticed friction with each other. Therefore the velocity of these particles in the direction of compaction equal to the velocity of the piston, while the velocity of other particles exist in good contact with each other or in contact with the wall of the die will be slower.

With the increasing of compaction pressure and density crashing process for arch which will appear always according to the spontaneous arrangement for the particles in the free pouring of powder in die. Also at this moment, the smaller particles will leak to the pores and cavities and deform the powder particles itself.

And in very high compaction pressure the deformation of particles increase also the particles will crush. Therefore, in compaction the powder a partial displacement will be with each other and deformation and crushing.

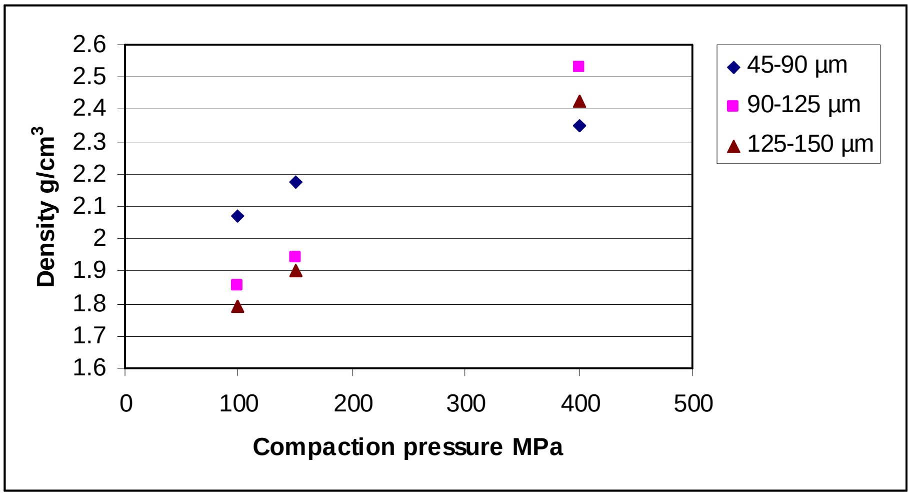

**Fig.3. Compaction Pressure and Density Relation for 2% vol.**

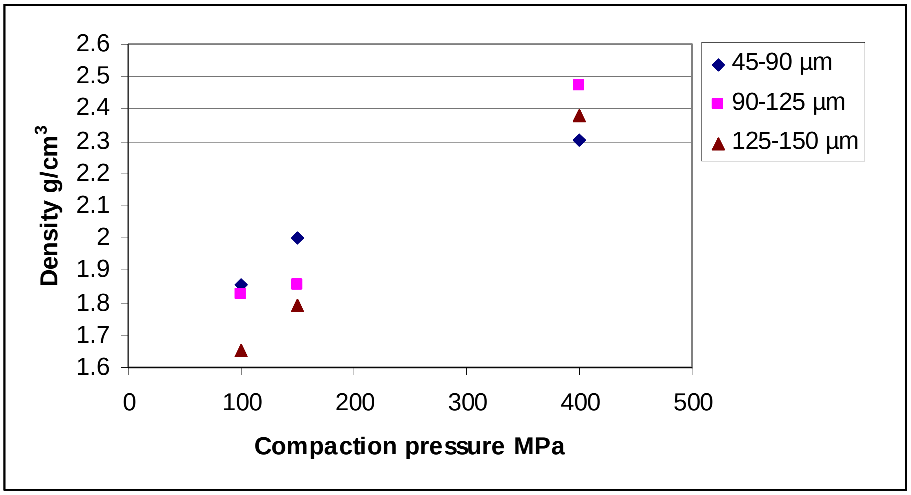

**Fig.4. Compaction Pressure and Density Relation for 10% vol.**

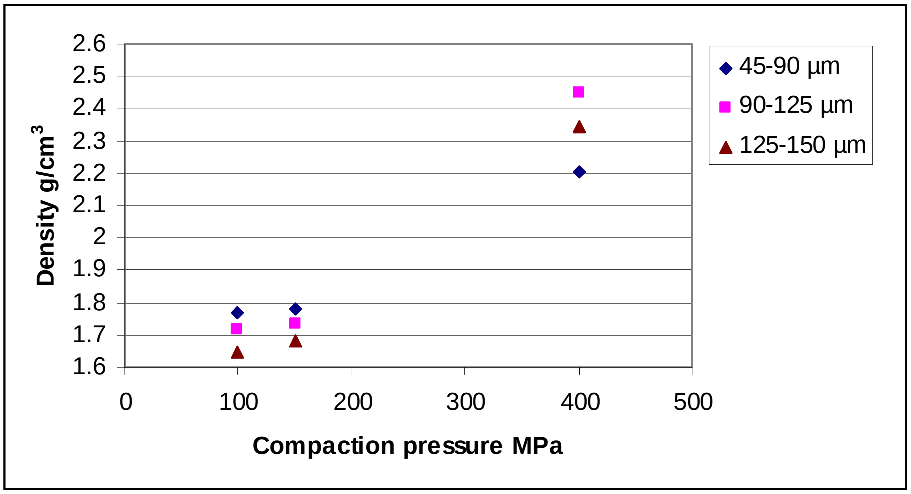

**Fig.5. Compaction Pressure and Density Relation for 20% vol.**

The deformation and crushing process happen at very high pressure with respect to pressure necessary to the partial displacement. But these processes happen along the compaction process and crushing at the first stages for compaction (not high pressure) also existing of sliding for the particles in high pressure. Therefore, the main factor in increasing the density in first stages of compaction is partial sliding and in second stage the main factor is the deformation of crushing particles. Table 2 shows the densities and percentage of density increase for all parameters.

### 3.1.2. Effect of Particles Size

In Fig 6 to 8 the density decrease from (2.073 g/cm$^3$ and 2.178 g/cm$^3$) to (1.792 g/cm$^3$ and 1.902 g/cm$^3$) for 2 vol.% also from (1.856 g/cm$^3$ and 2 g/cm$^3$) to (1.655 g/cm$^3$ and 1.79 g/cm$^3$) for 10 vol.% and from (1.769 g/cm$^3$ and 1.778 g/cm$^3$) to (1.649 g/cm$^3$ and 1.682 g/cm$^3$) for 20 vol.% as the particles size increases from (45-90) µm to (125-150) µm at low compaction pressure (100 MPa and 150 MPa) that is because small particles can slide to pores and cavities beside it easier than particles with large particles.

In high compaction pressure 400 MPa, the behavior will be changed with an optimum particles size (90-125) µm to reach the maximum density (95.7%, 94% and 93.9% of theoretical densities for volume fraction 2%, 10% and 20%) at constant pressure that is because the particles size affect indirectly to the density. When the particles decrease the contact surface also friction surface will increase. Therefore to get the required density the pressure of compaction must be must increased. In other side when the particles size increase the deformation process is decreased therefore the compaction pressure must be must increased. Table 2 shows the densities and percentage of density increase for all parameters.

**Table 2,**
**Densities and Percentage of Density Decrease with Respect to Theoretical Density for All Parameters.**

| Range particles size (µm) | Vol. frac. % | Density g/cm$^3$(difference of density decrease with respect to theoretical density) | | | |
|---|---|---|---|---|---|
| | | 100 MPa | 150 MPa | 400 MPa | Theo. density |
| 45-90 | 2% | 2.073(78.3%) | 2.178(82.3%) | 2.351(88.8%) | 2.645 |
| | 10% | 1.856(70.6%) | 2(76.1%) | 2.301(87.5%) | 2.628 |
| | 20% | 1.769(67.8%) | 1.778(68.2%) | 2.207(84.6%) | 2.606 |
| 90-125 | 2% | 1.864(70.4%) | 1.945(73.5%) | 2.533(95.7%) | 2.645 |
| | 10% | 1.824(69.4%) | 1.855(70.5%) | 2.472(94%) | 2.628 |
| | 20% | 1.714(65.7%) | 1.733(66.5%) | 2.449(93.9%) | 2.606 |
| 125-150 | 2% | 1.792(67.7%) | 1.902(71.9) | 2.424(91.6%) | 2.645 |
| | 10% | 1.655(62.9%) | 1.79(68.1%) | 2.38(90.5%) | 2.628 |
| | 20% | 1.649(63.2%) | 1.682(64.5%) | 2.343(89.9%) | 2.606 |

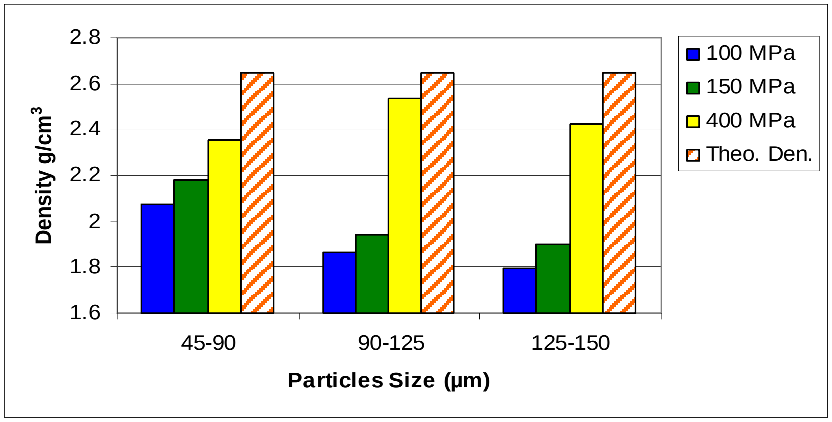

**Fig.6. Particles Size and Density Relation for 2% vol.**

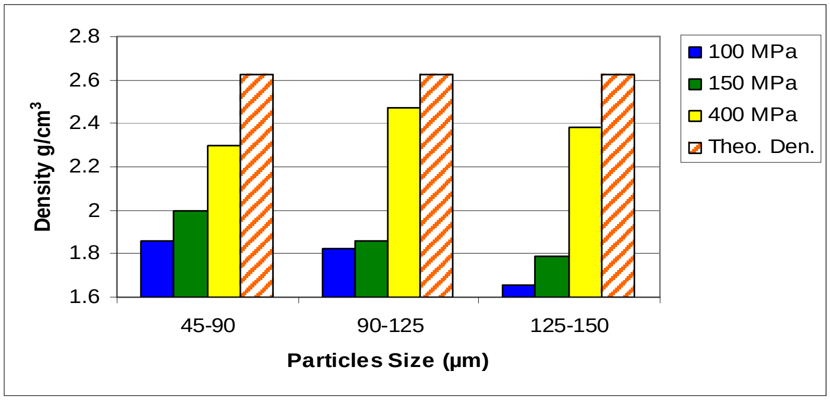

**Fig.7. Particles Size and Density Relation for 10% vol.**

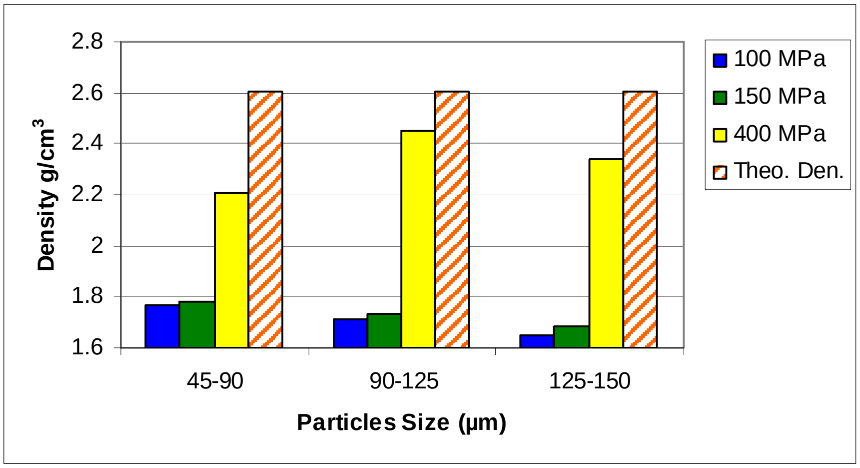

**Fig.8. Particles Size and Density Relation for 20% vol.**

### 3.1.3. Effect of Volume Fraction

It can seen from Fig 9 to 11 that the density decreases as the volume fraction increase when the pressure constant. That is because whenever the ductility of the material increased, the density will begin to increase by deformation process in lower pressure.

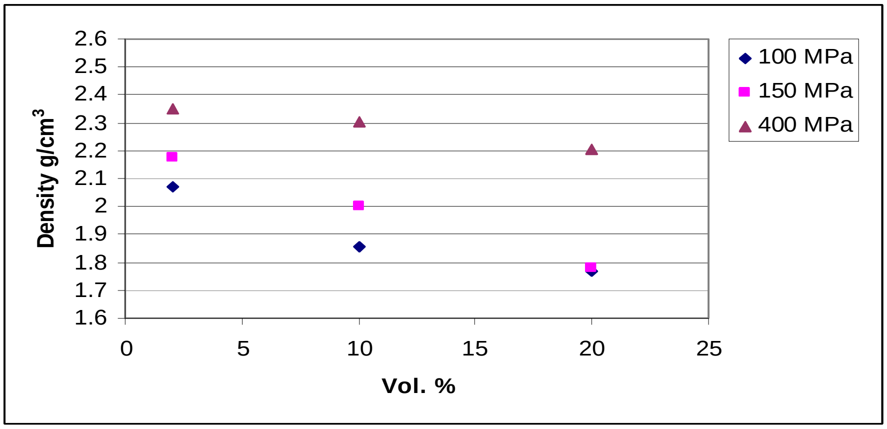

**Fig.9. Volume Fraction and Density Relation for (45-90) µm Particle Size.**

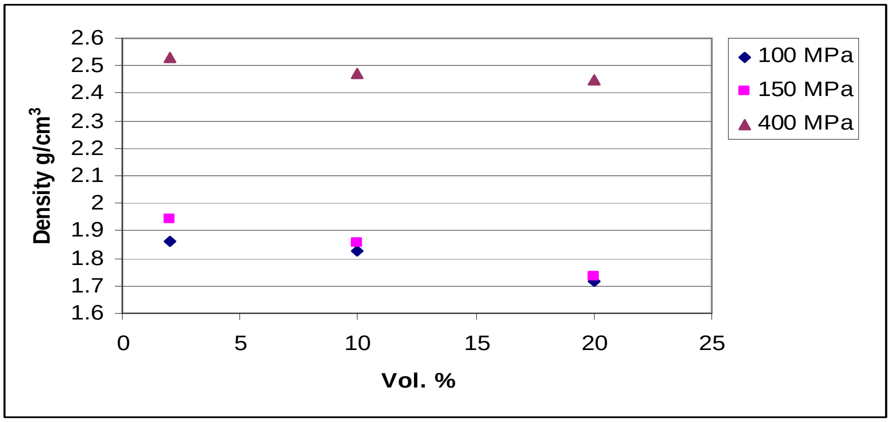

**Fig.10. Volume Fraction and Density Relation for (90-125) µm Particle Size.**

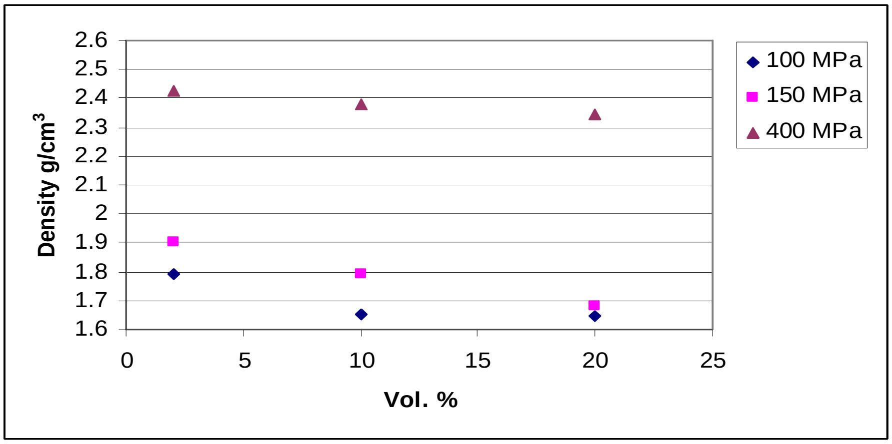

**Fig.11. Volume Fraction and Density Relation for (125-150) µm Particle Size.**

## 3.2. Microstructure Study

Figures 12 to 20 show the microstructure of composites with its variation condition. It can be seen that the distribution of reinforcement particles of which it seems to be distributed uniformly except in some places in which agglomeration of alumina hydrate particles can be seen and it increases when the volume fraction increases.

It can be seen that the deformed aluminum through compaction which is recrystalized through sintering more exist at high pressure (400 MPa) than at low pressure (100 MPa and 150 MPa) as shown clearly in Fig 21 also the cavities can be seen between particles which exist more and bigger in low pressure (100 MPa and 150 MPa) than in high pressure (400 MPa) as shown clearly in Fig 22.

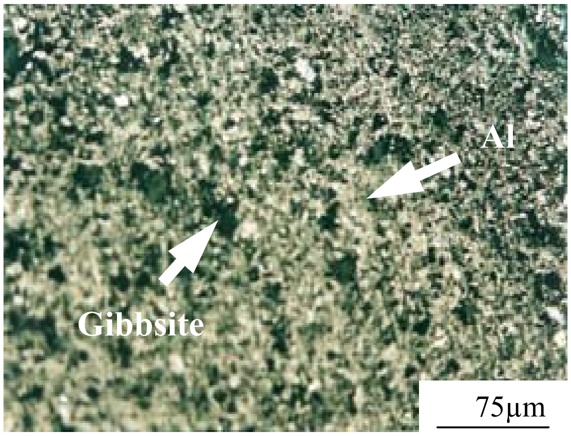

**Fig.12. The Microstructure of Al+2% Gibbsite of (45-90)µm at 100 MPa at (5X).**

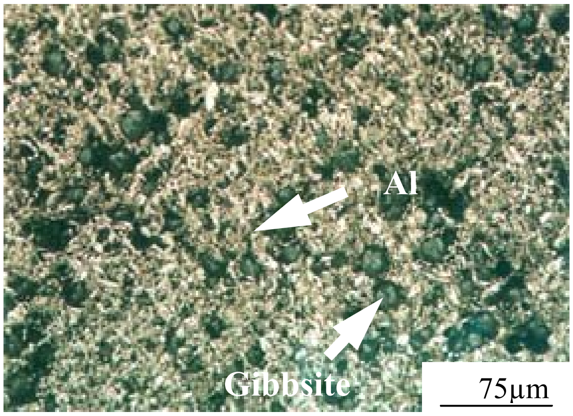

**Fig.13. The Microstructure of Al+10% Gibbsite of (45-90)µm at 100 MPa at (5X).**

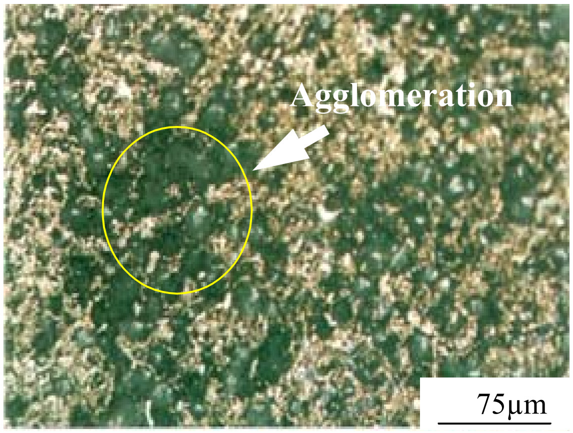

**Fig.14. The Microstructure of Al+20% Gibbsite of (45-90)µm at 100 MPa at (5X).**

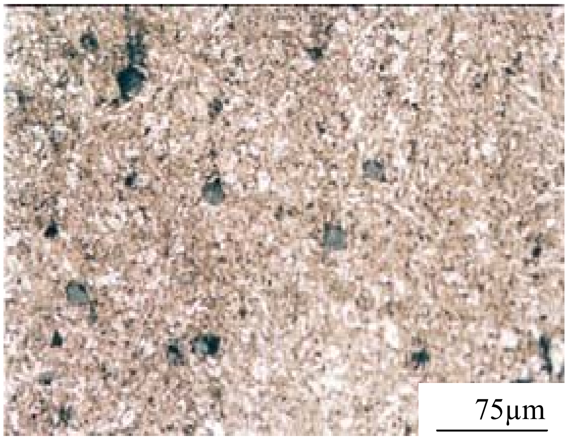

**Fig.15. The Microstructure of Al+2% Gibbsite of (45-90)μm at 150 MPa at (5X).**

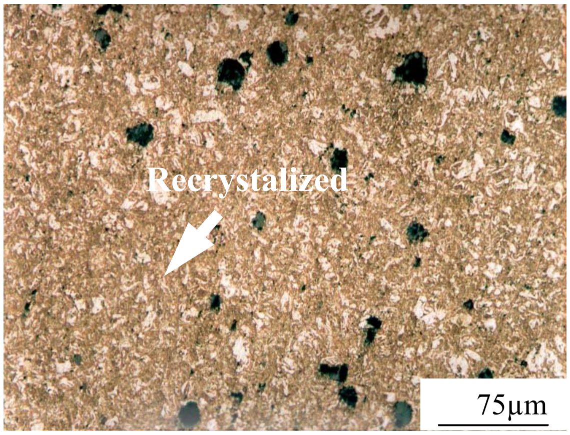

**Fig.18. The microstructure of Al+2% gibbsite of (45-90)μm at 400 MPa at (5X)**

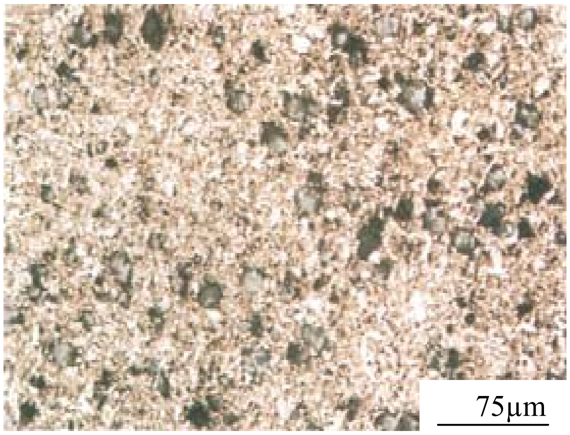

**Fig.16. The Microstructure of Al+10% Gibbsite of (45-90)μm at 150 MPa at (5X).**

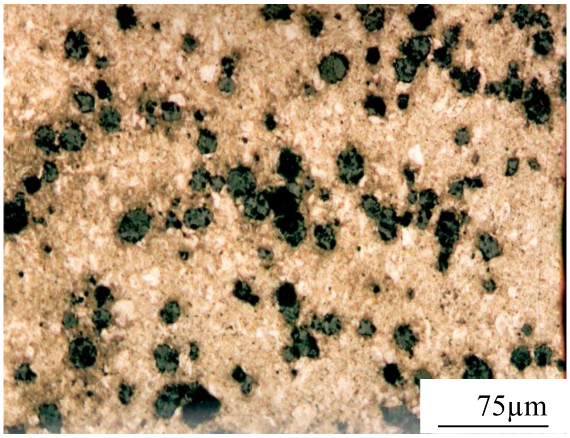

**Fig.19. The Microstructure of Al+10% Gibbsite of (45-90)μm at 400 MPa at (5X)**

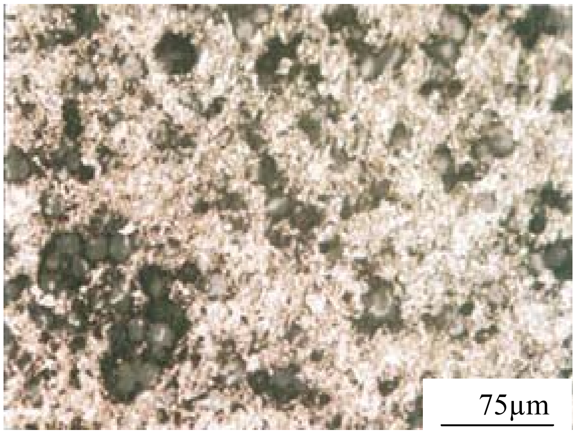

**Fig.17. The Microstructure of Al+20% Gibbsite of (45-90)μm at 150 MPa at (5X).**

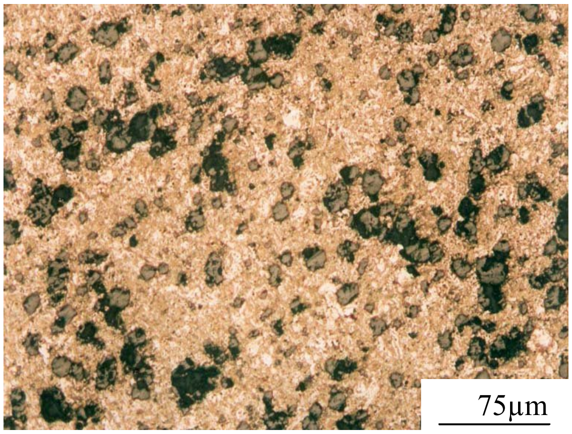

**Fig.20. The Microstructure of Al+20% Gibbsite of (45-90)μm at 400 MPa at (5X).**

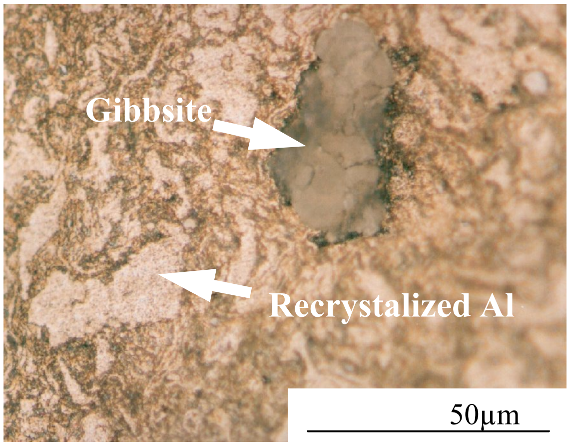

**Fig.21. The Microstructure of Al+2% Gibbsite of (45-90)µm at 400 MPa at (50X).**

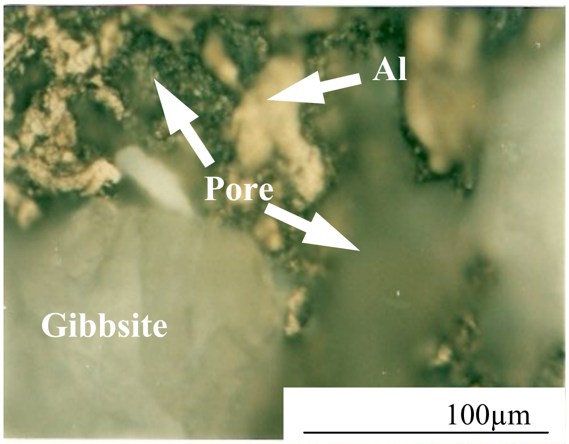

**Fig.22. The Microstructure of Al+10% Gibbsite of (90-125)µm at 100 MPa at (50X).**

### 3.3. X-ray Diffraction Study

The results of X-ray diffractometry are taken for Al powder and alumina hydrate powder and (2%, 10%, 20%) vol. composites at 400 MPa. It does not matter what the particles size is. It is obtained from this study that the major phase in all samples of composites is Al because whenever the crystallization of material is good the intensity will be better therefore alumina hydrate will never appear even when it increases from 2% vol. to 20% vol. Also phases which are less than 2% cannot be indicated.

### 3.4. Characterisation of Composites

#### 3.4.1. Compression Test

Figure 23 represents the relationship between Young's modulus and volume fraction where it can be seen that the Young's modulus decreases as the volume fraction increases for particles size (45-90) µm Young's modulus decreases from 2.626 GPa to 1.418 GPa which is about 46% of decreasing, for particles size (90-125) µm Young's modulus decreases from 2.112 GPa to 1.44 GPa which is about 12% of decreasing and for particles size (125-150) µm Young's modulus decreases from 1.67 GPa to 1.045 GPa which is about 37.5% of decreasing as the volume fraction increases from 2% to 20% the density will decrease and therefore the Young's modulus will decrease.

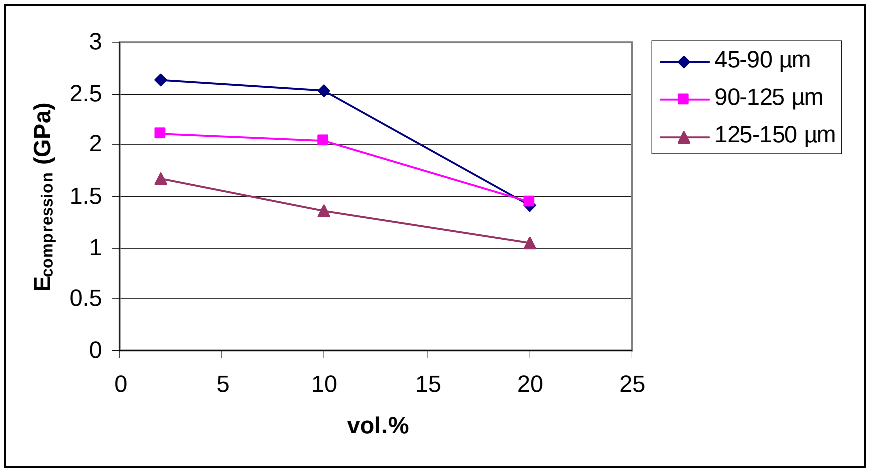

**Fig.23. Relationship between Young's Modulus in Compression and Volume Fraction Compacted at 100 MPa at Room Temperature.**

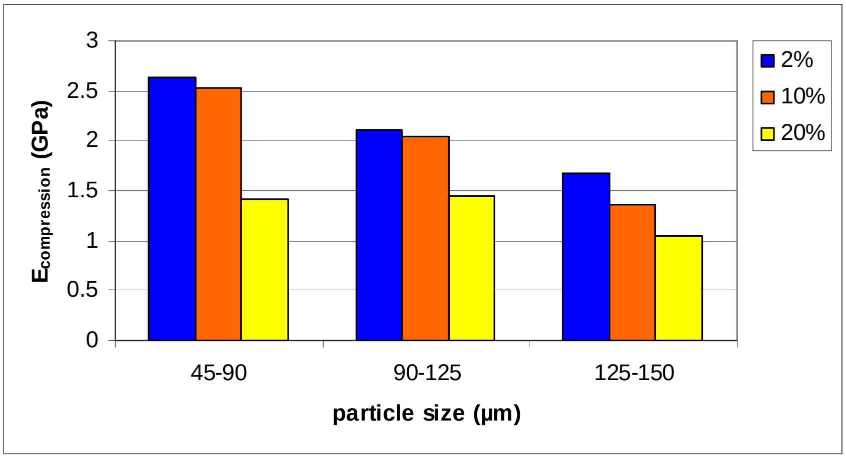

**Fig.24. Relationship between Young's Modulus in Compression and Particles Size Compacted at 100 MPa at Room Temperature.**

In Fig. 24 Young's modulus is decreased as particles size increases for volume fraction of 2% Young's modulus decreases from 2.626 GPa to 1.67 GPa which is about 36.4% of decreasing, for volume fraction of 10% Young's modulus decreases from 2.523 GPa to 1.359 GPa which is about 46.2% of decreasing and for volume fraction of 20% Young's modulus decreases from 1.418 GPa to 1.045 GPa which is about 26.4% of decreasing as particles size increases from (45-90) μm to (125-150) μm the density will decrease therefore the Young's modulus will decrease.

### 3.4.2. Vickers Hardness Test

The advantage of Vickers indentation method is that it is independent of the specimen geometry an only a small specimen is required to carry out the measurement.

Significant improvement in the hardness has occurred through pressure less sintering. It was noted that increasing amount of alumina hydrate from 2% wt to 20% wt under the same condition of sintering will increase the hardness. The results are shown in figure 25 and 26. This hardness is attributed to the presence of more brittle phase (alumina).

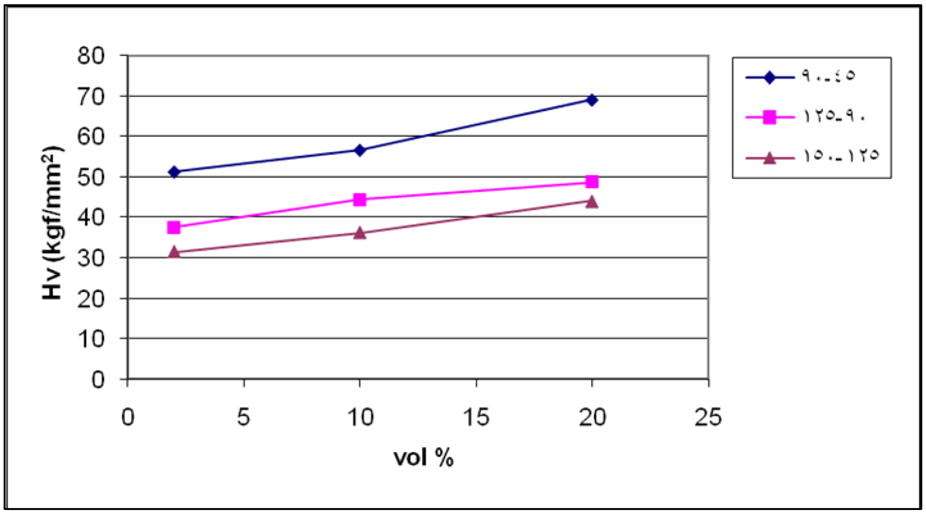

**Fig.25. Relationship between Vickers Hardness and Volume Fraction Compacted at 100 MPa.**

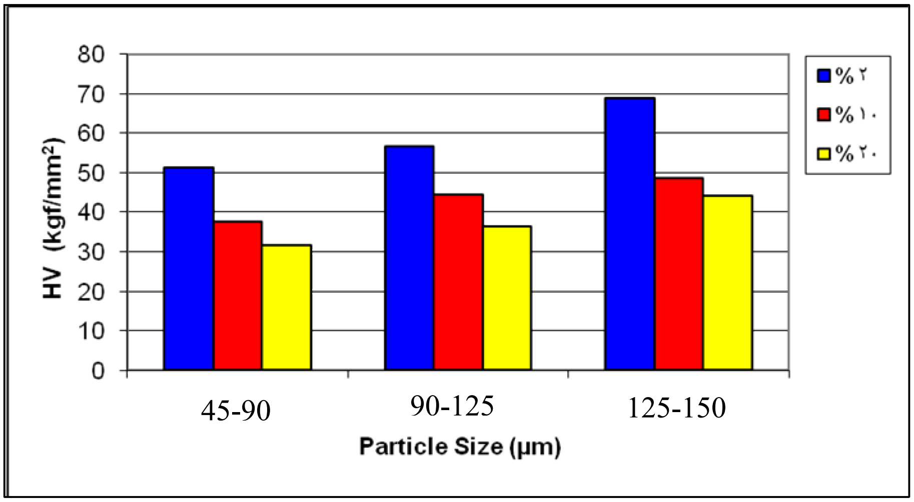

**Fig.26. Relationship between Vickers Hardness and Particles Size Compacted at 100 MPa.**

## 4. Conclusions

1. The density increases to reach maximum about 95.7% from the theoretical density as compaction pressure reaches to 400 MPa. The density decreases about 10.6% as particles size increases from (45-90) µm to (125-150) µm at compaction pressure of 100 MPa.
2. At high compaction pressure 400 MPa there is an optimum particles size which is (90-125) µm to reach maximum density. The density decreases maximum about 14.1% as volume fraction increases from 2% wt to 20% wt.
3. The microstructure enhances as compaction pressure increases, agglomeration of alumina hydrate particles increases with increasing of volume fraction especially at low compaction pressure 100 MPa and 150 MPa. Also cavities increases at low compaction pressure 100 MPa and 150 MPa more than at high compaction pressure.
4. Young's modulus in compression for specimens compacted at 100 MPa decreases as volume fraction increases from 2% wt to 20% wt about 46% in its maximum decreasing from first volume fraction. Also decreases as particles size increases from (45-90) µm to (125-150) µm about 46.2% in its maximum decreasing from first particles size.
5. Vickers hardness for specimens compacted at 100 MPa increase as volume fraction increases from 2% wt to 20% wt about 28.5% in its maximum increasing from first volume fraction. Also increases as particles size increases from (45-90) µm to (125-150) µm about 38.4% in its maximum decreasing from first particles size.

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# حساب الخصائص الميكانيكيةِ للمركّباتِ الجزيئيةِ

**محسن جبر جويج عبدالرحمن نجم عبد نوفل عبدالباقي عبدالرزاق**
*قسم الهندسة الميكانيكية/ جامعة النهرين*

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## الخلاصة

تعتبر ميتالورجيا المساحيق من مصادر المواد ذات الاداء العالي والمواد الحبيبية المتقدمة والسبائك مثل ادوات محملة بالماس لقطع الخزف، كربيد التنجستن و الزجاج. تم في هذا البحث حساب المواصفات الميكانيكية للمركبات الحبيبية (الالمنيوم-الالومينا هيدريت) التي تم تحضيرها بواسطة ميتالورجيا المساحيق.

تم خلط مسحوق الالمنيوم مع ثلاثة احجام حبيبية مختلفة μm (٤٥-٩٠)، μm (٩٠-١٢٥) وμm (١٢٥-١٥٠) وثلاث نسب خلط مختلفة (% ٢)، (% ١٠) و(% ٢٠) بواسطة مطحنة كهربائية. تم كبس المسحوق المخلوط في قوالب اسطوانية بقطرين مختلفين بضغط ابتدائي مقداره ٣٥ MPa ثم كبست اخيرا بثلاثة ضغوط مختلفة (١٠٠ MPa)، (150 MPa) و(400 MPa). النماذج المضغوطة لبدت بدرجة ٦٠٠ $^{o}C$ لمدة ساعتين.

الكثافات لكل النماذج الملبدة قيست. وجد ان الكثافة تزداد عند زيادة الضغط، تقل الكثافة عندما يزداد الحجم الحبيبي. في ضغط كبس ٤٠٠ MPa هناك حجم حبيبي امثل الذي هو μm (٩٠-١٢٥) للوصول الى اقصى كثافة، وتقل الكثافة عند زيادة نسبة الخلط من % ٢ الى % ٢٠.

يتحسن التركيب البلوري عندما يزداد ضغط الكبس. يزداد تكتل حبيبات الالومينا هيدريت بزيادة نسب الخلط و كذلك تزداد الفجوات خصوصا في ضغط كبس منخفض اكثر من ضغط الكبس العالي.

المواصفات الميكانيكية (اختبار الانضغاط وصلادة فيكرس) للنماذج الملبدة عند ضغط كبس ٤٠٠ MPa انجزت لثلاث نسب خلط مختلفة (% ٢)، (% ١٠) و(% ٢٠) وثلاث احجام حبيبية μm (٤٥-٩٠)، μm (٩٠-١٢٥) وμm (١٢٥-١٥٠). معامل المرونة في الانضغاط يقل بزيادة نسب الخلط. كذلك يقل بزيادة الحجم الحبيبي. وصلادة فيكرس تقل بزيادة نسب الخلط. كذلك تقل بزيادة الحجم الحبيبي.

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