Effect of Compaction Pressure on Physical Properties of Milled Aluminium Chip (AA6061)

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Abstract: ***AA6061 alloy is widely used material in the automotive and aerospace industries. Consequently, more of the metal has been lost during manufacturing. The present study is aimed at investigating of physical properties of the milled Aluminium chip for this alloy according to change compaction pressure. Three values of compaction pressure were taken (5,7,9) tons. On the other hand, four types of particle size were chosen (25, 63, 100, mix) µm. The results were showing that the density and Microhardness increased with increasing the compaction pressure, while the porosity and water absorption decreased with increasing the compaction pressure. It can be concluded, (9 ton) is the best choice. On the other hand, the type DI (mix) was given the best result for density, porosity and water absorption compare with others according to particle size.***

Keywords: physical properties, milling process, powder metallurgy, AA6061, particle size.

1. Introduction

Particle-reinforced aluminium matrix composites (AMCs) have been widely used in aerospace and automotive fields because of their attractive properties, such as low cost, low density, high stiffness and high strength [1] Al alloys and Al matrix composites produced by powder metallurgy (PM) have been receiving more attention than conventional melting-casting methods in aerospace, military and car industries, due to the improved physical, chemical and mechanical properties. The large surface area of fine Al or Al alloy powders makes it possible to introduce naturally formed ultra-thin and dense surface oxides, which cannot be reduced to Al [2].

Metal matrix composite (MMCs) is very important because of their high ratio of strength and weight, high Young modulus and high abrasive properties. Aluminium is one of the best materials for matrix because of its low density, high conductivity and high toughness [3].

Chip milling is the fine phase of comminuting after coarse step of size reduction such as crushing. Its goal is to reduce the particle size of the chip so that the economically valuable substance in the chip can be more efficiently separated by the subsequent process, such as flotation or magnetic separation [4-6]. Ball mill grinding process is often the most commonly seen and the most energy intensive operation [7]. The planetary ball milling can reduce particles to fine powders based on a mechanical energy transfer, or impact and friction forces through high hardness ball media. However, its energy efficiency is low, and the power cost is high [8]. As a construction, a ball milling device, usually consists of a cylindrical vessel mounted on an appropriate basis at both ends, which allows rotation of the vessel around the centre axis. The mill is driven by a girth gear bolted to the shell of the vessel and a pinion shaft moved by a prime mover. The prime movers are usually synchronous motors equipped with an air clutch or gear transmission [9]. Some important procedures are involved in the category of powder metallurgy which can be generally divided into three separate groups. Firstly, single step process like ball milling has been used as a dry process and the mixing is totally performed in a batch state. The second group has been employed by the continuous multistep procedure like ultrasonic-assisted then ball milling and nano-scale dispersion (NSD) methods which can be introduced as a semi-wet based process. In this group the unique properties of both dry and slurry based routes are considered to achieve the desired products. The last one is more complicated process comprising the wet-based methods which are applied by the fluid dispersive environment and chemical reactions to make the demanded products like flake powder metallurgy and in-situ chemical vapor deposition (CVD) methods. The more initial preparation is needed for materials in the third group of PM processing methods [10]. In the open literature, numerous prior studies have reported similar work on ball milling of other types of powders, but there is no report about the pore and surface properties of calcite-based mineral powder using planetary ball milling.

Nowadays, the manufacturing processes for closed-cell aluminium stochastic foams seem to abound. They can be fabricated by starting from melted metals or metal powders [11]. Aluminium is a relatively soft, ductile and lightweight metal with a density of 2.7 g/cm3. Metals owing to their thermal conductive nature are frequently used in industries [12]. In this study, the compaction pressure has an effect on the distribution of aluminium particles. The distribution of these particles affected to density, porosity and water absorption of the mass. Therefore, these physical properties are the basic characteristics of composites produced by powder metallurgy technique.

2. Experimental Work

Material

Aluminium metal AA6061 is a silver-white metal that has a strong resistance to corrosion and malleable. Then, it has a widely using in the industry. It is a relatively light metal compared to metals such as steel, nickel, brass and copper with a specific gravity of 2.7 gm/cm^3, the mechanical properties for Aluminium AA6061 is shown in Table-1.

Table 1: Mechanical properties of Aluminium AA6061 (ASTM B308/B308M)

Yield Strength MPa	Tensile Strength (MPa)	Density gm/cm^3	Hardness (Vickers)
240	260	2.7	107

Zinc stearate will be used as a binder to make the compaction process easier.

Chip Production

Firstly, chip was produced by using CNC milling machine, type HSM (SODICK – MC430l), Feed rate (1100 mm/min), Depth of cut (1.0 mm), cutting velocity (345.4 m/min).

Chip Cleaning and Drying

Milled aluminium particles were cleaned by ultrasonic bath apparatus. Type Fritsch (ultrasonic cleaner labarette 17). The duration was 1 hour for each patch. After that, it is treated with acetone solution for 20 min. Finally, the drying process was used by furnace type (Kuittho Linn High Therm) for 1 hour.

Milling Process

After that, the chip was milled by planetary ball mill type (Retsch PM100) under conditions of the speed (350 r.p.m) and time (20) HR. The ratio of ball to powder (r.b.p) was 20:1.

Aluminium Particles Sieving

Aluminium particles sieving was used by vibrator apparatus type (Fritsch analysette 3) with maximum interval time 5 second. Three sizes were classified (25,63,100) µm.

Table 2: Classification of specimens according to particle size

AI	Particle size (25 µm)
BI	Particle size (63 µm)
CI	Particle size (100 µm)
DI	Mix (78.5% (25 µm) + 21.5% (100 µm))

Table 3: Classification of specimens according to applied to the compaction pressure

AI1	Particle size (25 µm) applied to compaction pressure 5 tons
AI2	Particle size (25 µm) applied to compaction pressure 7 tons
AI3	Particle size (25 µm) applied to compaction pressure 9 tons

Mixing Theory

The high performance of the percentage of particle size is referred to as milled particle size bulk having mechanical properties exceeding that of normal strength of milled particle size. Figure 1 shows the concept of mixing method for particle size.

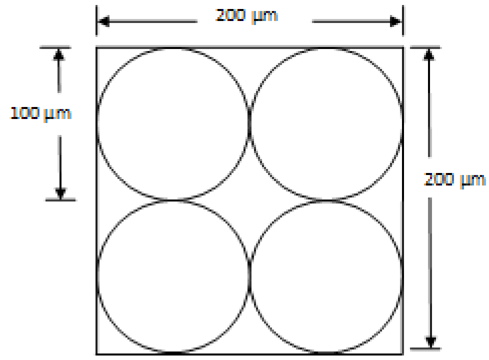

Figure 1: The concept of mixing method for particle size

Figure (4.28) shows the relationship if the particle size is 100 µm has been taken. Thus, The area of particle size is ($A = \pi r^2$) (7850 µm^2). The the area of all four particles is (31400 µm^2). The area of the square is (40000 µm^2).

$$\text{The ratio of particle size to the square} = \frac{\textit{The area of particle size}}{\textit{The area of square}}$$

$$= \frac{31400}{40000}$$

$$= 78.5\%$$

In this sample, the content is (78.5% (100µm) + 21.5% (25µm))

Mixing and Compaction

Ball mill machine was used for mixing the powders (1hr for time) and (300 r.p.m for speed) to make sure that the distribution was completed. The composition of mixture to produce the samples between (AA6061) and (Zinc stearate) was regular along the size that equal to 99% of AA6061 and 1% of zinc stearate.

Cold compaction of powder blends was performed in this study. Cold compaction was performed at room temperature (RT). In cold compaction, the mixed powder with a given amount of lubricant was pressed by uniaxial hydraulic operated press, The die was supported by two circular blocks of iron to allow uniform movement of the die during compaction, The cleaned surfaces of die wall and tools (upper and lower punch) were sprayed with a lubricant-saturated solution

Sintering Process

Sintering process is to provide extra bonding between atoms. The atomic diffusion takes place and welded areas formed during compaction will increase the connection by sintering process. The sintering will be controlled over heating rate time; temperature and atmosphere are required for reproducible results.

The equipment used during sintering process is tube furnace as shown in Figure 2, the inert gas used during the process is Argon gas. Then, enter the specimen metal (Aluminium and metal carbide) into the tube furnace, The temperature used is followed by sintering profile Figure 3. Sintering Temperature was taken according to the rule.

Sintering Temperature = (0.7-0.9) Tm

Hence: Tm = melting point

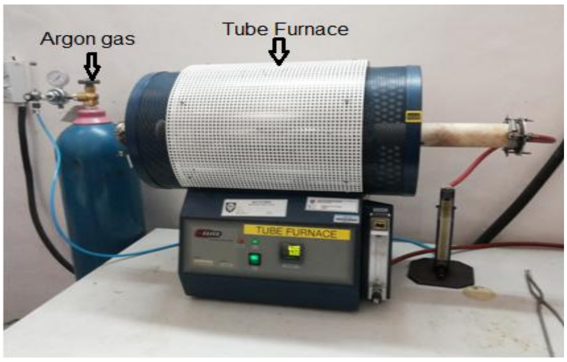

Figure 2: Sintering furnace.

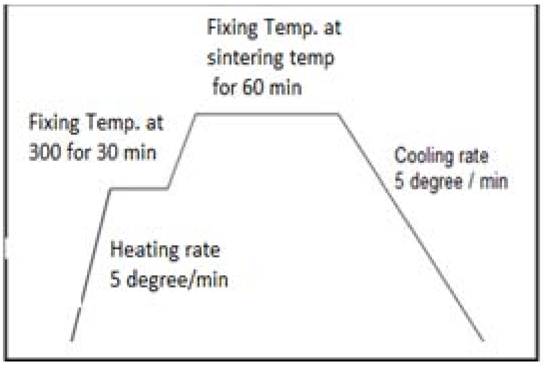

Figure 3: Sintering procedure

Physical properties inspection

Density, Porosity and water absorption were investigated in this study. Density (D_B) and dense, usually refer to a measure of how much of some entity is within a fixed amount of space. Then, the mass of many particles of a particulate solid or a powder, divided by the total volume they occupy is called Bulk density.

The process of water absorption (W_A) means that a water was captured inside the material. The water was distributed inside material. As well as, the apparent porosity (A_p) has a significant effect on the physical properties.

3. Results and Discussion

It is possible to accomplish the process of pressing the powder on many of the powders at various pressing conditions without relying on optimal conditions with physical properties. But in this case, the compaction piece is of durability is weak and there is a high probability of exposure to failure when it is used due to the various problems take place during the compaction process such as pores and weak bonding. Therefore, some physical properties have been studied. Density, porosity and water absorption were selected for this study.

Effect of compaction pressure on compression strength

The compaction pressure is a significant effect on the sample resistance. Figure 4 describes the relationship between the Compaction pressure and sample strength for all the suggested samples. Three values of compaction pressure were used. The values were 5 , 7 and 9 Tons. It is noted that the sample strength increases with increasing of hanging compaction pressure for all the suggested samples (AI, BI, CI, DI).

It is clear from this, when low compaction pressure was applied lead to be weak bonding between the particles while at a high compaction pressure has high bonding.

The maximum value was upon the mix (DI) which equal to (134) Mpa due to there are very little of pores because it has various particle sizes of powder While (BI) and (CI) have one size of particle therefore they have more pores. Then, the compression strength were (59) and (43) Mpa respectively. Hence, (AI) has little of pores due to the particle size was smaller. Hence, the compression strength was (109) Mpa

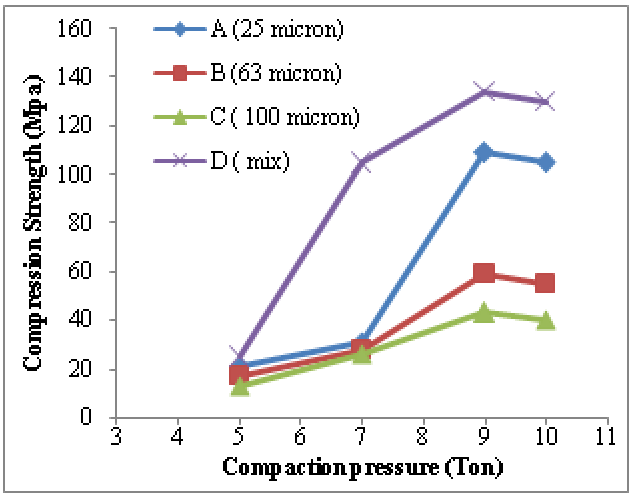

Figure 4: Relation between compaction pressure and compression strength for AI , BI , CI , DI

Effect of compaction pressure on Microhardness

Hardness gives good idea about the durability and coherence of the material mass by using small loads. In this test which is non-destructive, the instrument consists of a hard and accurate head for easing the penetrating in the material. Usually the material suffering from elastic deformation then the plastic deformation

In this test, eight values for each sample was taken to calculate the average. Figure 5 shows the relationship between compaction pressure and Microhardness for the groups (AI, BI, CI, DI).

Four groups for Microhardness was noted.The biggest one was (DI) because it has a large amount of grain boundaries, therefore it has big value of hardness which was (61HV).While (CI) has the lower one, which was (49HV) due to it has big particle size and pores. Whereas (AI) and (BI) have values between them which were (59HV) and (52HV) respectively. Generally, the relationship between compaction pressure and hardness is Direct proportional.

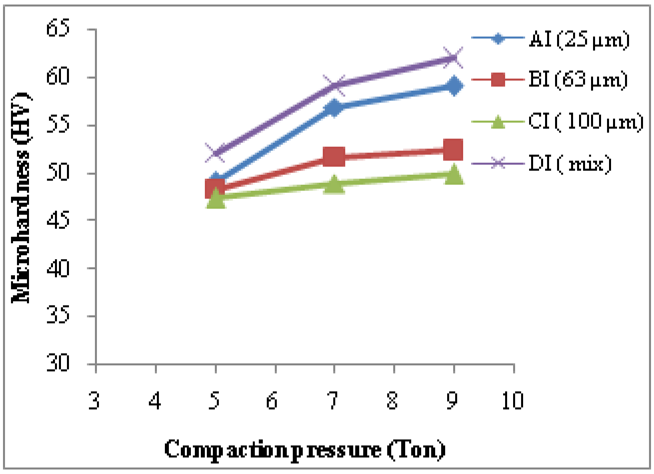

Figure 5: The relationship between compaction pressure and Microhardness for the groups (AI, BI, CI, DI).

Effect of compaction pressure on Microstructure

Various types of technologies are used to observe and characterize the microstructure of aluminium alloy on different scales. Microstructure observation is conducted by using Optical Microscope. This apparatus is widely used to observed polish sample to obtain qualitative information about the size, shape and orientation of grains. The solid cylinder shape was fabricated for this test, (13)mm diameter (10) mm height. Figure 6 shows the effect compaction pressure on Microstructure.

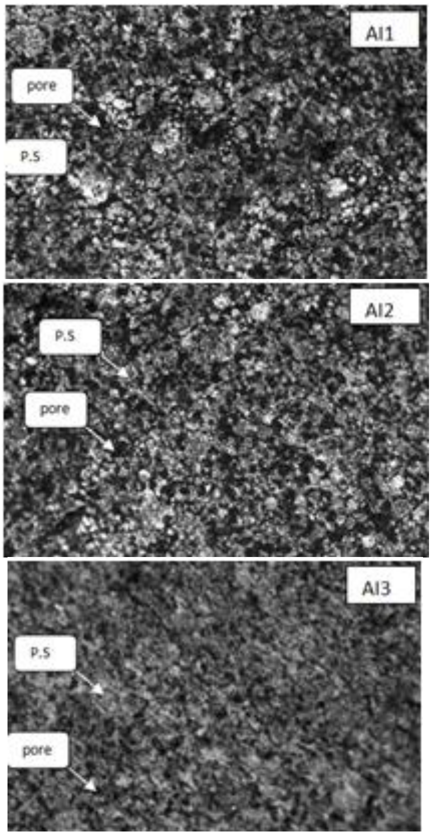

Figure 6: Effect compaction pressure on Microstructure of AI (25 µm particle size)

Effect of Compaction Pressure on physical properties

Physical properties show more idea about the connections among the Aluminium powder particles. Therefore, Compaction pressure is effected on the bonding between the powder particles. Figure 7 shows the relation between compaction pressure and some physical properties (Density, Porosity, water Apsorbtion) for (25µm) particle size. We can be seen that the Density will be increased by increasing compaction pressure. Whilst, the Porosity and Water Apsorbtion will be decreased by increasing compaction pressure

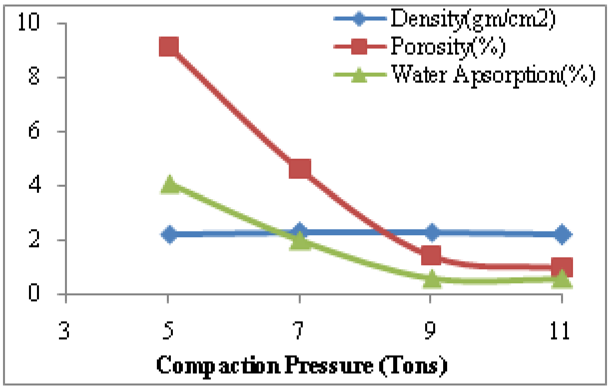

Figure 7: Relation between Compaction pressure and Physical properties For AI (25 µm particle size)

Effect of Particle size on physical properties

Effect of Particle size on Density

Usually, it can compress the powder or convert it to a much greater bulk density range, and the material can also be coarse granular to be very light powder, when manufactured by spraying, or when shaken or pressure may become too dense to lose their ability to flow. The bulk density of coarse particles does not differ significantly on the scale, assuming the negligence of the pores between the particles. Figure 8 illustrates the relationship between the compaction load and the density for different particle sizes.

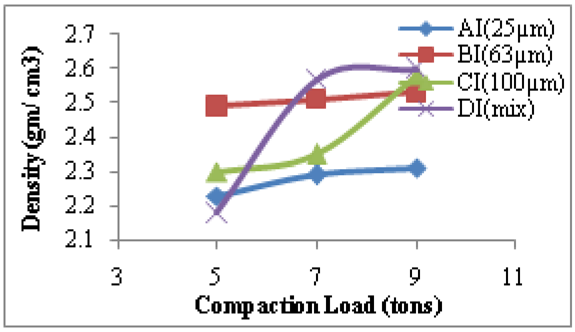

Figure 8: The relationship between the compaction load and the density for different particle sizes

It can be seen that the density was high value (2.49 gm/cm^3) for the type (BI) while was lower value (2.18 gm/cm^{3}) for (DI) at compaction load (5 tons) due to the compaction load not enough to decrease the number of pores at type (DI), whereas the type (DI) sharply raised at (7 tons) and slightly rise at (9 tons). Thus, the types (AI, BI,CI) have slightly risen from (5tons) to (7tons). Consequently, the type (CI) sharply rises at (9 tons) but the type (AI) slightly drops. Finally, we can see at (9 tons), the maximum value for density was (2.6 gm/cm^3) for the type (DI) while the minimum value was (2.3 gm/cm^3) for (AI) whereas were (2.53 , 2.58) for (BI, CI) respectively.

Effect of Particle size on Porosity

Porosity is the percentage of the size of the pores in the powder for the total volume of the powder bulk. Figure 9 illustrates the relationship between the compaction load and the Porosity for different particle sizes

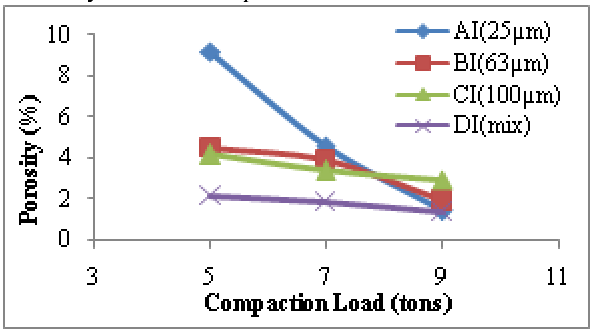

Figure 9: The relationship between the compaction load and the porosity for different particle sizes

It can be seen that the porosity slightly drop for the type (DI) due to the number of pores was the lowest amount while it was higher for the types (AI, BI, CI). On the other hand, we can see that the value of porosity for the type (BI) was bigger than the type (CI) at compaction load (7 tons) whereas the value was lower at compaction load (9 tons) lead to that the small size affected much more of large size for the porous value.

Effect of Particle size on Water absorption

Water absorption is used to determine the amount of water absorbed under specified conditions. Factors affecting water absorption include: type of plastic, additives used, temperature and length of exposure. The data sheds light on the performance of the materials in water or humid environments. Figure 10 shows the relationship between the compaction load and the Water absorption for different particle sizes

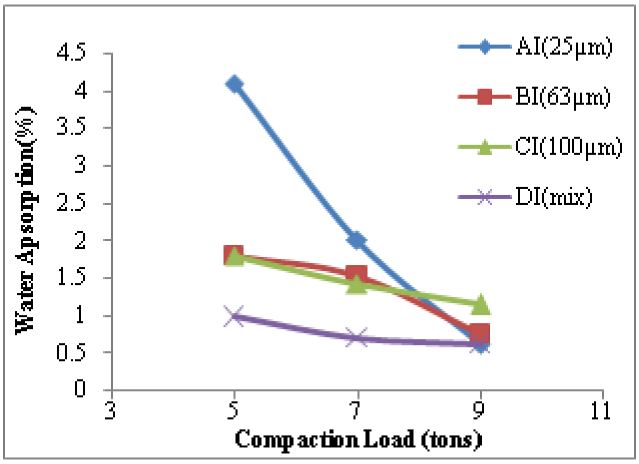

Figure 10: The relationship between the compaction load and the Water absorption for different particle sizes

The results of water absorption are similar to the results of the porosity. The relation between the porosity and the water absorption is Positive relationship. Then, when the number of pores, increased, the water absorption value increased.

4. Conclusions

Based on investigations, it is revealed that the particle size designed experiments were successfully conducted. So, we can be concluded the relationship between compaction pressure and physical properties (Density, Porosity and Water absorption). When compaction pressure was increased, the Density is increased, but the porosity and water absorption are decreased.

On the other hand, high Density, low porosity and low water absorption were given by the mix particle size specimen. Whereas, the others by single particle size have been given higher density by using bigger particle size at 9 tons compaction pressure while it has been given lower porosity and water absorption by using smaller particle size. In addition, the increasing of compacted pressure has led to decreasing of the pores and increasing of contact points. So, Direct proportion was detected between the compaction pressure and both of the density and hardness.

5. Future Scope

AA6061 is an important metal in the industry. Many of parts were fabricated by it in many applications. Chemical reactions should be invested. The corrosion rate is so important to investigate. On the other hand, particle size and other parameters for compaction method are also important to investigate.

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