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Physical Properties of Recycling Milled Aluminium Chip (AA6061) for Various Sintering Temperature

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Abstract: **In this investigation, AA6061 milled particle size was fabricated by milling machine plus compacted by hydraulic press in room temperature. Finally, sintering in the temperature range of 478-617 ^{O}C. Four groups of particle size were chosen (25, 63, 100, mix) µm. Each group has compacted by three specimens for various of Sintering temperature (487, 552, 617) ^{O}C, the compaction pressure and holding time were constant (9) tons, (20) min respectively. The physical properties of the four groups depend on the variations of sintering temperature. So, it is useful first to present and discuss the results of microstructure to understand the physical properties. In this study, the density value was increased with the increasing of sintering temperature value to (552) ^{O}C of all types of suggested groups due to the bonding between particles was stronger, in addition, the pores amount was decreased. After that, it was decreased due to the particles become big size lead to the barriers were decreased. The maximum value of density was detected by mix group which was (2.601 gm/cm^3) while the particle size (25) µm was the minimum value which was (2.494 gm/cm^3). Whereas the groups (63) µm and (100) µm were (2.590 gm/cm^3) and (2.593 gm/cm^3) respectively.**

Keywords: **physical properties, milling process, sintering temperature, powder metallurgy, AA6061.**

I. INTRODUCTION

For the sintering of ceramic materials, processing under high pressure (> 1 GPa) offers the possibility of a significant improvement. The energetic gain associated with densification, which in pressureless sintering is only associated with the reduction of surface energy by the porous reduction. As a consequence, lower temperatures and/or shorter times can be used to produce highly densified bodies, preventing grain growth and possible changes in the chemical composition [1]. Compared with unreinforced aluminium alloys, aluminium metal matrix composites present a remarkable combination of outstanding physical and mechanical advantages, such as low density, high strength, fatigue resistance, low coefficient of thermal expansion and tribological properties, and are widely applied in spacecrafts, automobiles, bicycles and electronic components as high-temperature structural or electronic packaging materials[2].

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 [3-5]. Ball mill grinding process is often the most commonly seen and the most energy intensive operations [6]. 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 [7]. 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 [8]. 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 [9]. 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 [10]. 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 [11-14].

In this study, the sintering temperature 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.

II. EXPERIMENTAL WORK

A. 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 Chemical Composition for Aluminium AA6061 is shown in Table. 1.

Table. 1 Chemical Composition of Aluminium AA6061 (ASTM B308/B308M)

Ele.	Wt %	Ele.	Wt %	Ele.	Wt %
Si	0.4-0.8	Mn	0-0.15	Zn	0-0.25
Fe	0-0.7	Mg	0.8-1.2	Ti	0-0.15
Cu	0.15-0.4	Cr	0.04-0.35	Al	95.8-98.5

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

B. 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).

C. 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.

D. 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.

E. 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. Tables. 2 and 3 show the classification of specimens according to particle size and sintering temperature respectively.

Table. 2 classification of specimens according to particle size

AII	Particle size (25 µm)
BII	Particle size (63 µm)
CII	Particle size (100 µm)
DII	Mix (78.5% (25 µm) + 21.5% (100 µm))

Table. 3 classifications of specimens according to applied to the Sintering temperature

AIII1	Particle size (25 µm) applied to Sintering temperature $(487)^{O}C$
AIII2	Particle size (25 µm) applied to Sintering temperature $(552)^{O}C$
AIII3	Particle size (25 µm) applied to Sintering temperature $(617)^{O}C$

F. 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.

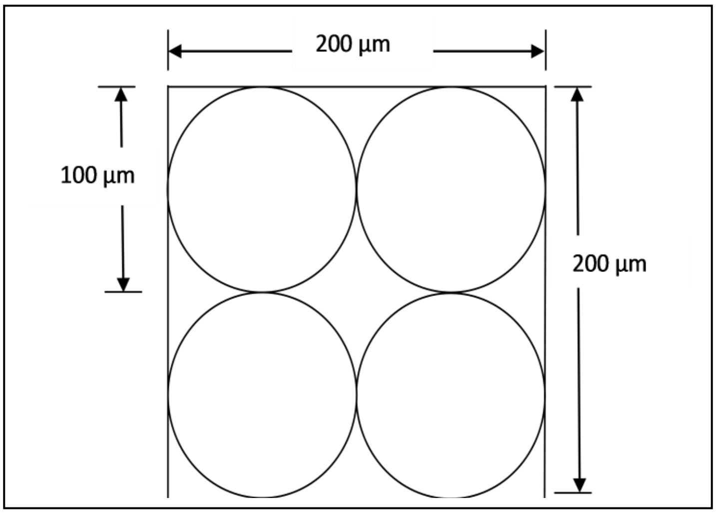

Figure. 1 the concept of mixing method for particle size

Figure. 1 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).

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))

G. 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

H. 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

Sintering Temperature = (0.7-0.9) Tm

Hence: Tm = melting point

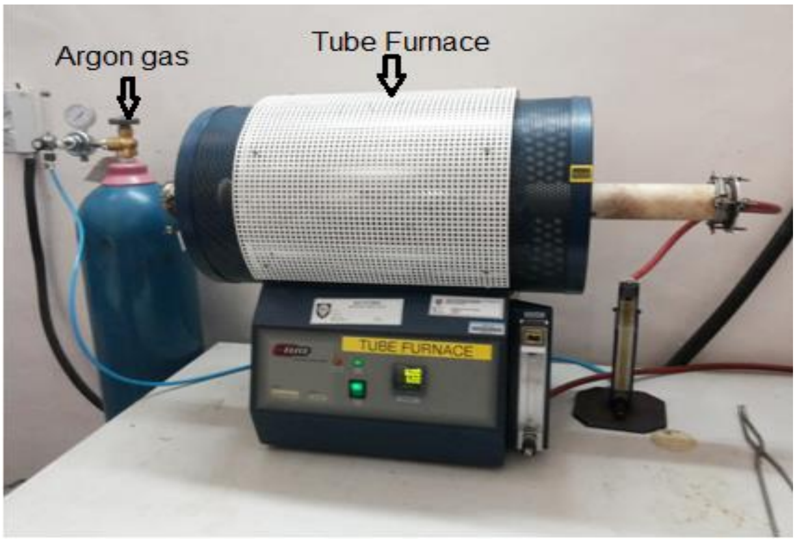

Figure. 2 Sintering furnace.

III. PHYSICAL PROPERTY 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.

IV. 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.

A. Effect of Sintering Temperature on physical properties:

Sintering is the process of compacting and forming a solid mass of material by heat without melting it to the point of liquefaction. The atoms in the materials diffuse across the boundaries of the particles, fusing the particles together and creating one solid piece. Because the sintering temperature does not have to reach the melting point of the material. Figure. 3 shows the effect of Sintering temperature on Physical properties. We can be seen that the Density will be increased by increasing Sintering temperature to reach to value (552^{o}C), then it will be decreased due to the particle size will be grown and there are some interior cracks were taking place. Whereas, the Porosity and Water Apsorbtion will be decreased by increasing Sintering temperature due to the particle size will be grown. In addition, the pores will be decreased.

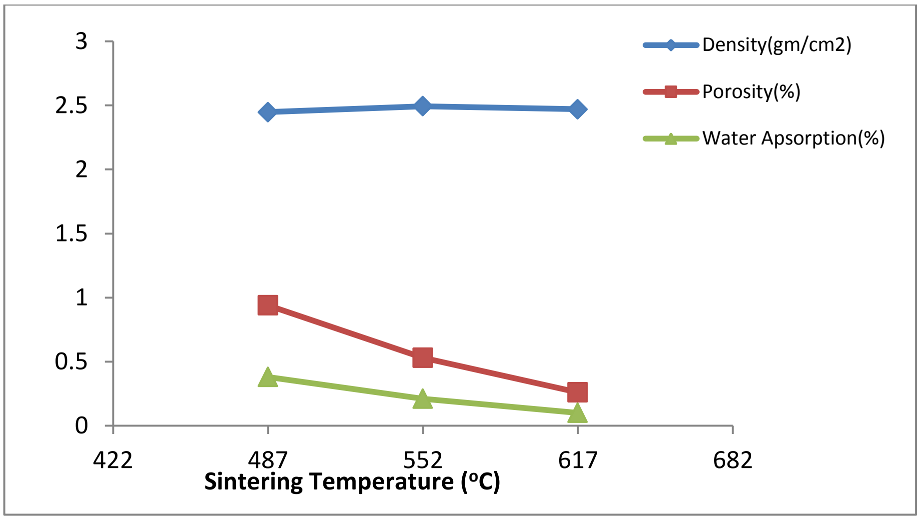

Figure. 3 relation between Sintering temperature and Physical properties

B. 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. 4 illustrates the relationship between the sintering temperature and the density for different particle sizes.

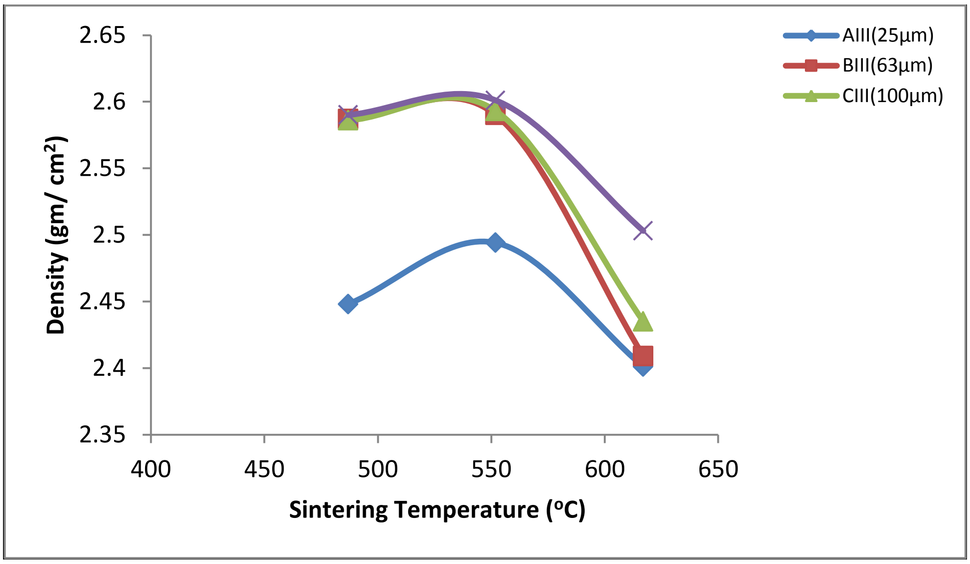

Figure. 4 the relationship between the sintering temperature and the density for different particle sizes.

It can be seen that the density was high value (2.601 gm/cm^3) for the type (DIII) while was lower value (2.494 $gm/cm^{3)}$ for (AIII) at the sintering temperature (552 ^{O}C) due to the sintering temperature not enough to decrease the number of pores at type (AIII) and there are much more amount of grain boundaries. The type (AIII) sharply raised at (552^{O}C) and sharply drop at (617^{O}C). Thus, the types (BIII, CIII,DIII) have slightly risen from (478 ^{O}C) to (552 ^{O}C). Consequently, the types (BIII,CIII,DIII) sharply drop at (617 ^{O}C). Finally, we can see at (552 ^{O}C), the maximum value for density was (2.601 gm/cm^3) for the type (DIII) while the minimum value was (2.494 gm/cm^3) for (AIII) whereas were (2.590 , 2.593 gm/cm^3) for (BIII, CIII) respectively.

C. 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. 5 illustrates the relationship between the sintering temperature and the Porosity for different particle sizes.

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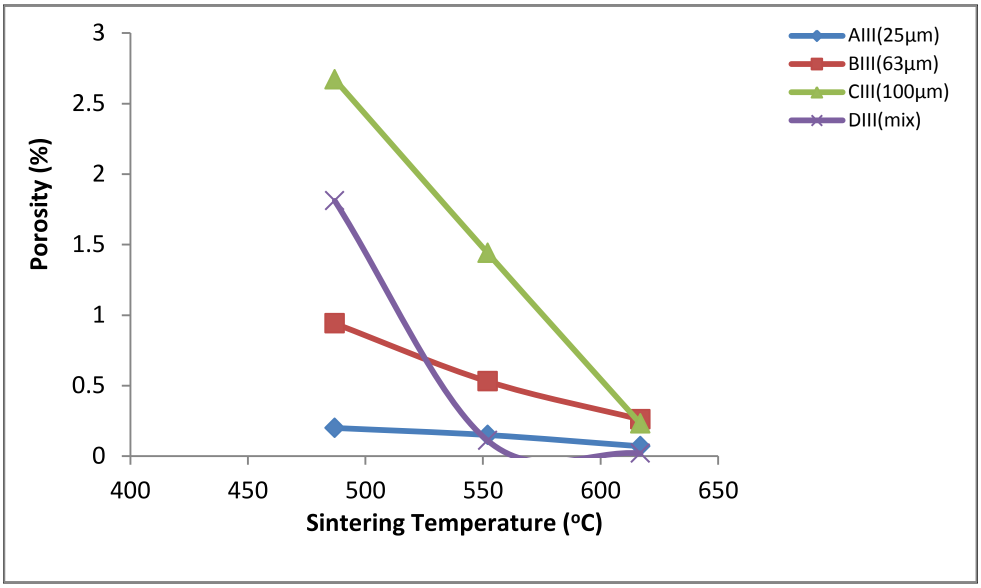

Figure . 5 the relationship between the compaction load and the porosity for different particle sizes

It can be seen that the porosity slightly drop for the type (AIII) due to the number of pores was the lowest amount while it was higher for the types (BIII, CIII, DIII). On the other hand, we can see that the value of porosity for the type (CIII) was bigger than the others at the sintering temperature (478 ^{O}C) whereas the value was lower at the sintering temperature (552 ^{O}C) for type (DIII) lead to that the mix of particles size affected much more of large size for the porous value.

D. 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. 6 shows the relationship between the compaction load and the Water absorption for different particle sizes.

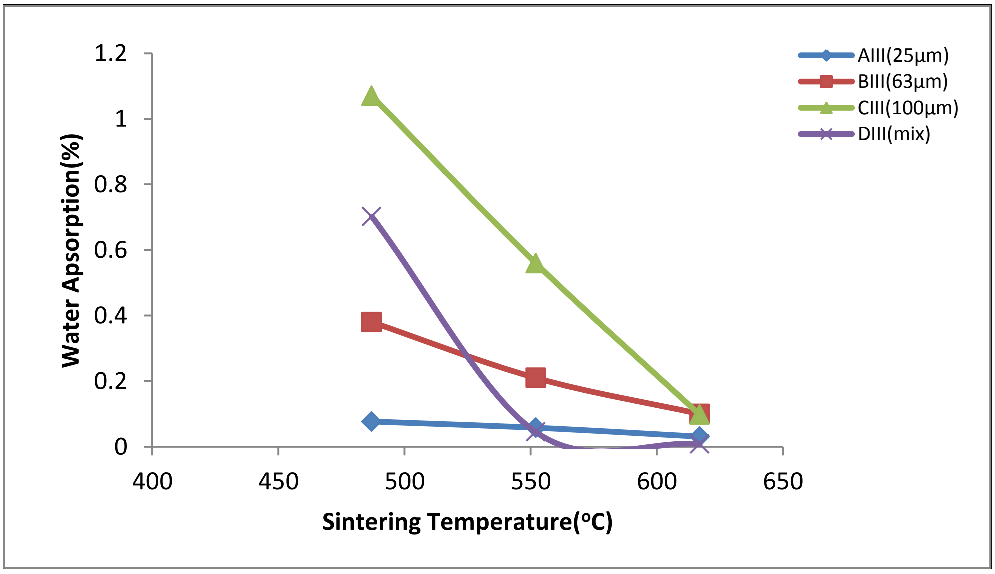

Figure. 6 the relationship between the compaction load and the Water absorption for different particle sizes

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.

E. Effect of Sintering Temperature on Microstructure:

Overview and extensive knowledge have been given by Microstructure inspection. Every previous sample was inspected. Figure.7 shows the bonding and pores for every sample was tested. At sintering temperature equal to (487)^{o}C, It can be seen many of pores due to the particle of aluminium didn't reach to enough temperature which it leads to bond the particles.While at sintering temperature (552) ^{o}C, it can be seen the pores become less than the previous temperature and the bonding becomes stronger.whereas at (617) ^{o}C, although the bonding becomes more but the crack becomes longer, therefore the strength becomes smaller.

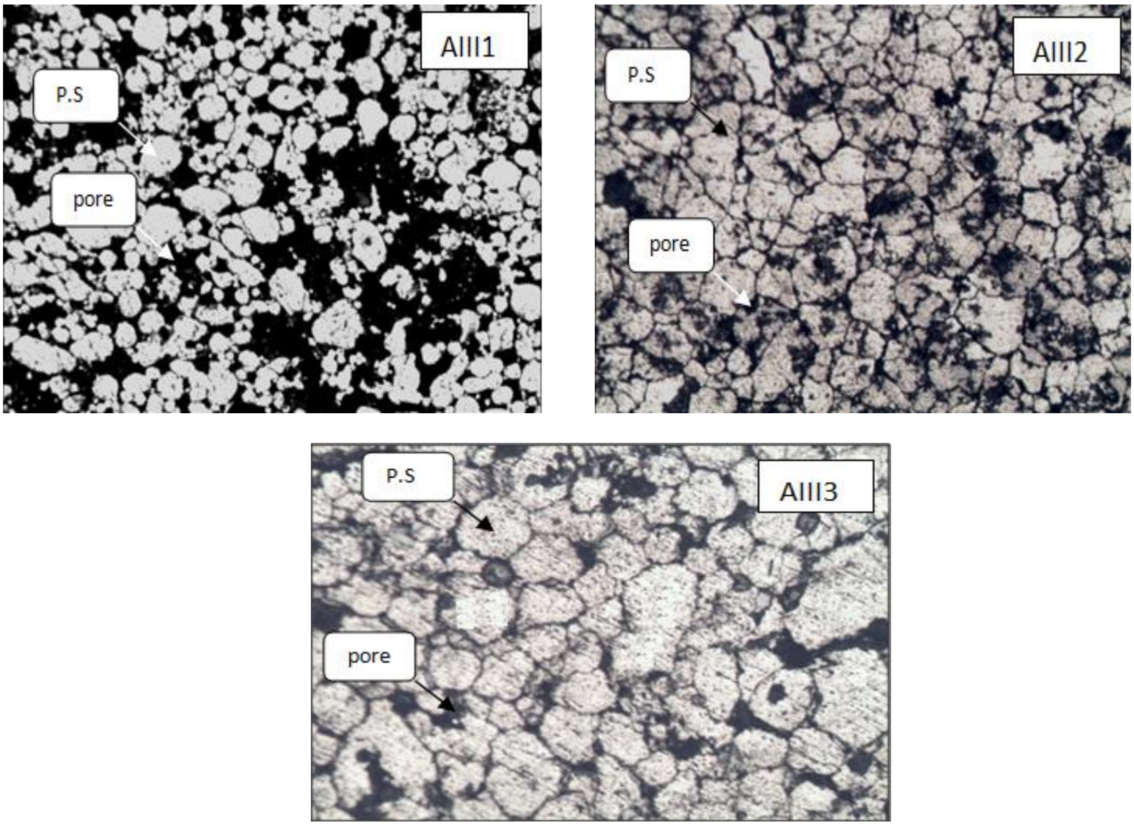

Figure. 7 effects sintering temperature on Microstructure of AIII (25 µm powder)

V. CONCLUSIONS

Based on investigations, it is revealed that the particle size designed experiments were successfully conducted. So, we can be concluded the relationship between sintering temperature and physical properties (Density, Porosity and Water absorption). When the sintering temperature 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 552^{O}C sintering temperature while it has been given lower porosity and water absorption by using smaller particle size. In addition, the increasing of sintering temperature has led to decreasing of the pores and increasing of contact points. So, Direct proportion was detected between the sintering temperature and the density.

VI. 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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