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The Effect of Aging on Physical Characteristics of Recycled AA6061 Aluminium Chips

Mohd Arif Samsi[#1], Mohammad Sukri Mustapa[#2], Nur Azam Badarulzaman[*3], Ahmed Sahib Mahdi[#4], Muhammad Irfan Ab Kadir[#5]

[#] Structural Integrity and Monitoring Research Group (SIMReG) of Mechanical and Manufacturing Engineering, UTHM, 86400 Parit Raja, Batu Pahat, Johor, Malaysia

[1] arif_samsi90@gmail.com
[2] sukri@uthm.edu.my
[4] ahmedaltaei@yahoo.com
[5] irfankadir91@gmail.com

[*] Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia (UTHM) Johor, 86400 Parit Raja, Batu Pahat, Johor, Malaysia

[3] azam@uthm.edu.my

***Abstract*—Solid state recycling AA6061 chips by cold compression is a technique that used lower energy consumption and operating cost compared to the conventional recycling technique by casting. This research is to investigate physical characteristics of the milled recycling aluminium AA6061 according to the change of the aging time (heat treatment) using the milling process and followed by a cold press forging process. The chip of AA6061 that produced from high speed milling was used. Physical property of the milled recycled chip of AA6061 was studied. Six values of aging time were taken (0, 2, 4, 6, 8, and 10) hours. On the other hand, the quenching and aging temperature is constant. The results were showing that the microstructure, porosity and density, and microhardness increased with increasing the aging time until 10 hours. Its shows that density (2.54 g/cm3), porosity (5.46 %), and hardness value (125.34 HV). And for the lower results are shows at 0 aging time where the result is density (1.96 g/cm3), porosity (25.39 %), and hardness value (81.36 HV). It can be concluded; 10 hours of aging time is the best choice for all groups.**

Keyword - Aging time, Hardness, Quenching, Physical Characteristics, AA6061.

I. INTRODUCTION

Nowadays, the usages of aluminium are worldwide. There was 50.2 million tons of total primary aluminium consumption in the world in 2013. The main user of primary aluminium worldwide, with 23.2 million tons in 2013 is in the China, North America (5.5 million tons) and Europe (7.2 million tons) continue to be key regions for the consumption of primary aluminium [1]. These happen due to the outstanding application of aluminium in the world. However, lack of government control caused primary resources become shortage day by day and in fact give many pollution effects to the environment. Aluminium is the most heavily consumed nonferrous metal in the world, with the current annual consumption at 24 million tons. About 75% of this total volume, or 18 million tons, is primary aluminium (that is, extracted from ore) as opposed to secondary aluminium which is derived from scrap metal processing [2].

Aluminium is experiencing an increasing success in diverse industrial sectors including automotive, building, packaging and household product. The increasing demand from both professional and private consumers, demonstrates the utility of aluminium in everyday life and the increasing of the aluminium is importance in aluminium industry. In global context, Europe has emerged as one of the world’s largest manufacturing base for the aluminium industry owing to large mass production capacities across the European countries. In 2010, Europe remained the second major producer of primary aluminium and its aluminium production increased around 7% in 2010 compared to the previous year [3].

Instead of so many products were used in aluminium, there must be some waste. To make some aluminium product, there have a machining process. From that, the chips will produce. The aluminium chips are called a waste product. In case of that, the waste from the product of aluminium must be reused to avoid from wasted. The bauxite is a natural source (mineral) before aluminium produce. In other word, the aluminium chip must be recycled. There are so many methods that can be used to recycle the aluminium chip.

From Fig 1 shows conventional aluminium recycling process. An alternative approach to overcome the problem of material loss is by during re-melting of aluminium chips and to further improve the energy balance of the aluminium production is the direct conversion of aluminium alloy machining chips into finished or semi-finished products by hot extrusion where first presented and patented by Stern 1945 [4]. In this process, the chips are compacted to chip-based billets and extruded on a conventional hot extrusion press to the chip-based extrudes. Different kinds of aluminium chips can be recycled by hot extrusion. Just for example turning chips or milling chips [5].

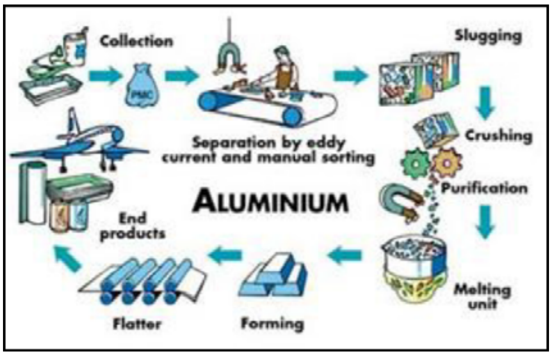


Fig 1: conventional aluminum recycling process (FPO, Belgium).

As all kinds of aluminium chips are naturally covered by an oxide layer, the large plastic deformation (for example strain) and compressive stresses (for example pressure) must affect the chips during the extrusion process in order to break the oxide layers and to enable contact between surfaces of pure metal [6]. Those requirements for the extrusion of chips are in accordance with the investigations of Bay 1979 [7], who proposed a theory for a cold pressure welding. He showed that by the process of cold pressure welding of aluminium includes the expansion of the surface, the mechanisms of fracture of a work-hardened surface layer, and finally the pressing of the material around the particles of the cracked hard surface layer [8].

From previous studies, the results showed that green density of AA6061 was lower than pure AA6061. As the speed of ball mill increases from 100, 150 and 200 rev/min, the green density increases. Next, the samples were sintered at 500, 550 and 600°C. Microstructure of samples having the lowest green density shows larger and more frequent porosity compared to higher green density samples with smaller and less visible porosity. The Vickers hardness value is in the range from approximately 60–150 HV [9].

The hot compaction has a good result prefer the cold compaction. But the value has not much different. For ultimate tensile strength (UTS) for cold compaction is 292 MPa and for hot compaction is 309 MPa [10]. Cold compaction can achieve a good result when applied a heat treatment. The pores in the specimen will be small when the specimen applied a heat treatment [11].

The sintering process will affect the structure of density of particle. With this operation, the density must be at 97% - 98%. It also must have suitable carbon contain in the specimen to make have good mechanical properties to the sample. [12].The optimum pressure was defined at 650MPa. This pressure can produce compacted chips with a density of 2.48 g/cm3.

II. EXPERIMENTAL PROCEDURE

A. Material

Aluminium block AA6061 has a high resistant to corrosion and malleable that widely used in the industries. The chemical composition (in wt. %) of the AA6061 alloy are Si (0.59), Fe (0.092), Cu (0.289), Mn (0.08), Mg (0.975), Cr (0.2), Zn (0.031), Ti (0.1), and Al (remnant). It is a lightweight metal compared to the other metal such as nickel, steel, brass and cooper with the specific gravity 2.7 g/cm3. The mechanical properties of the aluminium AA6061 are shown in Table 1.

TABLE I. MECHANICAL PROPERTIES OF ALUMINUM AA6061 (ASTM B308/B308M)

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

B. Preparation of chip

Chip was produced by the high speed CNC milling machine (SODICK-MC4301) with feed rate (11000 mm/min), width of cut (1mm), and cutting velocity (345.4 m/min). Aluminium chip were cleaned by ultrasonic bath (FRITSCH - ultrasonic cleaner Labarette 17). The duration of cleaning was 1 hour for each patch. After that, chips were treated with acetone solution for 20 min. Finally, the drying process was done via drying oven (Linn High Therm) for 1 hour at 85 °C.

C. Mixing and Compaction Process

The compaction process used was uniaxial hydraulic press machine (Carver model 3851-0). The chips were poured into the mould, then mould was closed to be compress into a shape called green compact. The composition of mixture to produce the samples between aluminium chips AA6061 (99 wt. %) and Zinc stearate (1 wt.%) and compact with cold compaction was performed at room temperature (RT). The load of the compaction is 9 tons and the duration of holding time is 20 minutes [13].

D. Sintering process

Sintering is the process to enhance the bonding between particles. 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. Fig 2 shows the schematic diagram of sintering process in tube furnace. The inert gas used during the process is Argon gas. Then, enter the specimen metal into the tube furnace. The temperature used is followed by sintering profile Fig 3. At 300°C in 30 minute the zinc stearate will be burning out. The sintering process will be start at 552°C in 60 minute. Sintering Temperature was taken according to the rule [14].

Sintering Temperature = (0.7-0.9) T_m,

Where T_m = melting point of the material.

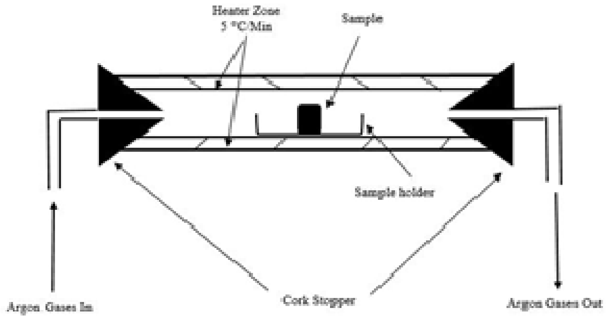


Fig 2: Schematic diagram of sintering process

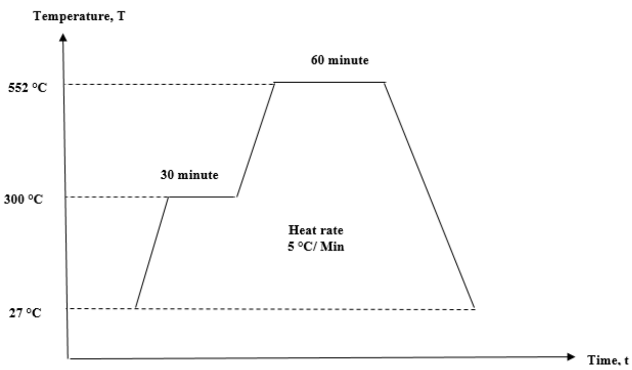


Fig 3: Sintering profile [14].

E. Heat Treatment (Aging)

The heat treatments used are quenching and aging process. The equipment used is furnace (PROTHERM). The heat treatment will be controlled over heating rate time; temperature, holding time, and atmosphere are required for reproducible results. The temperature used is followed by heat treatment (quenching and aging) profile Fig 4. The quenching and aging is constant temperature but the aging are variables in holding time.

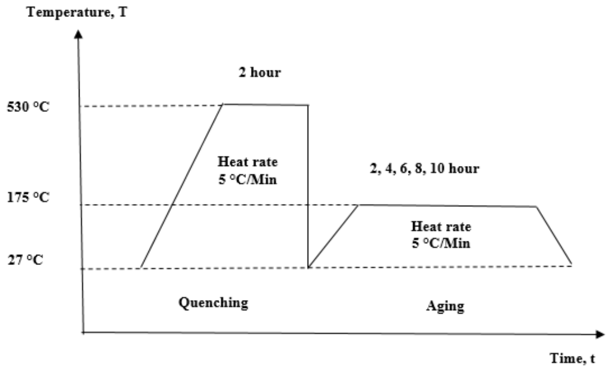


Fig 4: Heat treatment (aging and quenching) profile

III.RESULT AND DISCUSSION

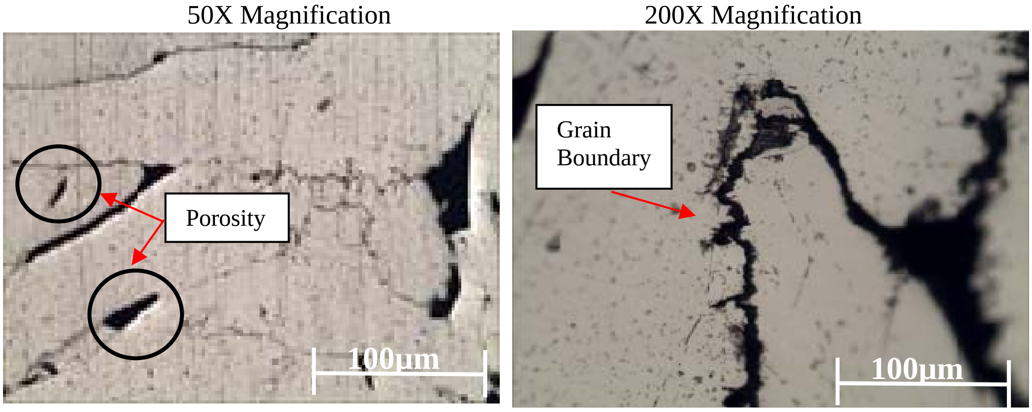
A. Microstructural Behaviour

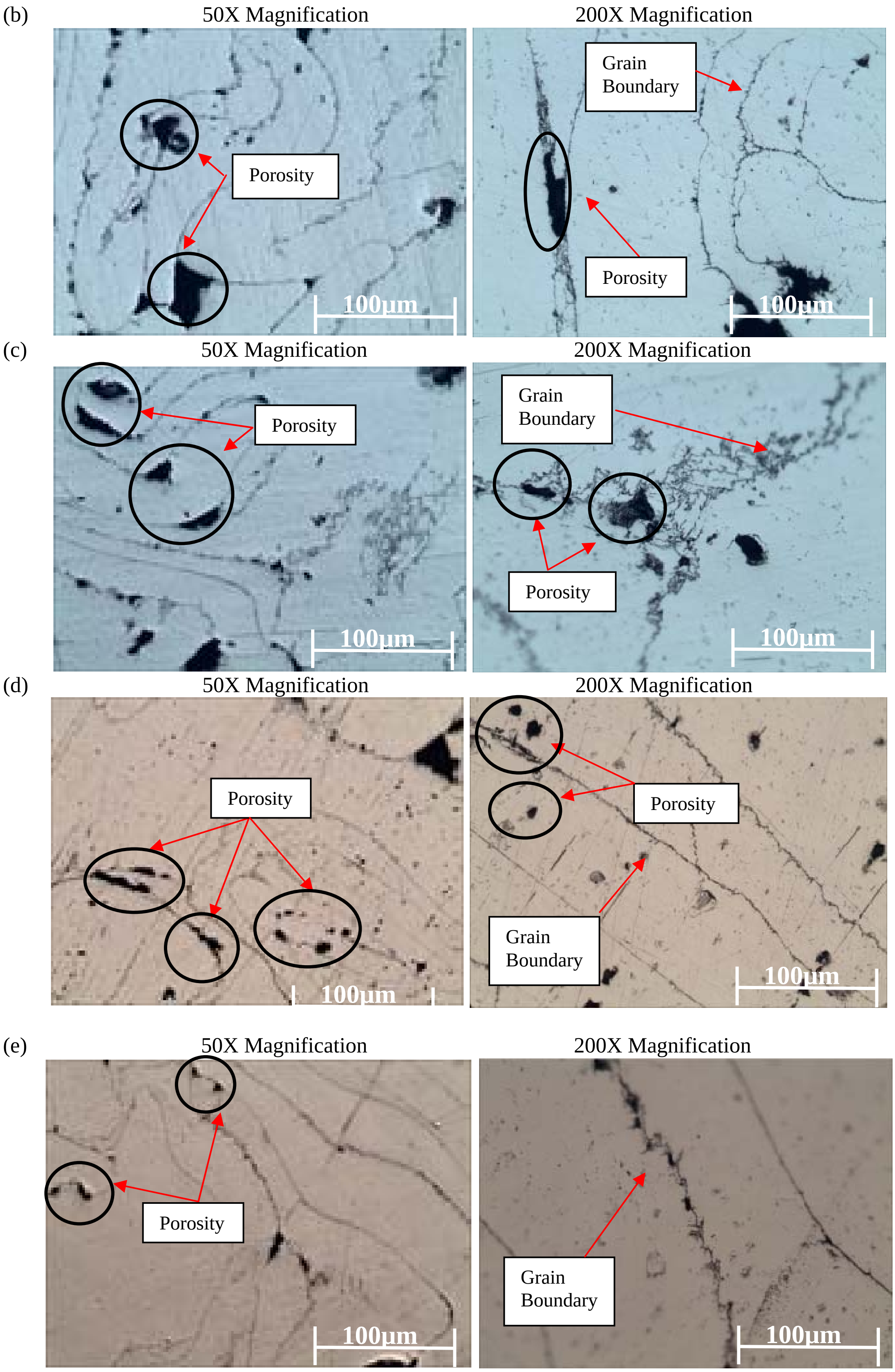
The surface of a manufactured part generally has properties and behaviour that is considerably different from those of its bulk. Although the bulk material generally determines the component's overall mechanical properties, the component's surface directly influences several important properties and characteristics of the manufactured part. Microstructure is the key point of the structure. The success of the recycling of chips by cold compaction, sintering and heat treatment (aging) with the quality of the consolidated samples depend on the resulting of the microstructure. The microstructures of the sintered and heat treatment (aging) samples were characterized using optical microscopy

Fig 5 shows the microstructure of groups (0, 2, 4, 6, 8, and 10) with magnification 50x and 200x. There are 6 values of aging time were taken which was (0, 2, 4, 6, 8, and 10) hours. It is observed from these figures, the less aging time produced more pores and it has recorded lowest hardness value, so the higher aging time can be seen on microstructure have lower pores, higher bonding and higher hardness value. That means, the increasing of aging time leads to an increase in the microhardness of compacted metal.

For sample 0 hour, it can be seen many of large pores formed on the surface due to there are no aging process on it when the aging time were increased, it can be seen that the pores become less. The chips absorbed the heat and the particle expanded. It will cover the pores and forming a good surface on the sample. Whereas at sample 10 hours have a good surface but there has a small pore formation on the surface of the sample. That can be attributed to the effect of aging time will be decreased the porosity and consequently increased the densification behaviour [10].

(a) 50X Magnification 200X Magnification




(b)
50X Magnification
200X Magnification
Porosity
100µm
Grain Boundary
Porosity
100µm
(c)
50X Magnification
200X Magnification
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100µm
Grain Boundary
Porosity
100µm
(d)
50X Magnification
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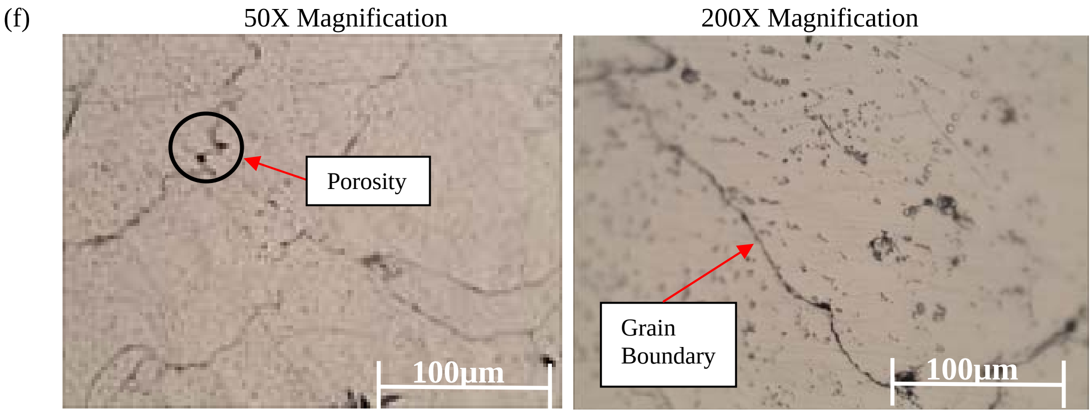


Fig 5: Optical microscopy images of AA6061 chips samples after aging: (a) 0 hours, (b) 2 hours, (c) 4 hours, (d) 6 hours, (e) 8 hours, and (f) 10 hours

B. Physical properties

Table 2 shows the obtained result from porosity and density test were identified through Archimedes' Principle technique. From the table, the density increased by heat treatment (aging) increased. Meanwhile, the porosity become decreased and at aging (10 hour) the porosity become increased. But, in the density the aging at 10 hour shows that the density is increased. The purpose of heat treatment (aging) is to make the bonding of the barrier of atom become stronger. The particle in the specimen become bigger that mean the pores become smaller.

The relationship between porosity and aging time always refers to the fraction or percentage of pores within the volume of a porous solid. The higher porosity that shows 25.39 % is at sample there have not aging and the lower it porosity value is at 8 hours aging time that show 2.79 %. Meanwhile at 10 hours aging time the porosity is increase at 5.46 %. It can show that at sample 10 hours when the sample is increasing the aging time, the pores become smaller. The pores become smaller because of the particle absorbed the heat and it will expend.

The relationship between density and aging time also refers to the fraction or percentage of pores within the volume of a porous solid. The higher density that shows 2.54 % is at sample 10 hours aging time and the lower density value is at 0 hours aging time that show 1.96 %. It can show that at sample 0 hours when the sample is increasing the aging time, the density also increases. The particle of aluminium chip AA6061 will become bigger when the particle absorbs the heat. The bonding of the particle becomes stronger. The densification of sample is based on the pores. If there are so many pores, the densification of the sample become lower. That why at sample 0 hours there have a less pores. The porosity and density also have correlated. It is vice versa from the density. When the porosity becomes decreased, the density becomes increased.

Significantly, changes of density and apparent porosity can be analysed as increasing aging density resulted in lower pore fraction and as well as less percentage of porosity.

TABLE 2. POROSITY AND DENSITY

Time (Hour)	Wd (g)	Ws (g)	Ww (g)	Porosity (%)	Density (g/cm^3)
0	4.00	2.48	4.50	25.39	1.96
2	3.99	2.47	4.10	6.29	2.45
4	3.87	2.36	3.95	5.37	2.44
6	3.97	2.47	4.05	4.98	2.51
8	3.93	2.41	3.97	2.79	2.52
10	3.98	2.50	4.07	5.46	2.54

C. Microhardness

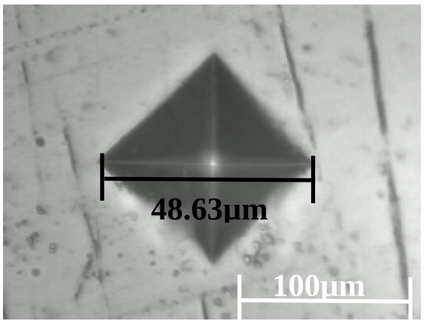
The microhardness test was carried out to find out the degree of hardness of the material surface by using small load. In this test, the hardness test was conducted using the microhardness Vickers machine in which the instrument consists of a hard and accurate head for easing the penetrating in the material. Five values for each sample were taken to calculate the average from the 5 microhardness Vickers value from each sample. Table 3 shows the results of microhardness Vickers tests of the 6 groups which is 0, 2, 4, 6, 8, and 10. These groups were noted. The biggest one was 10 hours aging time because it has a large amount of grain boundaries, and higher value of density. Therefore, it has big value of microhardness which was 125.34 HV. While, the sample that did not have aging has the lower one, which was 81.36 HV due to it has big pores. Whereas, at aging time 2, 4, 6, and 8 hours have values between them which were 91.13 HV, 100.80 HV, 104.16 HV, and 111.12 HV respectively. The range of the microhardness is between 60Hv – 150 Hv [9].

TABLE 3. MICROHARDNESS VICKERS

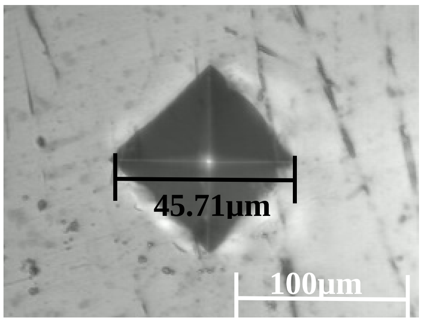
Aging Time (Hours)	Hardness Vickers (HV)	Standard Deviation
0	81.36	1.69
2	91.13	1.03
4	100.80	0.71
6	104.16	4.41
8	111.12	1.18
10	125.34	4.34

In Fig 6 shows that the micrograph of indentation from microhardness Vickers test. The indention used 1 kgf at 10 seconds. From micrograph we can see the indent become smaller. It is because the hardness of the sample is increasing. This is correlated to the heat treatment (aging time). It is a same theory that when the density increases, the porosity decreases while hardness becomes increased. The stronger bonding of particle made the hardness become stronger.

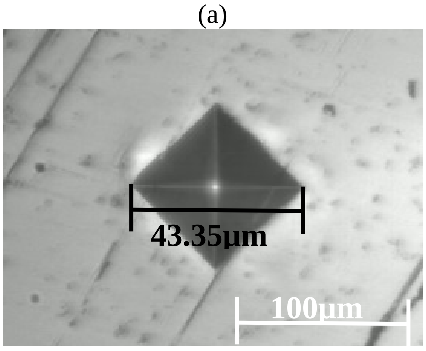
Significantly, the hardness decreased with a decreased time of aging. The hardness values showed an irregular distribution for all aging time. It is clearly to understand that the aging can change the phase of the sample, leading to an increase in the amount of hardness.



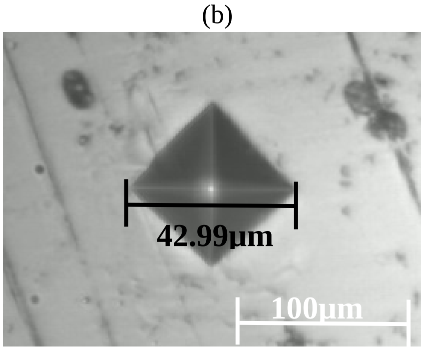
(a)



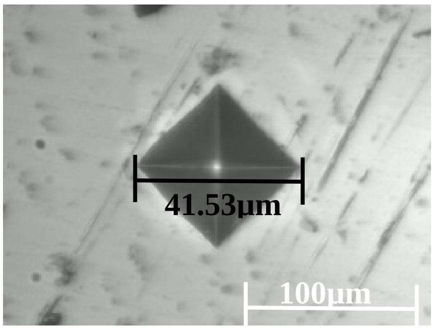
(b)



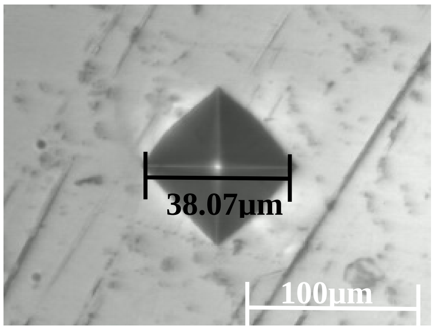
(c)



(d)



(e)



(f)

Fig 6: Micrograph of indentation from hardness Vickers test.

IV. Conclusion

Based on the preparation and characterization of sample made of recycled AA6061 chips, the following conclusions can be drawn. The increasing of the aging time managed to form a good microstructure with less formation of large pores on the surface of a sample. Six groups of aging time were used for these study (0, 2, 4, 6, 8, and 10) hours. It can be shown that the aging time (10) has a bigger value for this study. It can be concluded that the longer aging time will be higher the hardness value. The results were showing that the microstructure, porosity and density, and microhardness increased with increasing the aging time until 10 hours. Its shows that density (2.54 g/cm3), porosity (5.46 %), and hardness value (125.34 HV). And for the lower results are shows at 0 aging time where the result is density (1.96 g/cm3), porosity (25.39 %), and microhardness value (81.36 HV). Significantly, changes of density and apparent porosity can be analysed as increasing aging density resulted in lower porosity. It can be concluded; 10 hours of aging time is the best choice for all groups. It is because the heat treatment made the boundary of the aluminium chips become stronger. When the heat absorbs to the particle, the particle become bigger and pore become smaller.

Acknowledgment

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