



# THE MECHANICAL BEHAVIOR OF NANO SIZED $Al_2O_3$ -REINFORCED AL-SI7-MG ALLOY FABRICATED BY POWDER METALLURGY AND FORGING

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## ABSTRACT

The study is to be undertaken to investigate the effect of Alumina particle size, sintering temperature, sintering time on the microstructure and mechanical properties of Al-Si7-Mg0.3 (A356). This metal matrix composite has been investigated by powder metallurgy. Powder metallurgy (PM) is a widely used fabrication method for producing metal matrix composites. This usually involves three major stages: blending of the metal and ceramic powders, pressing or cold compaction, and sintering. These last two steps are often combined during hot pressing. One of the advantages of PM compared to casting is having better control on the microstructure, where better distribution of the reinforcement is possible in PM compacts. Particle size and the amount of reinforcement had pronounced effect on the mechanical properties of composites. Proper addition of reinforcements to aluminum composites has a positive effect on mechanical properties, such as hardness, strength and wears resistance. The difference composition of Nano sized alumina particles is added 2wt%, 3wt%. The average size of aluminium and reinforcement particle size  $30\mu m$  and  $100nm$  respectively. For Proper production of the powder which will be placed in planetary ball mill. The sintering Temperature and time are in the range of  $550-610^\circ C$  for 60-120 min. Forging had been involved for increasing the properties of composites at  $350-400^\circ C$ . The results that exhibited at elevated sintering temperatures, lower porosity is obtained. Higher relative densities are achieved at higher sintering temperature. Higher hardness was observed in samples containing finer alumina particles. The dependence of the diffusion to time may be explained for sintering temperature. It can be seen that the atomic displacement is proportional to the square root of time. This is responsible for the atomic diffusion leading to grain coarsening. It is seen that, at higher sintering temperatures, a denser structure is formed due to higher diffusion rates.

**Keywords:** A356/ Nano  $Al_2O_3$  composite mechanical properties, microstructure, Nano-structures, sintering.

## 1. INTRODUCTION

The need for composite materials which has become a necessity for modern technology because of increasing the physical and mechanical properties. In recent years the metal matrix composites MMC which have been developed with aluminium matrix composites that have found various application in the industry. This is mainly due to its low density, high toughness and corrosion resistance. This is mainly for major application include aerospace, military and car industries. Reinforcing of light metals such as Aluminium with ceramics Nano particles which enhance with spectrum of properties that including tensile and yield strength at room temperature hardness compressive. Creep and fatigue resistance at higher temperature Alumina after silicon carbide particles which has been made many application in industry when compared to sic particles which has had better thermal stability at high temperature. Powder metallurgy (PM) which is thought to be the most common production technique for mmc's. the main advantages of powder metallurgy when compared to casting is having better control on microstructure, where better distribution of the reinforcement is possible in powder metallurgy compacts. A review which in the literature that little attention which has been made to uniaxial pressing even though it's the most economical production. Technique for formation and growth of inter particle bonding solid state diffusion which plays major role in PM and the diffusion which has a major effect on mechanical and microstructure Properties.

However diffusion itself is mainly depend sintering time and temperature. In the present study of the novel approach of forging and powder metallurgy in fabrications of Aluminium (Al)- $Al_2O_3$  Nano composite which were investigated and comparable the microstructure and mechanical properties. The Nano alumina which was different contents of 2 wt %, 3 wt % has been produced which Al matrix and their various properties which were studied separately as were as together.

## 2. EXPERIMENTAL PROCEDURE

Aluminium- $Al_2O_3$  Nano composites which were produced by power metallurgy as well as forging can be employed for increasing mechanical properties of composites. The nano alumina which was used with the average particle sine  $100nm$  2 wt. % and 3 wt %. The average particle size matrix material  $20mm$ . Table-1 is illustrated the chemical composition of alumina.

**Table-1.** Chemical composition of alumina.

$Al_2O_3$ Wt %	CaO Wt %	$Fe_2O_3$ Wt %	$TiO_2$ Wt %	others Wt %
93	1.2	0.7	1.2	0.3

Visually, these bonds may be format by reaction (or) mutual dissolution of the matrix and particulates. The reaction at which the interface of  $Al_2O_3$  composite chat is Alumina dissolving into aluminium. So, inter marinate



phase are nano anticipated at which the interface. However forging and extrusion can be taken where the mechanical properties are needed for increasing the better mechanical properties of the composites with to be done in effective size of the practical and amount of the reinforcement. The better mechanical properties to be done when adding a proper addition of reinforcement to the aluminium matrix composite that may be reduced, moreover, reducing the practical size of Alumina which greatly improves the strength of the composites. For the proper of the powders which had been placed in a planetary but mill for 240 minutes and 250 rpm. In spite of controlling agent. The ball to powder ratio in the ball mill was 10:1. After compaction the preparations of alloy. The powder compaction which is the process of compacting the powders in which a die through the application of higher pressures can be employed. The density of the compacted powder which is directly proportional to the amount of pressure range between 250-300KN as well as the range of time 1500-1800S. having done the compaction process. The sintering process which had been employed the green compacted of the sintered samples at 550°C and 600°C for 2 hours.

The density measurements which has been done according to ASTM standard B328. The compressive test is done, according to ASTM standard 59 at room temperature and at 0.5mm per minute. The microstructure analysis was also employed for the analysis of morphological aspects of the samples. In order to devoid errors. The reported data which has been average of three experiments values.

### 3. RESULTS AND DISCUSSION

#### A. Density measurements

The effects of the nano alumina particle on the sintered density of the composite is illustrated in Table-2.

**Table-2.** Sintered density of the composite.

Alumina Wt%	Theoretical density (g/cm <sup>3</sup> )	Sintered density (g/cm <sup>3</sup> )	Relative density (%)
2wt%(550°C)	2.72	2.70	0.992
3wt%(550°C)	2.74	2.720	0.993
2wt%(600°C)	2.72	2.713	0.997
3wt%(600°C)	2.74	2.736	0.996

The results prove that increasing sintering temperature which enhance the density values in sintered composites which are due to the facilitation of atomic diffusion that increase wettability and sinter ability of composites so that which can different faster and fill the pores of the whole specimen. Theoretical density which has been employed and it has been divided from following calculation.

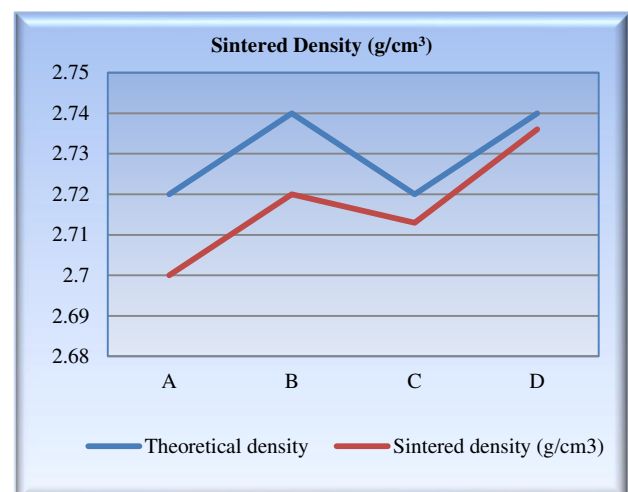
$$\rho_{\text{composite}} = \rho_{\text{Al}} V_{\text{Al}} + \rho_{\text{Alumina}} V_{\text{Alumina}} \quad (1)$$

Where,  $\rho_{\text{composite}}$  - density of the matrix material [ $\rho_{\text{Al}} - 2.7\text{g/cm}^3$ ] and density of the reinforcements [ $\rho_{\text{Alumina}} - 3.95\text{g/cm}^3$ ] and  $\text{wt}_{\text{Al}}$  and  $\text{wt}_{\text{Alumina}}$  are the weight percentage of Al and Alumina in composite. The calculation of control out for finding the theoretical density of the composites.

$$\rho_{2.0} = (2.7 \times 0.98) + (3.95 \times 0.020) = 2.725 \text{ g/cm}^3 \quad (2)$$

$$\rho_{3.0} = (2.7 \times 0.97) + (3.95 \times 0.030) = 2.737 \text{ g/cm}^3 \quad (3)$$

There is a slightly difference between theoretical densities and experimental densities. The forging results which are also increased when compared to sinter densities. The investigation of the individual PM sample that is illustrated that growth of density values with increasing the weight ratio of Alumina.

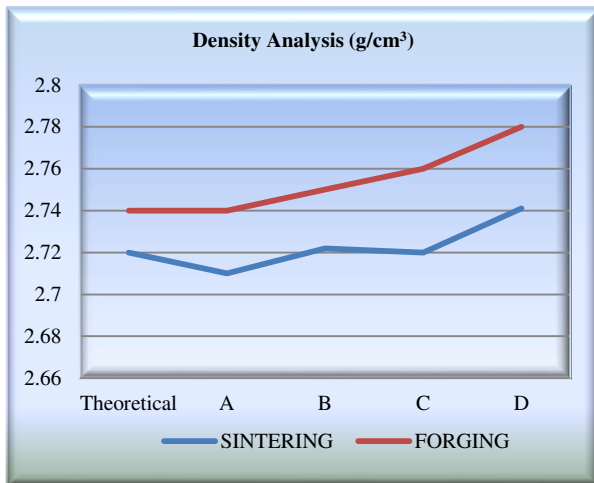


**Figure-1.** Theoretical density and sintered density of the composite.

The results shows have are powder metallurgy samples which have more density than Alumina, As well as the forging samples that have higher density compared to un reinforced matrix Alumina Alloy. Increasing  $\text{Al}_2\text{O}_3$  wt content in matrix resulted in increasing of density on etc other hand, when increasing the sintering temperature, it's enhanced density values in sintering composites. The aluminium can diffuse faster and fill where the pores of etc whole samples, due to facilitation at atomic diffusion that increase the wettability and sinter ability of composites.

#### B. hardness test

The hardness measurements of Aluminium A356 -  $\text{Al}_2\text{O}_3$  nano composite were investigate with different kinds of Nano reinforcements where as different sintering temperature results which has been showed in Figure-4. It's showed that the hardness of sample in sintering process at 600°C more than at 550°C as well as forging results which has greater value at 600°C. The homogeneity of hardness values which had compared between sintered composites and forging composites.



**Figure-2.** The experimental density values of A1 -  $\text{Al}_2\text{O}_3$  nano PM composites with various  $\text{Al}_2\text{O}_3$  contents of 2 wt% and 3 wt%. Nano powder metallurgy composites with forging with same weight traction.

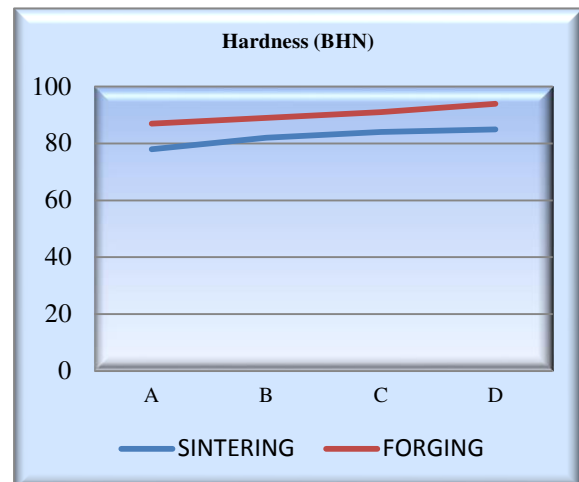
The comparison of the hardness of A356 Alloy with different sintering temperature and sintered forging composites proved that Addition of Nano Alumina as a reinforcement boosts hardness of A356 Alloy. It can be attributed harder Nano alumina particles compared harder to Aluminium and it can be role in enhancement of the density of dislocations and protibling grain growth of Aluminium. In casing samples, increase of  $\text{Al}_2\text{O}_3$  contents from 2 to 3 wt%. in all sintering temperature results which are increased in hardness which due to mention effective role of  $\text{Al}_2\text{O}_3$ . In increasing of hardness values on the contrary sintered samples at  $550^\circ\text{C}$  have lower hardness compared to sintered at  $600^\circ\text{C}$  of Nano alumina have higher hardness compared to all sample which are prepared by sintering process. The samples which can be due to the deformation of microprobes in the interface of  $\text{Al}_2\text{O}_3$ .

The hardness of the composites samples which are more than A356 Alloy, in sintering process. This is due to higher density and lower porosity portions which is achieved, when increasing temperature. When application of forging, the higher density has been obtained than sintering process. The sintering tempering at  $600^\circ\text{C}$  which has been given positive in samples. This temperature that can be aided for joining of Nano alumina to Aluminum matrix. It can be showed in all samples, when increasing the sintering temperature cause enhancement of hardness.

### C. Compression test

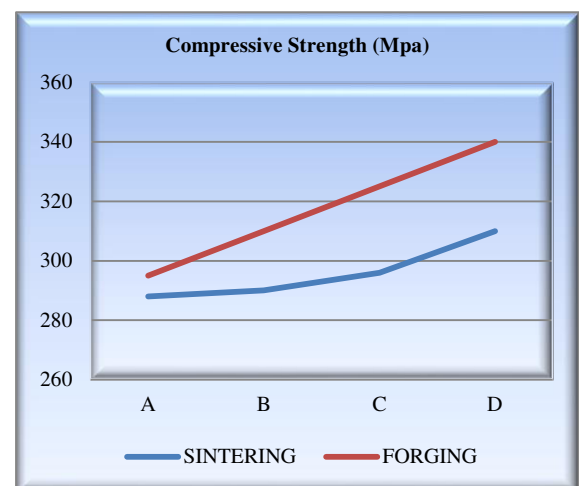
In general the compressive strength which is greatly more than sintered samples. Figure-5: Represents that the compressive strength of sintering and forging samples of A1 - Nano  $\text{Al}_2\text{O}_3$  composites. Due to the homogenous and continues Aluminium matrix, less porosity portion, and better wettability of  $\text{Al}_2\text{O}_3$  Nano composites in forging method compared to sintering. Furthermore, the samples of compressive strength which is

greater than un reinforced A356 Alloy which proves that the vital role of Nano Alumina particles in prohibition of grain growth and work hardening which is enhanced the mechanical properties of composite when compare to unreinforced Alumina Alloy



**Figure-3.** The hardness values of A1 -  $\text{Al}_2\text{O}_3$  Nano composites with various Alumina contents of 2 wt%, 3 wt%. prepared with (a) sintering at different temperature and (b) forging samples of sintered composites.

In compressive test, the results that can be ascended as increasing the Nano Alumina from 2wt%.



**Figure-4.** The Compressive strength of A1 -  $\text{Al}_2\text{O}_3$  Nano composites with various Alumina contents of 2 wt%, 3 wt%. prepared with (a) sintering at different composition and (b) forging samples of sintered composites.

Elastic properties at which an important role in deformation behavior of material. In spite of Alumina's large amount of elastic constant than Aluminium which impacts plastic deformation of A1 matrix that has been increased compressive strength of the composite. As various coefficient of thermal expansion between A1 and  $\text{Al}_2\text{O}_3$  interface, even though stress concentration increase, the dislocation density which bragggers stringing.



In constant particle size and increasing weight fraction of Alumina that the results of which reduce the particle distance which enhance density of dislocation which is increased the amount of stress for what dislocation pile-up according to the following equation.

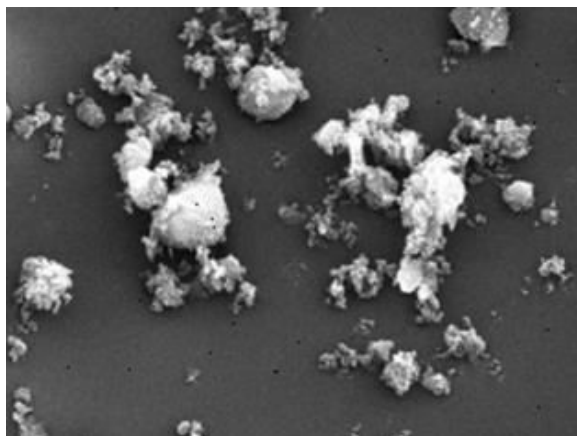
Where,  $\tau$  refers shear stress,  $G$  refers shear module,  $b$  refers burger's vector and  $\lambda$  refers particle distances. The above all of the explanations which is shown that increasing compressive strength of Al. Nano Alumina with increasing Nano Alumina content of the composite.

#### D. Microstructure studies

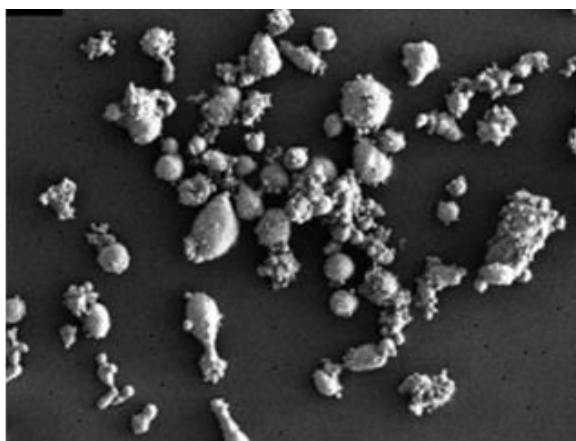
The surface morphology of Al - Nano Alumina composite samples which has been shown. Figure-6: There are not only taken the different sintering temperature ( $550^{\circ}\text{C}$  and  $600^{\circ}\text{C}$ ) and also forging samples which are surface morphology has been investigated.

The porosity which is related to density. In spite of adding alumina particles on which is decreased, there by, porosity may be interested, to alumina's lower compressibility when compared to alumina, lower green density on which samples in which words relative density may be obtained.

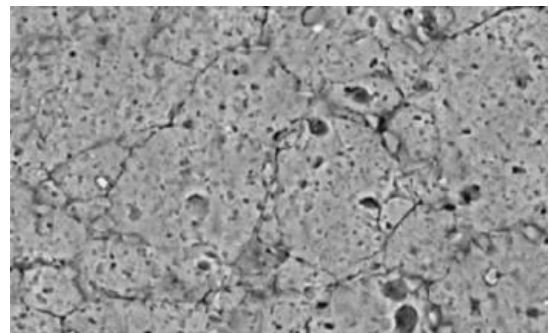
In order to avoid this, reduction of particle size and different sintering temperature has been carried out. Due to the alumina particle size, the level of porosity was lower at which the samples. In other hand, at elevated sintering temperatures, the level of porosity is obtained lower. Whereas higher relative densities are achieved at higher sintering temperature. The better sintering which situation is achieved by increasing the sintering. Temperature that boosts wet ability of  $\text{Al}_2\text{O}_3$  nano particles. In powder metallurgy sintering is one of the most important part and higher temperature will be facilitated it. And also uniformity of inner density is strongly depended on sinter ability of powders.



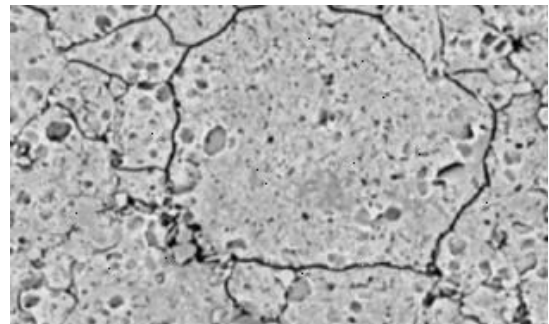
(a)



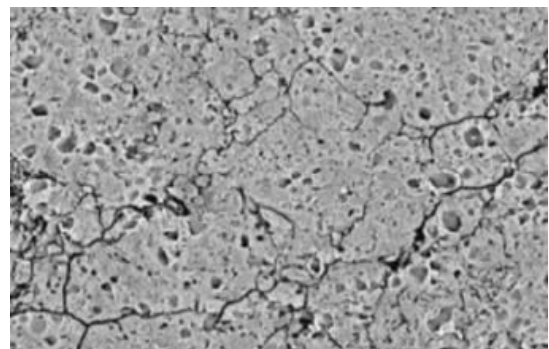
(b)



(c)

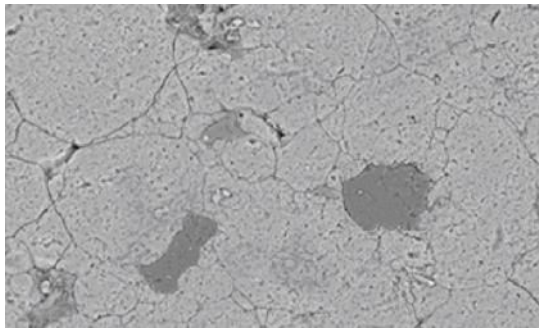


(d)



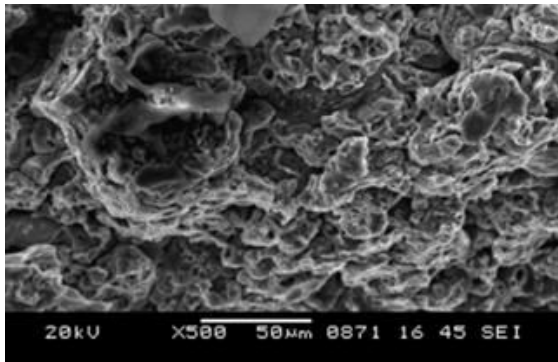
(e)

**Figure-5.** Scanning electron micrographs of matrix alloy and nano reinforcement (a) Aluminum-  $30\mu\text{m}$  and (b) Alumina -  $100\text{ nm}$ .

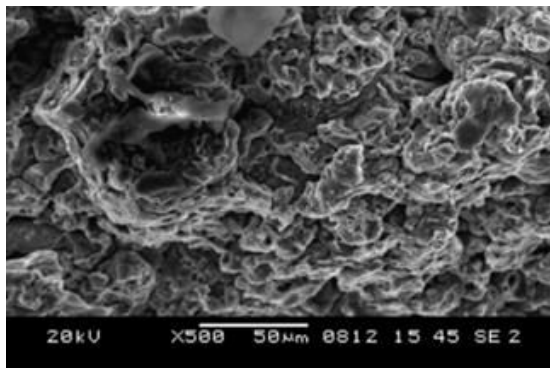


(f)

**Figure-6.** The effect of nano Alumina on the microstructure and particle dispersion of the composites of Al-Al<sub>2</sub>O<sub>3</sub> nano composites with various Alumina contents of 2 wt%, 3 wt%. prepared with (b) and (c) sintering at different temperature and (e) and (f) forging samples of sintered composites.



(i)



(j)

**Figure-7.** The Scanning electron micrographs of Al - Al<sub>2</sub>O<sub>3</sub> nano composites with various Alumina contents of 2 wt%, 3 wt%. prepared with (b) and (c) sintering at different 600°C temperature (i) and (j) with forging samples of sintered composites.

The increasing in sinter temperature which cause the easier powder diffusion of atom. In a sense which helps the ability of specimens to sinter and finally which leads the better mechanical properties. In the sense, in appropriate Al - Al<sub>2</sub>O<sub>3</sub> interface will be generated which can be caused better stress transformation among matrix and particles.

#### 4. CONCLUSION

The Al - Al<sub>2</sub>O<sub>3</sub> nano composites has been investigated with various Al<sub>2</sub>O<sub>3</sub> content at 2 and 3 wt%. In other hand, there are two different sintering temperature and forging process also employed. The results which shows that the density measurement value of sintering process with two different temperature of the composites is increased. The relative density of Al-Al<sub>2</sub>O<sub>3</sub> composite which has achieved containing fine particle sizes.

The higher relative density of 99.96% was observed in sintered specimen of forging at 600°C. Hardness and compressive strength which illustrated enhancement of mechanical properties because of adding nano Alumina particles to Al matrix when compare to pure A356 Alloy. At 600°C of sintered forging samples than all sintered samples where as sintered samples except forging also lead better properties except forging also lead better properties and this is slightly below to the forging sample which has been formed less porosity level. In general the result which is domination properties of forging when compare to powder metallurgy.

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