



THE EFFECT OF COLD COMPACTING PARAMETERS FOR PRODUCING RECYCLES ALUMINIUM BY MILLING PROCESS

Ahmed Sahib Mahdi¹, Mohd Sukri Mustapa², Mohd Amri Lajis², and Mohd Warikh abd Rashid³

¹Southern Technical University, Iraq

²Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia, Parit Raja, Batu, Johor, Malaysia

³Universiti Teknikal Malaysia Melaka, Malaysia

Email: ahmedaltai@yahoo.com

ABSTRACT

Pressing process can be performed in any circumstances for compaction parameters. The optimum conditions were experimentally evaluated from compression test. These inspections are very useful to determine the variations in the bonding between the powder particles and the effect of compaction parameter on compression strength, Microhardness and microstructure. Four groups of particle size were selected which were (25, 63, 100, mix of them) μm . The mechanical properties of the four groups depend on the variations in particle size for powder and the pores between particles. So, it is useful first to present and discuss the results of microstructure to understand the strengthening mechanism. In this study, compression strength value was increased with the increasing of compaction pressure value to (9) tons of all types of suggested groups. After that, it was gradually decreased. The maximum value of compression strength was detected by mix group which was (160) MPa while the particle size (100) μm was the minimum value which was (115) MPa. whereas the groups (25) μm and (63) μm were (150) and (134) MPa respectively.

Keywords: powder metallurgy, AA6061, particle size, optimum conditions, milling process.

INTRODUCTION

An alternative to conventional alloys are metal matrix composites (MMCs) (Lajis *et al.*, 2015), Aluminium hybrid composites are a new generation of metal matrix composites that have the potentials of satisfying the recent demands of advanced engineering applications which have a high specific modulus, good wear resistance and a tailorable coefficient of thermal expansion (Michael *et al.*, 2015; Umanath *et al.*, 2014).

Aluminium is the most abundant metal in the Earth's crust, and the third most abundant element, after oxygen and silicon. It makes up about 8% by weight of the Earth's solid surface. Due to easy availability, High strength to weight ratio, easy machinability, durable, ductile and Malleability Aluminium are the most widely used non-ferrous metal in 2005 was 31.9 million tons (Jenix *et al.*, 2012). Aluminium alloy is used in many automotive and airplane applications due to light weight, excellent weldability, and corrosion resistance (Loganathan *et al.*, 2014; Zakaria *et al.*, 2013).

Applications of metal matrix composites (MMCs) have not emerged at the rate needed to justify the development costs. One reason for this may be the lack of data regarding the workability of these materials to obtain the final shape (Ceschini *et al.*, 2009; Salehi *et al.*, 2012). Metal matrix composites (MMCs) are currently being investigated because of their superior properties as compared to those of the more conventional materials (Adamiak *et al.*, 2004).

The optimization of the mechanical properties of aluminium matrix composites is largely dependent on the microstructure of the material. Several parameters characterize this structure, i.e. size, shape and particle distribution, and to the matrix, i.e. grain size, texture, precipitates and dispersoids. A thorough characterization

of the composite microstructure is required in order to understand the mechanical properties of aluminium matrix composites (Corrochano *et al.*, 2011).

Powder metallurgy (PM) is another important processing technique for composite preparation, which offers homogeneity of both, composition and microstructure in the final product (Estrada *et al.*, 2012). Aluminium has been widely investigated and is presented as a key material in order to face these challenges. So, aluminium alloys have been extensively investigated in order to improve their mechanical performance (Perez *et al.*, 2012).

A wide range of production techniques has been developed for aluminium matrix composite materials. This is generally done by dispersion of high temperature resistant fine ceramic reinforcement particles into the aluminium matrix. Even though a number of processing techniques are available for producing MMCs, the mechanical milling (MM) using powder metallurgy (PM), is a useful technique to synthesize Al-based composites. The conventional PM route for making Al matrix composites includes: (1) Al is blended or mechanically alloyed with reinforcement particles; (2) compaction, and (3) sintering (Santos *et al.*, 2015).

During the past 20 years, high energy ball milling has extensively been utilized as a versatile method to produce a variety of advanced compound powders. The main difference between high energy milling by the planetary ball mill, this process has been given large input energy makes high energy mills capable of producing materials with special properties that could not be synthesized by other methods. On the other hand, the large amount of energy consumed by high energy mills is potentially a burden on industrial application of this method. That is because the electrical energy spent for



production of the powders by high energy mills is added to the final price of the products (Razavi *et al.*, 2015).

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/cm³, the mechanical properties for Aluminium AA6061 is shown in Table-1.

Table-1. Mechanical properties of Aluminium AA6061 (Loganathan *et al.*, 2014).

Yield Strength (MPa)	Tensile Strength (MPa)	Density gm/cm ³	Hardness (HV)
214	311	2.7	94

Zinc Stearate was used as a binder to make the compaction process easier.

Milling process

Firstly, chip was produced by using CNC milling machine, type HSM (SODICK – MC430I), Feed rate (1100 mm/min), Depth of cut (1.0 mm), cutting velocity (345.4 m/min). After that, the chip was milled by planetary ball mill type (Retsch PM100) under condition of the speed (350 r.p.m) and time (20) HR. The ratio of ball to powder (r.b.p) was 20:1.

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

Choosing of optimum conditions

There are many variable considered in the selection, in a research study, a parameter that considered which is sintering temperature, compaction pressure and Time delay. A set of parameter is used for each compaction as shown in Table-2.

Table-2. Classification of specimens.

	A (25 µm)	B (63 µm)	C (100 µm)	D (Mix)
I (Change in pressure)	AI1 (5 tons)	BI1	CI1	DI1
	AI2 (7 tons)	BI2	CI2	DI2
	AI3 (9 tons)	BI3	CI3	DI3
II(Change in Holding Time)	AII1 (10 mins)	BII1	CII1	DII1
	AII2 (15 mins)	BII2	CII2	DII2
	AII3 (20 mins)	BII3	CII3	DII3
III(Change in Sintering Temp.)	AIII1 (478)	BIII1	CIII1	DIII1
	AIII2 (552)	BIII2	CIII2	DIII2
	AIII3 (617)	BIII3	CIII3	DIII3

Mix = 78.5% (100 µm) + 21.5% (25 µm)

P.S = particle size (µm)

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-1, the inert gas used during the process is Argon gas. Then, enter the specimen metal into the tube furnace, Figure-2 is showed the temperature used by sintering profile. We should take sintering Temperature according to the rule.

$$\text{Sintering Temperature} = (0.7-0.9) T_m \quad (1)$$

Hence: T_m = melting point

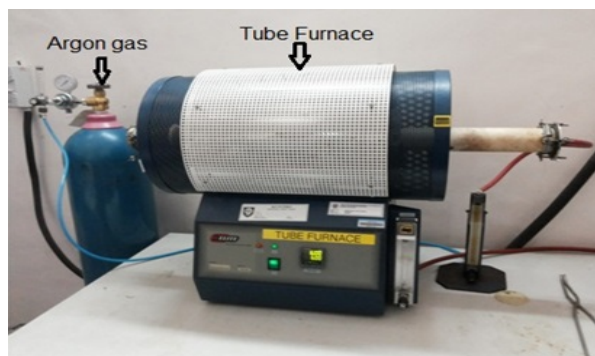


Figure-1. Sintering furnace.

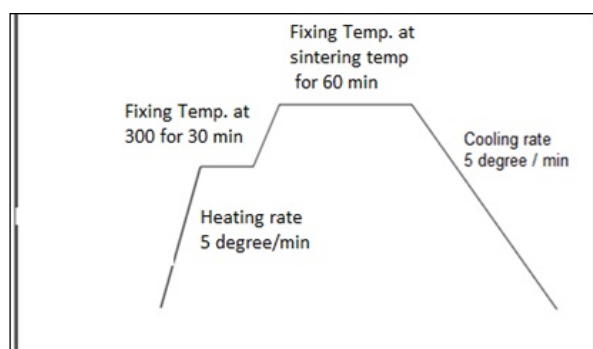


Figure-2. Sintering procedure.

RESULTS AND DISCUSSIONS

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.

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, the process must be in optimal conditions.

The optimal conditions for compaction process were studied. Compaction pressure, Holding time and Sintering temperature were selected for this study.

Effect of compaction pressure on compression strength

The compaction pressure is a significant effect on the sample resistance. Figure-3 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.

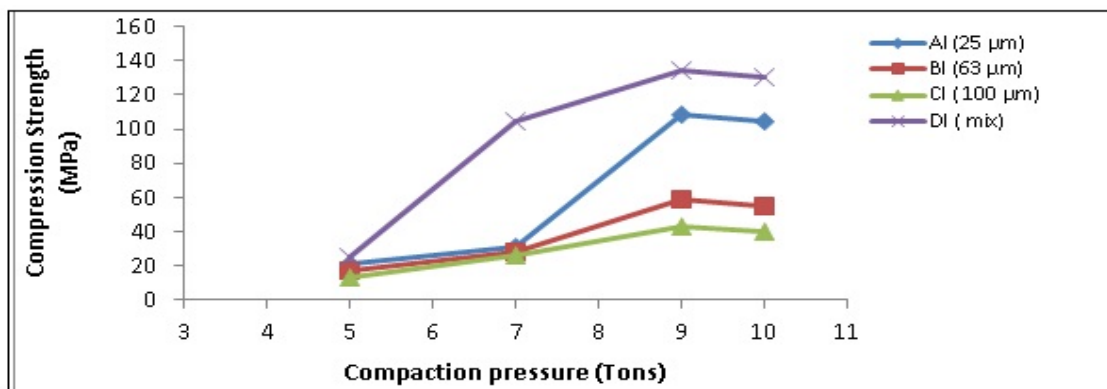


Figure-3. Relation between compaction pressure and compression strength for AI, BI, CI, DI.

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-4 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.

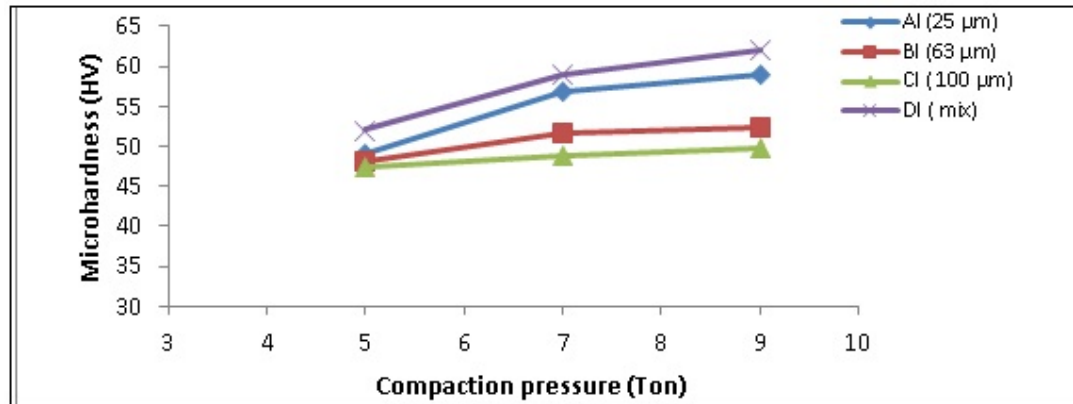


Figure-4. The relationship between Compaction Pressure and Microhardness for the groups (AI, BI, CI, DI).

Effect of holding time on compression strength

The Holding time is the main parameter that effect on the compressive strength of of the compacted specimen. Figure-5 describes the relationship between the Holding time and compression strength for all the suggested samples. Three values of holding time were used. The values were 10 , 15 and 20 mins . It is noted that the compression strength increases with increasing of hanging compaction pressure for all the suggested samples (AI, BI, CI, DI).

The relation between holding time and compression pressure was direct proportional. Then, when

the holding time was increased that's mean the compression strength to become stronger.

The maximum value was upon the mix (DI) which equal to (155) 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 (112) and (111) MPa respectively. Hence, (AI) has little of pores due to the particle size was smaller. Hence, the compression strength was (148) MPa.

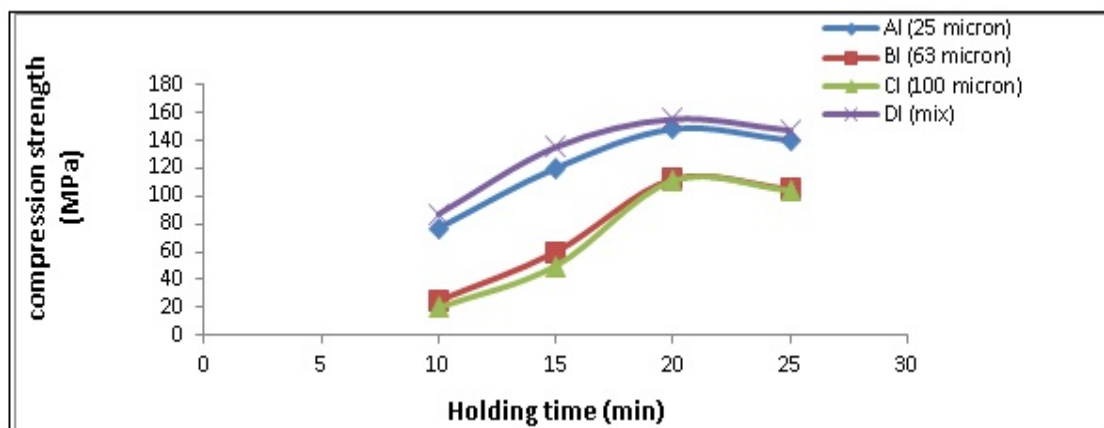


Figure-5. Relation between holding time and compression strength for AI, BI, CI, DI.

Effect of Holding Time on Microhardness

Eight values for each sample was taken to calculate the average. Figure-6 shows the results of Vickers Microhardness tests of the four groups. (AI, BI, CI, DI).

These groups were noted. The biggest one was (DI) because it has a large amount of grain boundaries, therefore it has big value of hardness which was (64HV).

While (CI) has the lower one, which was (51HV) due to it has big particle size and pores. Whereas (AI) and (BI) have values between them which were (54HV) and (52HV) respectively. Generally, the relationship between Holding time and Microhardness is direct proportional. It is observed that the Microhardness increases with increasing holding time.

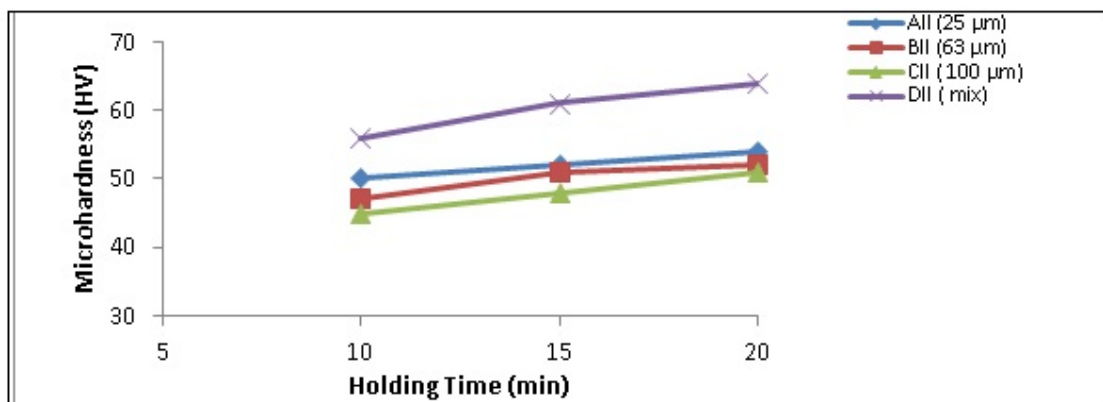


Figure-6. The relationship between holding time and Microhardness for the groups (AI, BI, CI, DI).

Effect of sintering temperature on compression strength

Figure-7 shows the relationship between compression pressure and the value of temperature for each group of selected powder. It can be seen that the value of compression pressure for the lower selected temperature was (150) MPa For the powder (AIII) while this value was (134) MPa for (BIII) that attributed to that the increasing at grain size causes decreasing in grain boundaries (Barriers against crack growth), So the value was (117) MPa at (CIII) due to the particle size was (100 μm). Whereas the (DIII) was the bigger one which was (160) MPa attributed to particle size was varied, therefore the barriers against crack growth were affected. On the other hand, the cracks were little amount at (DIII) while were the more amount of the others.

The same figure shown is the relation between the sintering temperature and compression strength, Then, three values of sintering temperature were used which were (487, 552, 617) °C. The value of compression strength on (487 °C) was (134)MPa. When the sintering temperature increased, the compression strength increased due to that the aluminium particle was more flexible and the bonding was stronger. Therefore, the compression strength on (552 °C) was (160) MPa while the increasing of Sintering Temperature will be decreasing the compression strength. Hence, It is shown in Figure-7, then, the value of compression strength on (617 °C) was (127) MPa.

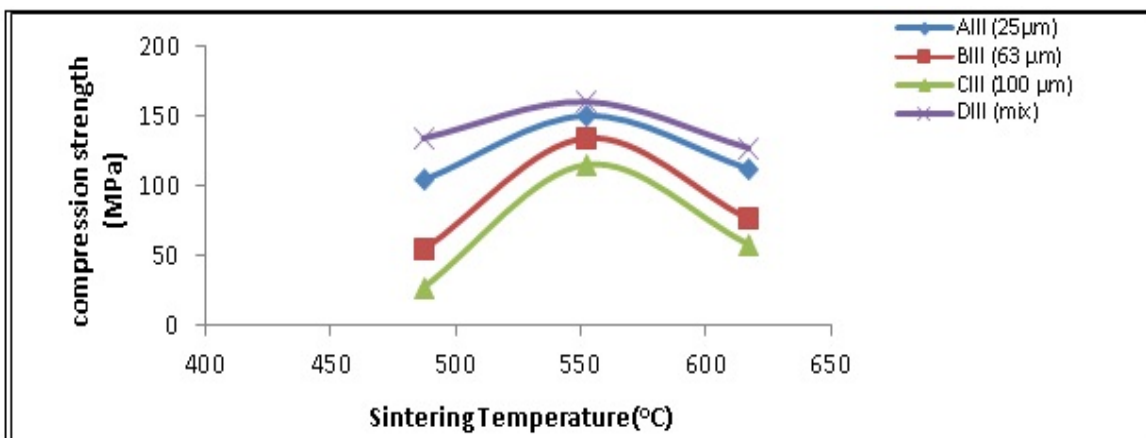


Figure-7. Relation between sintering temperature and compression strength.

Effect of sintering temperature on microhardness

Figure-8 shows the relation between sintering temperature and Microhardness. Four groups were taken for different particle sizes which were (AIII, BIII, CIII, DIII). Three sintering temperatures were used for each group. It can be seen that the Microhardness will be decreased with the increasing of sintering temperature. So, the Microhardness was related to the particle sizes.

Therefore, the type (AIII) has Microhardness (63 Hv) is bigger than the types (BIII) and (CIII) which were (56.58Hv) and (49.55Hv) respectively, these results are attributed to the particle size of powder, while the type (DIII) has the biggest value which was (68.72Hv) due to the cracks were a little amount.

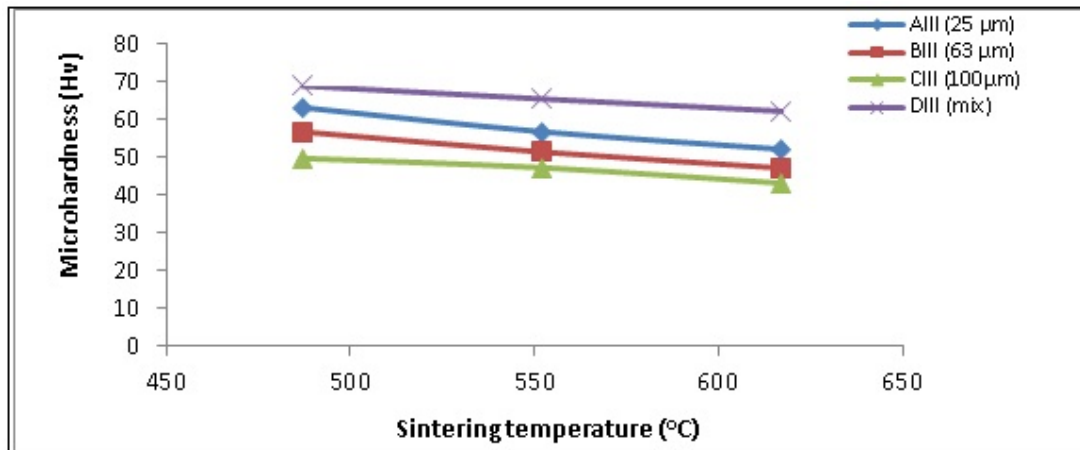


Figure-8. The relation between sintering temperature and Microhardness.

Microstructure of optimum conditions

Overview and extensive knowledge have been given by Microstructure inspection. Every previous sample for optimum conditions was inspected. Figure-9 shows the bonding and pores for every sample was tested. At sintering temperature equal to (487)°C, It can be seen many of pores due to the particle of aluminum didn't reach to enough temperature which it leads to bond the particles. While at sintering temperature (552) °C, it can be seen the pores become less than the previous temperature and the bonding becomes stronger. Whereas at (617) °C, although the bonding becomes more but the crack becomes longer, therefore the strength becomes smaller.

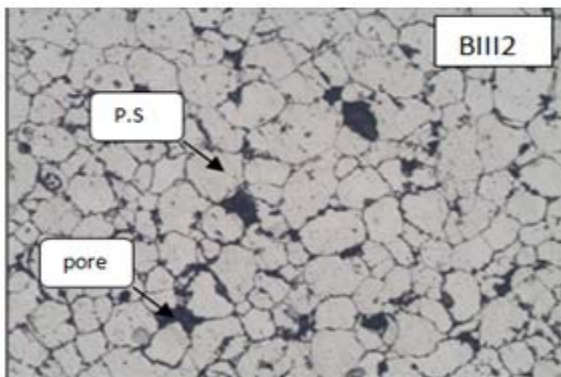
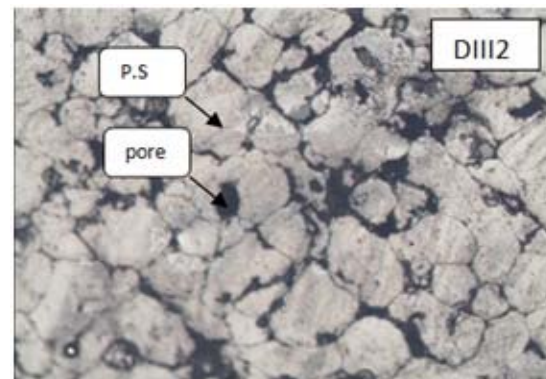
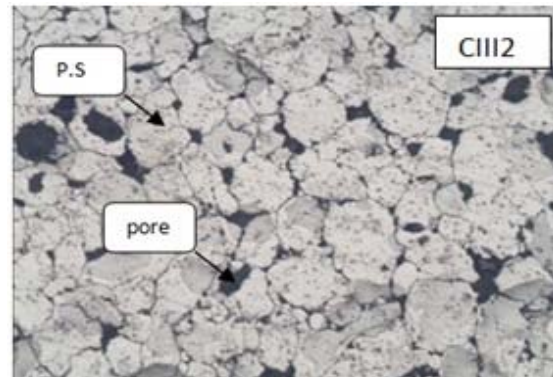
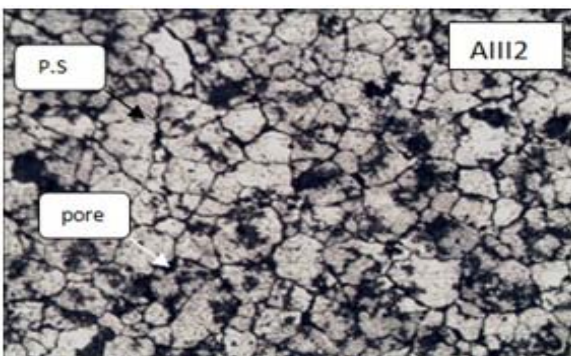


Figure-9. Microstructure at optimum conditions.

CONCLUSIONS

The experiments were carried out on milled AA6061 using four different particle sizes (25, 63, 100, mix) μm. They were observed that the compression strength and hardness were possible on the same when they were sintered. The experiments were discovered that the mix of particle size was the best of compression strength and hardness due to it has variety of particle sizes to fill the pores to obtain more connection for the powder particles. Consequently, the smaller particle size was



detected better than the bigger particle size if the powder contains the single particle size. Addition to, The optimum conditions of compression strength, Holding time and sintering temperature were 9 tons, 20 mins and 552 °C respectively.

ACKNOWLEDGEMENTS

The authors would like to thank to University Tun Hussein Onn Malaysia (UTHM) for sponsoring this work and short term Grant No. U 358.

REFERENCES

- [1] S.S. Khamis, M.A. Lajis, R.A.O. Albert (2015)" A Sustainable Direct Recycling of Aluminum Chip (AA6061) in Hot Press Forging Employing Response Surface Methodology" ScienceDirect. Procedia CIRP 26. 477 – 481.
- [2] Michael Oluwatosin Bodunrin, Kenneth Keneth Alaneme, Lesley Heath Chown, (2015)" Aluminium matrix hybrid composites: a review of reinforcement philosophies; mechanics, corrosion and tribological characteristics" j mater res Technol.
- [3] K. Umanath, S. T. Selvamani, K. Palanikumar and R. Sabarikreeshwaran (2014)" Dry Sliding Wear Behavior of AA6061-T6 Reinforced SiC and Al₂O₃ Particulate Hybrid Composites" ScienceDirect, Procedia Engineering 97,694 – 702.
- [4] J.Jenix Rino, D.Chandramohan, K.S.Sucitharan (2012)" An Overview of Development of Aluminium Metal Matrix Composites with Hybrid Reinforcement" International Journal of Science and Research. Volume 1 Issue 3, December.
- [5] D. Loganathan, A. Gnanavelbabu, K. Rajkumar and R. Ramadoss.(2014)" Effect of Microwave Heat Treatment on Mechanical Properties of AA6061 Sheet Metal" ScienceDirect, Procedia Engineering 97 ,1692 – 1697.
- [6] K.A. Zakaria, S. Abdullah, M.J. Ghazali (2013)" Comparative study of fatigue life behavior of AA6061 and AA7075 alloys under spectrum loadings" Materials and Design 49, 48–57.
- [7] L. Ceschini, G. Minak,A. Morri, F. Tarterin (2009)" Forging of the AA6061/23 vol.%Al₂O₃p composite: Effects on microstructure and tensile properties" Materials Science and Engineering A 513–514 ,176–184.
- [8] M. Salehi, M. Saadatmand, J. Aghazadeh Mohandesi (2012)" Optimization of process parameters for producing AA6061/SiC nano-composites by friction stir processing" ScienceDirect. Trans. Nonferrous Met. Soc. China 22, 1055_1063.
- [9] M. Adamiak , J.B. Fogagnolo , E.M. Ruiz-Navas , L.A. Dobrzański , J.M. Torralba (2004)" Mechanically milled AA6061/(Ti3Al)P MMC reinforced with intermetallics – the structure and properties" Journal of Materials Processing Technology 155–156 ,2002–2006.
- [10]J. Corrochano , M. Lieblich, J. Ibáñez (2011)" The effect of ball milling on the microstructure of powder metallurgy aluminium matrix composites reinforced with MoSi₂ intermetallic particles" Composites: Part A 42 ,1093–1099.
- [11]Estrada-Guel, C. Carreño-Gallardo, R. Martínez-Sánchez (2012)" Effect of carbon nanoparticles addition on the mechanical properties of an aluminum composite prepared by mechanical milling and leaching process" Journal of Alloys and Compounds 536S ,S175– S179.
- [12]R. Pérez-Bustamante, M.J. González-Ibarra, J. González-Cantú, I. Estrada-Guel, J.M. Herrera-Ramírez, M. Miki-Yoshida, R. Martínez-Sánchez (2012)" AA2024-CNTs composites by milling process after T6-temper condition" Journal of Alloys and Compounds 536S ,S17– S20.
- [13]Santos-Beltrán, R. Goytia-Reyes, H. Morales-Rodriguez, V. Gallegos-Orozco, M. Santos-Beltrán F. Baldenebro-Lopez, R. Martínez-Sánchez (2015)" Characterization of Al–Al₄C₃ nanocomposites produced by mechanical milling" Materials Characterization 106 , 368–374.
- [14]S.S. Razavi-Tousi and J.A. Szpunar (2015)" Effect of Ball Size on Steady State of Aluminum Powder and Efficiency of Impacts during Milling" Department of Mechanical Engineering, University of Saskatchewan, S7N 5A9 Saskatoon, Saskatchewan, Canada.
- [15]D. Loganathan, A. Gnanavelbabu, K. Rajkumar and R. Ramadoss" Effect of Microwave Heat Treatment on Mechanical Properties of AA6061 Sheet Metal" ScienceDirect, Procedia Engineering 97 (2014) 1692 – 1697.