BORANG PENGESAHAN STATUS TESIS

JUDUL: ALUMINIUM CHIP WASTE FOR SECONDARY MATERIALS USING DIRECT RECYCLING PROCESS

SESI PENGAJIAN: 2012/2013

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ALUMINIUM CHIP WASTE FOR SECONDARY MATERIALS USING DIRECT RECYCLING PROCESS

MAIZATUL MASTURA BINTI MUHAMMAD NAZRI

Thesis submitted in fulfilment of the requirements
for the award of the degree of
Bachelor of Manufacturing Engineering

Faculty of Manufacturing Engineering
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JUNE 2013

UNIVERSITI MALAYSIA PAHANG

FACULTY OF MANUFACTURING ENGINEERING

I certify that the project entitled " Aluminium Chip Waste for Secondary Materials using Direct Recycling Process " is written by Maizatul Mastura Binti Muhammad Nazri. I have examined the final copy of this project and in our opinion; it is fully adequate in terms of scope and quality for the award of the degree of Bachelor of Engineering. I herewith recommend that it be accepted in partial fulfillment of the requirements for the degree of Bachelor of Manufacturing Engineering.

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Dedicated to my beloved family

Muhammad Nazri Bin Khalid

Maryani Binti Mat Zakaria

and

My supervisor

Dr. Ahmad Razlan B Yusoff

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ABSTRACT

Direct recycling process is a simple method because it only consumed a small amount of energy and no harmful effect on the environment compare to the conventional recycling process in which involved re-melting the chips to produces secondary materials. the aims of this project is to investigate the influence on different shape and size of AA6061 and AA7075 chips as secondary materials billet using cold compaction process. Different type of chip was cut by various turning parameter on CNC turning machine. Turning chips from aluminium alloys were cold compacted in a closed cylindrical die by means of Universal Testing Machine (UTM). Several pre-compacting are needed due to low filling density of chip inside the die cavity at once. The compacted billets are analyzed base on their density, porosity percentage and structure by using manual calculation. Results show that the different shape and size of the chips influence the final compacted billets integrity. Smaller the thickness of the chip, the higher the resulting density after the compaction process in which increasing the number of compacting for each operation leading to differences in the volume. The lower the relative density percentage shows the poor quality of their solidification. At the same time, the higher the thickness of the chip, the higher the percentage of the resulting porosity and more empty space formed between the compressed chip's structures. As a conclusion, the depth of cut plays an important role in producing the desired chip thickness where the spindle speed and feed rate lead to the length of the chips. Furthermore, the chip's thickness influenced the density of compacted billets and they have different volume due to differ number of compacting. The number of compacting for each type of chips affected the density of the compacted billets where the relative density shows the quality of the compacted specimens. Last but not least, the porosity percentage shows the empty space between the chips occur on the structure of the compacted billets.

ABSTRAK

Proses kitar semula langsung adalah kaedah yang mudah kerana ia hanya menggunakan sedikit tenaga dan tidak memberi kesan buruk kepada alam sekitar berbanding dengan proses kitar semula konvensional yang melibatkan melebur semula cip untuk menghasilkan bahan-bahan menengah. Matlamat projek ini adalah untuk menyiasat pengaruh pada bentuk dan saiz yang berbeza pada cip AA6061 dan AA7075 untuk dijadikan bahan menengah bilet menggunakan proses pemadatan sejuk. Cip yang berlainan jenis telah dipotong oleh pelbagai parameter turning pada mesin CNC turning. Turning cip daripada aloi aluminium adalah disejuk padatkan di dalam acuan silinder tertutup melalui Universal Testing Machine (UTM). Beberapa pra-memadat diperlukan disebabkan kepadatan mengisi rendah oleh cip ke dalam rongga mati sekaligus. Bilet yang dipadatkan dianalisis berdasarkan kepadatan, keliangan peratusan dan struktur mereka dengan menggunakan pengiraan manual. Kesimpulannya, bentuk dan saiz yang berbeza menjejaskan integriti bilet yang dipadatkan. Semakin kecil ketebalan cip, semakin tinggi ketumpatan yang terhasil selepas proses pemadatan di mana meningkatkan bilangan memadat bagi setiap operasi yang membawa kepada perbezaan isipadu setiap bilet. Peratusan relative ketumpatan yang rendah menunjukkan bilet yang dipadatkan mempunyai kualiti pemejalan yang rendah. Pada masa yang sama, lebih tinggi ketebalan cip, lebih tinggi peratusan keliangan yang terhasil dan lebih banyak ruang kosong yang terbentuk antara struktur cip mampat itu. Kesimpulannya, kedalaman potongan memainkan peranan penting dalam menghasilkan ketebalan cip yang dikehendaki di mana kelajuan gelendong dan kadar suapan membawa kepada panjang cip. Tambahan pula, ketebalan cip mempengaruhi ketumpatan bilet dipadatkan dan mereka mempunyai jumlah yang berbeza kerana perbezaan bilangan memadat. Bilangan memadat bagi setiap jenis cip mempengaruhi ketumpatan bilet dipadatkan manakala ketumpatan relatif menunjukkan kualiti spesimen yang dipadatkan. Akhir sekali, peratusan keliangan menunjukkan ruang kosong antara cip berlaku pada struktur bilet dipadatkan.

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LIST OF SYMBOLS

Φ	Shearing angle
v_c	Cutting speed
d	Depth of cut
a_p	Depth of cut
f	Feed
N	Rotational speed
°C	Celsius
H_B	Hardness
Ø	Diameter

LIST OF ABBREVIATIONS

AA	Aluminium Alloy
Al	Aluminium
B	Boron
Bi	Bismuth
BUE	Build Up Edge
CAD	Computer-Aided Design
cm	centimeter
CNC	Computer Numerically Controlled
Cr	Chromium
Cu	Copper
FKP	Faculty of Manufacturing Engineering
Mg	Magnesium
mm	millimeter
Mn	Manganese
Pb	Lead
SEM	Scanning Electron Micrograph
Si	Silicon
UTM	Universal Testing Machine
UMP	Universiti Malaysia Pahang
Zn	Zinc

CHAPTER 1

INTRODUCTION

1.1 PROJECT BACKGROUND

In recent decades, materials and energy usage by the industry is likely to have experienced growth may exceed the limits of earth's resources. Therefore, the emergences of strong awareness for use of materials and energy more efficiently and orderly. In sustained the environment needs to take into consideration of the requirement for manufacturing practices where it becomes urgent and different approaches are adopted in various countries (Kaebernick and Kara, 2006). Aluminium is one of very important consumption materials that use by the industries and the reusable resource among other metals due to its physical characteristics that make the aluminium recycling economically attractive. Aluminium finds extensive use in automotive industry, construction, packaging and aerospace. All aluminium can be recycled repeatedly and melted without down-cycling and property losses. Recycling the aluminium saves a huge amount of energy and generally, eliminates the environmental damage advocated with aluminium mining and increasing the energy usage (Schlesinger, 2006).

In the United States, the primary aluminium production in 2004 is equal to 2.52 million metric tons. The recovering of secondary aluminium is equal to 3.03 million metric tons, with 1.16 million metric tons from old scrap (38%) and 1.87 million metric tons (62%) from new scrap. As a result, approximately 55% of total domestic production of aluminium in 2004 came from recovery of scrap; while 45% came from primary production of new ore (Gelles, 2006). As for China, this country is a major participant in global aluminium trade where it's accounted 40% of the total net increase in world aluminium production between years 1995 to 2002, and the first quarters of 2003 the same figure was 60%. This is due to the strong economic growth in China's economy. The rate for China's scrap recycling approximately 80%, but this still accounts only 25% of scrap demand. Low labor cost in China also contributed to the economic scrap separation (Bergsdal, Stromman and Hertwich, 2004).

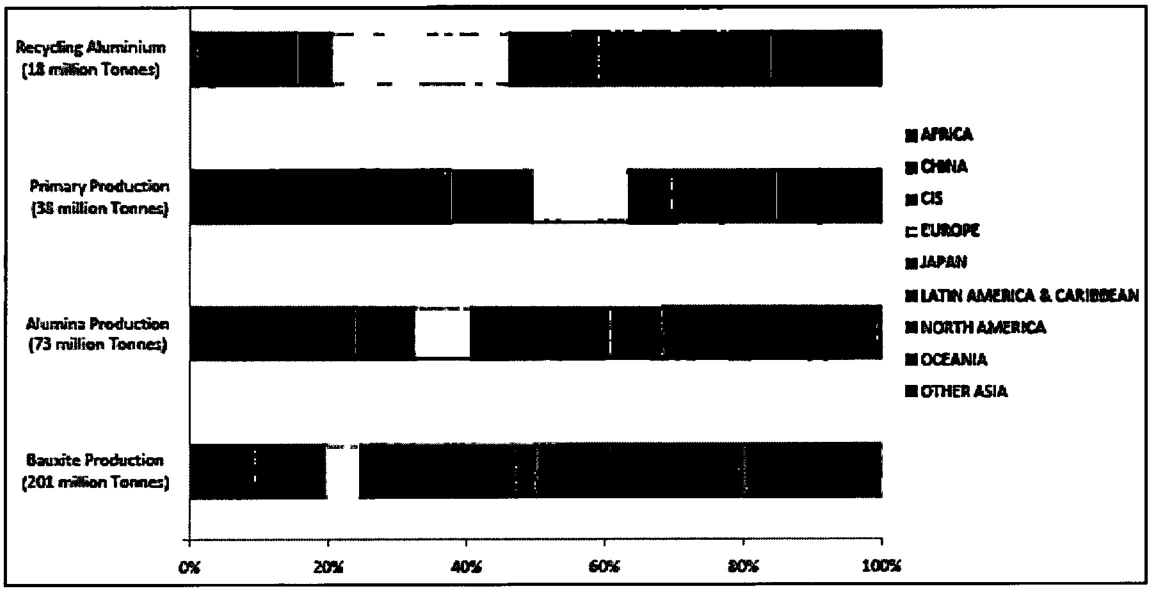


Figure 1.1: The regional of bauxite, alumina, primary and primary recycled aluminium, 2007

Source: Global Aluminium Recycling, 2009

There are many countries that already have industrial recycling facilities but recycling plays a particularly leading lead in Europe, North America and Japan. Figure 1.1 shows the regional of bauxite, alumina, primary and primary recycled aluminium in 2007. Refiners produced close to 18 million tones of recycled aluminium in 2007. Compared to primary aluminium produced in same year, excess 38 million tonnes of recycled aluminium have been produced (Global Aluminium Recycling, 2009).

Nowadays, recyclability of aluminium became the most economical saving and save the energy as well. Its contribution to environmentally friendly by reducing waste disposal is beneficial compared with processing of aluminium from its bauxite ore, while reducing capital equipment that used in recycling process which is less expensive. Industrial field used many type of method to eliminate their chips waste in order to reduced energy and materials consumption. Gaseous that emits from conventional recycling causes greenhouse effect during chips remelting. Widely used in the production market makes the demand for aluminum products increased from time to time, particularly in the transportation, machinery and equipment, bulding and construction and many more. In order to reduce the energy consumption by the primary aluminium production and carbon dioxide emissions into the air, a study will be conducted to determine the condition of recycled aluminium product using direct recycling process at the end of this research.

1.2 PROBLEM STATEMENT

When machining metal products, many of waste generated during the process in which producing a small size of chips and surface contamination with oxides and lubricant oil from the manufacturing industry. These kinds of chips are difficult to recycle because they are not uniformly shape and the size is small compared with other scrap. In traditional ways, aluminium scrap melted using conventional method that usually utilized much of energy and emitted hazardous gases into Earth's atmosphere. During melt the chips, oxidation result from the loss of a lot of metal and their characteristic makes them inconvenient for handling and transportation due to the low density of the chips. Without a proper disposal, these chips will cause both environmental and economic issues. In order to overcome this problem, a review of the current recycling processes by using direct recycling method needs to be investigated where this project will covers on the compaction process aiming to compacting different sizes of chip into solid form as secondary aluminium.

1.3 PROJECT OBJECTIVE

The main objectives for aluminium chip waste for secondary materials using direct recycling process are:

i) To investigate the influence on different type of aluminium alloy (AA6061 and AA7075) chip shape and sizes as secondary materials of billet using cold compaction process.

ii) To design, fabricate and test the die device for cold compaction operation of machining chip recycles.

iii) To perform the analysis focuses on the density, porosity percentage, and the structure of the final products

1.4 PROJECT SCOPE

This project is focusing on direct recycling process of aluminium machining chips as secondary materials using a compaction method.

i) Literature review on direct recycling process of aluminium chips

ii) Production of aluminium chips on CNC lathe machine by turning operation. Two type of aluminium alloy billet (AA6061 and A7075) with three different parameters are involved in this experiment.

iii) Design and fabrication of the die device for compaction operation.

iv) Perform the compaction operation and analyze the final products using calculation for density, porosity percentage and their structure.

v) Preparation of final report.

1.5 SUMMARY

This chapter discussed briefly about project background, problem statements, project objectives and scope of the project on aluminium chip waste as secondary materials using direct recycling process. Figure 1.2 shows the flow chart of the project that related with project scopes on how the project flow can be done at the right time. The duration of this project takes about 14 weeks for the final year project 1 and can refer to Appendix A1. This chapter acts as a guideline for the project completion.

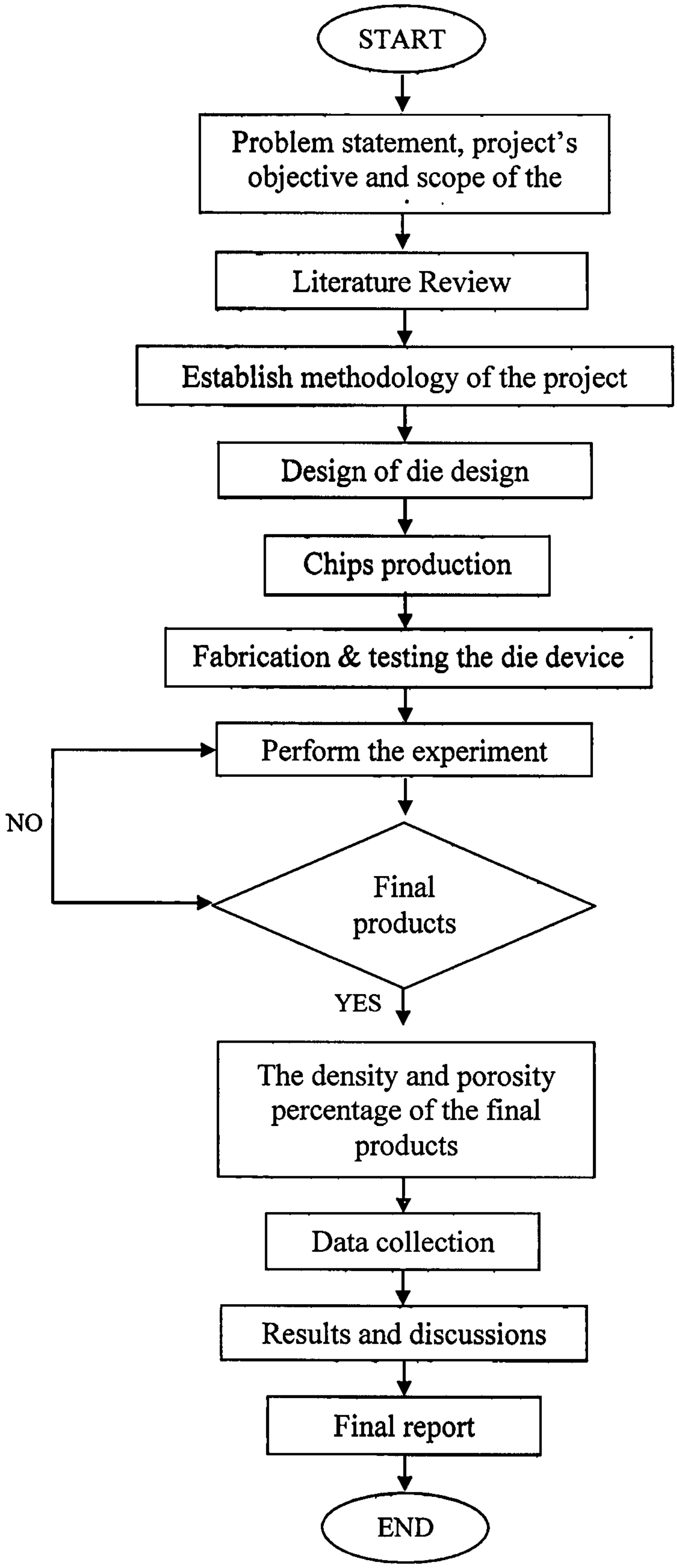


Figure 1.2: Flow Chart of the project

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Aluminium is the most commonly used metal after iron and the third most common element in the Earth's crust as a chemical element with weight of about 8% (Pepeljak et al., 2011). Aluminium is a silver-white metal with many important properties that produced from its bauxite ore. Bauxite is the term for a rock composed by aluminum oxide hydrate which is the main ore of alumina to produce aluminium (Mineral Information Institute). Because of the low density of aluminium (2.71 g/cm^3) which makes it remarkable metals for its ability to resist corrosion due to the passivation and strong mechanical properties. Although pure aluminum is soft and brittle, but it can be strengthened by adding a small amounts of copper, magnesium and silicon to make the composition of alloy materials. Compared with other metals, aluminium surface is very sensitive and easy to scratch or abrasions when colliding with the surface of other materials.

2.2 ALUMINIUM ALLOY

Aluminium alloy used widely in engineering design due to their lightweight characteristic and high strength-to-weight ratio as well as corrosion resistance and relatively low cost materials. The term of alloy is used when one or more elements mixed together and change the nature of existing properties with a sufficient quantity. Pure aluminium is soft so to overcome this alloying elements are implementing. Aluminum alloys are classified as casting alloy or wrought alloys. The most used alloy elements for aluminium are copper, magnesium, silicon, manganese and zinc (Budynas and Nisbett, 2011).

The wrought products that mostly use in aluminium alloys contain less than seven percent of alloying elements. There are two categories of alloys namely non-heat treatable and heat treatable. For the non-heat treatable alloys, it cannot be strengthened by heat treatment because they are ductile and moderately strong and depends on alloying elements concentration. The different circumstances for heat-treatable alloys where they can be hardened by heat treatment and uses an alloying element that dissolves in the aluminium. Table 2.1 shows the designation of wrought aluminium and aluminium alloy in order to provides a standard form of alloy identification for user.

Table 2.1: Wrought Aluminium and Aluminium Alloy designation

Alloy	Main Alloying Element
1000	Mostly pure aluminum; no major alloying conditions
2000	Cooper
3000	Manganese
4000	Silicon
5000	Magnesium
6000	Magnesium and silicon
7000	Zinc
8000	Other elements (e.g., iron or tin)
9000	Unassigned

Source: Kaufman (2002)

6000 series is one of the wrought aluminium alloys designation family. This group consists of Magnesium (Mg) and Silicon (Si) as the major alloying elements. Minor alloying elements may be added such as Copper (Cu), manganese (Mn), chromium (Cr), zinc (Zn), boron (B), lead (Pb) and bismuth (Bi) to this alloy series. Through the presence of the main alloying elements, this series are high strength alloys that can be strengthened by heat treatment (precipitation hardening). This alloy system gives the best combination of high strength, formability, corrosion resistance, weldability, machinability and heat treatable. Based on their strength, 6000 series have been used widely in automotive, marine, heating and also as a structural part in building applications (Aluminium Matter UK). Alloy 6061 extrusion and plate is the most commonly used in the industrial sector due to its versatility of heat treatable aluminium alloy and less expensive. Furthermore, it has a good quality of aluminium and offers a range of good mechanical properties as well good corrosion resistance. Even in the annealed condition, it has good workability and can be fabricated by most of the commonly used techniques (Aircraft Spruce and Speciality.Co).

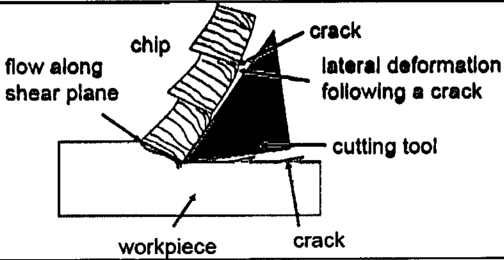
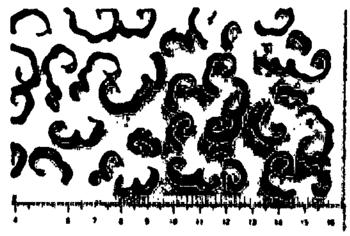
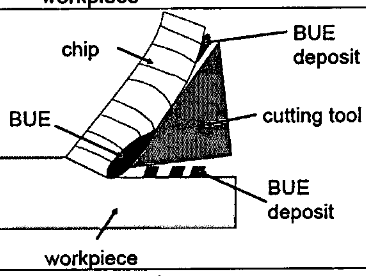
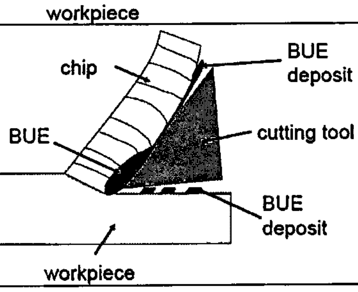
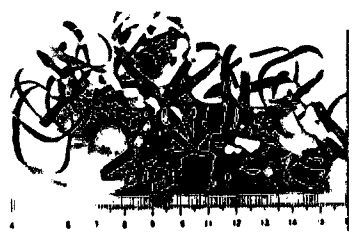
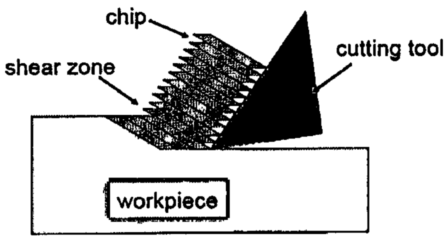
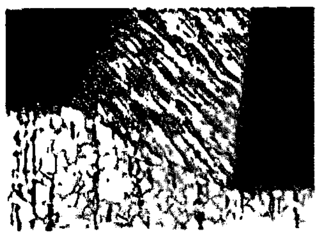
The major alloying element for 7000 series is zinc (Zn). Its characteristics are heat treatable and provide the higher strengths of all aluminium alloys particularly among the Al-Zn-Mg-Cu version. In commercial processes, these alloys are not considerable as weldable and mostly used in riveted construction. Although, the 7000 series cannot resist corrosion as good as 5000 and 6000 alloy, so in such service they are usually coated for sheet and plate. There are widely used in aircraft application due to fracture-critical design concept have provided the impetus for the high toughness development (Kaufman, 2002). Alloy 7075 is one of the highest strength aluminium alloys available and its strength-to-weight ratio is excellent. It is ideally used for highly stressed parts.

2.2.1 Aluminium Chips

Chips are formed by metal shearing by cutting edge tool in upstream area where it is located on both sides of the plane and makes an angle φ with the direction of cutting (Aluminium.matter.org.uk). There are several type of chips produced in metal cutting such as discontinuous chip produced at low speeds and rake angles, continuous chip with narrow primary shear zone, secondary shear zone at chip-tool interface, continuous chip with BUE, continuous chip with large primary shear zone and segmented chip (Kalpakjian, 2006). Table 2.2 shows clearly illustration of chips formation during machining operation.

In a study by Puga et al. (2009), most of the aluminium chips are produced by machining operations usually 3-5% of the casting weight. Chips are the most difficult to recycle among other aluminium scrap by conventional method due to their irregular elongated shape, spiral shape and small size compare to other forms of scrap. This characteristic makes them not suitable for preliminary and hot extrusion (Gronostajski et al., 1998). The density of the chips obviously low makes them not good for handling and transportation besides covered with oxides and machining oil. Their surface area is very high to volume ratio because the oxide on the chips is dependent on the total surface area. The formation of a new oxide skin during melting phase has a significant influence on metal losses. Skin formed during melting can contain up to 95% metal and requires further process need to be done in order recovering the metal from it (Gronostajski and Matuszak, 1999). Tekkaya et al. (2009) used uncoated cemented carbide indexable turning inserts and side milling cutter to produce the chips without a cutting fluid (Figure 2.1).

Table 2.2: Illustration of chips formation during machining operation

Type of chip	Chip formation	Chips
1) Discontinuous chip		
2) Build up edge		
3) Continuous chip		
4) Segmented chip		

Source: Kalpakjian, 2006

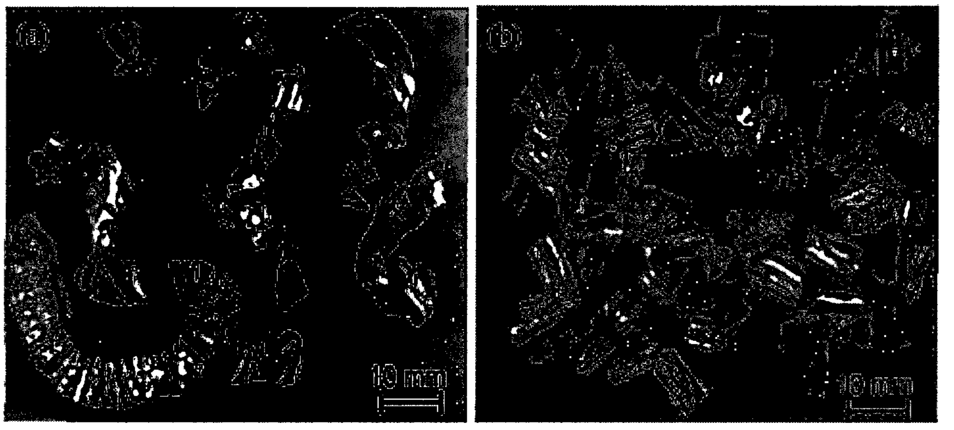


Figure 2.1: Aluminium chips production by machining operation. (a) Turning (b) Milling
Source: Tekkaya et al. (2009)

Chip form also plays an important role in order for experiments performed smoothly. Rubio et al. (2006) studied on chip arrangement in the dry cutting of aluminium alloys. The research's aim is to make a first analysis of the chip formed in the dry turning process of AA2021 (Al-Cu) and AA7075 (Al-Zn) aluminium alloys. the approach consisted of proving a series of parameters combinations: feed rate, f, cutting speed, v, and depth of cut, d, also analyzing the different types of chip appered during each one of them. They proposed a single classification that specific for the studied alloys. Furthermore, the relationship between chip arrangement and workpiece surface finish has been studied through the comparison between chip form and roughness overall, Ra parameter for different cutting conditions.

Figure 2.2 shows the classification of chips produced to meet the requirements of ISO 3685:1993. The ISO 3685 standards is stand for tool-life testing for single-point turning tools. The chip type is divided into two parts; favourable and unfavourable chips. The relationship between chip arrangement and workpiece surface has been studied through the comparison between chip form and *Ra* parameter for different cutting conditions. As a result, they are seven types of chip which are ribbon chips, tubular chips, spiral chips, washer type chips, conical helical chips, arc chips and natural broken chips.

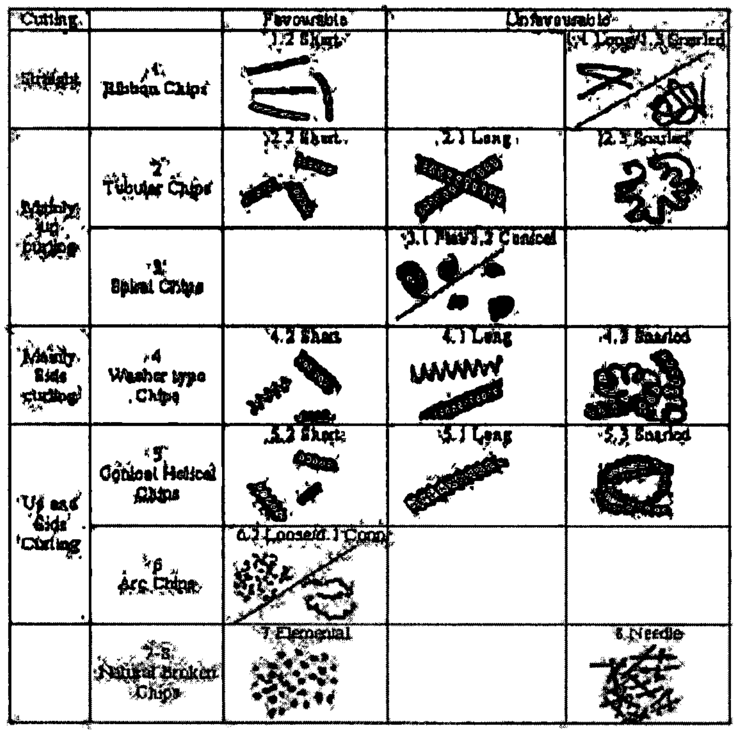


Figure 2.2: Chip form classification

Source: Rubio et al. (2006)

2.2.2 Secondary Aluminium

Nowadays, the importance of secondary aluminium stream is becoming increasingly important from the aluminium production and is attractive due to its economic and environmental advantages (Cui et al., 2010). Secondary aluminium is produced from scrap containing aluminium depending on operation processes through the recycling process. Scrap containing aluminium can be described into two categories as new and old scrap (Luo and Surio, 2007). New scrap is the surplus material removed during machining operations while old scrap is the waste material that has high aluminium content such as beverage can, automotive parts, electrical appliances, construction materials and many more.

Pepelnjak et al. (2012) studied on recycling of AlMgSi1 aluminium chips by cold compaction. They discovered several pre-compressions are needed due to low initial relative density of the chips. Chips with smallest volume required more pre-compacting process. However, the quality of compactness remains an issue even though all chips types reached sufficient densities and integrity after cold compaction. Figure 2.3 shows low integrity of compacted specimens due to insufficient load force for current study.

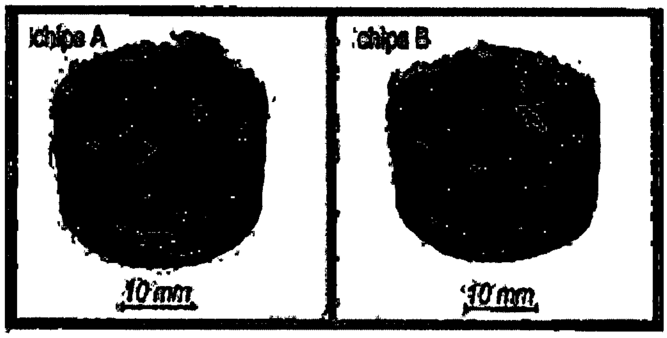


Figure 2.3: Compressed aluminium chips

Source: Pepelnjak et al. (2012)

2.3 MECHANICAL PROCESSING METHOD

Turning means that the part is rotated while it is being machined. The material used is generally a workpiece that have been made by other processes such as casting, forging, extrusion, drawing or powder metallurgy. Turning process is carried out on a lathe machines which very versatile and capable of producing a wide variety of shapes. Figure 2.4 (a) shows the schematic illustration of basic operation for turning process showing the depth of cut, *d*; feed, *f*; and spindle rotational speed, *N* in rev/min. Cutting speed is the surface speed of the workpiece at the tool tip.

Most turning operation involve in using the simple single-point cutting tools, with the geometry of a typical right-hand cutting tool. Right-hand means that the tool is travels from right to left. Such tools are described by a standardized nomenclature as been seen through the figure. There are three principal forces in turning that acting on a cutting tool is shown in Figure 2.4 (b). In designing the machine tools, these forces are important as well as in deflection of tools and workpieces for precision-machining operations. The machine tool must be able to withstand these forces without causing significant deflections, vibrations and chatter in the overall operation (Kalpakjian, 2006). Spacer between the part and mounting prevent marks on the metal and deformation.

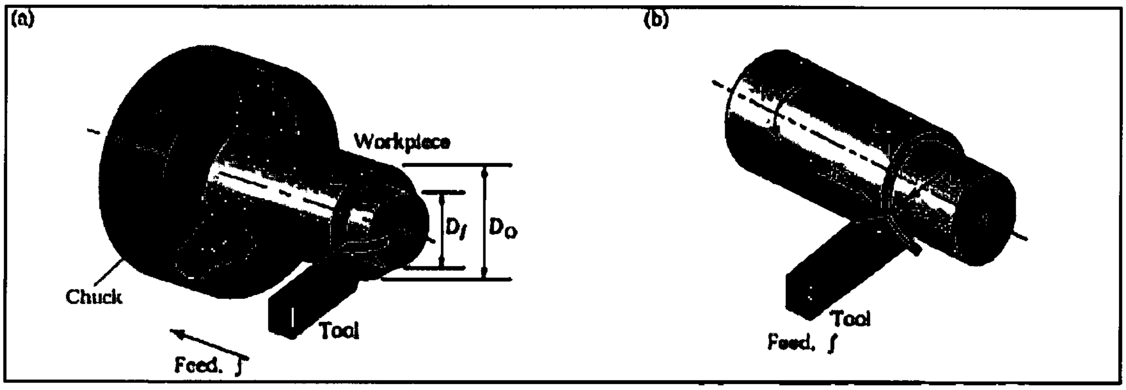


Figure 2.4: (a) Schematic illustration of the basic turning operation. (b) Forces acting on a cutting tool in turning.

Source: Kalpakjian, 2006

2.4 PRODUCTION OF PRIMARY ALUMINIUM

Aluminium was first produced in 1825 in which primary aluminium is aluminium metal produced from its bauxite ore. Basically, there are five independent stages in producing primary aluminium: mining the primary of bauxite, production of alumina (Al_2O_3), production of primary aluminium, fabrication of aluminium and production of aluminium into finishing product. The suitable portion of bauxite in order to produced aluminium generally contains at least 50% of aluminium. The largest bauxite deposits with the density of aluminium are found in Arkansas, United States (Plunkert, 2000).

Gelles (2006) has presented on aluminium economics recycling. In 1989, Karl Joseph Bayer developed a process to treated the crushed bauxite where treatment at the mining site is minimal that usually confined to crushing and drying. This process is invented because most bauxite are found in deposits close to the surface and mined in open pits. Primary melting is using the electrolytic Hall-Heroult process to converted alumina and then shipped to a reduction plant. In producing a pound of pure aluminium metal, needed two pounds of alumina, small amount of carbon and cryolite and approximately 10, 000 watt-hours of electricity are required. Figure 2.5 shows a strong increasing trend for alumina and aluminium production since the 50s.

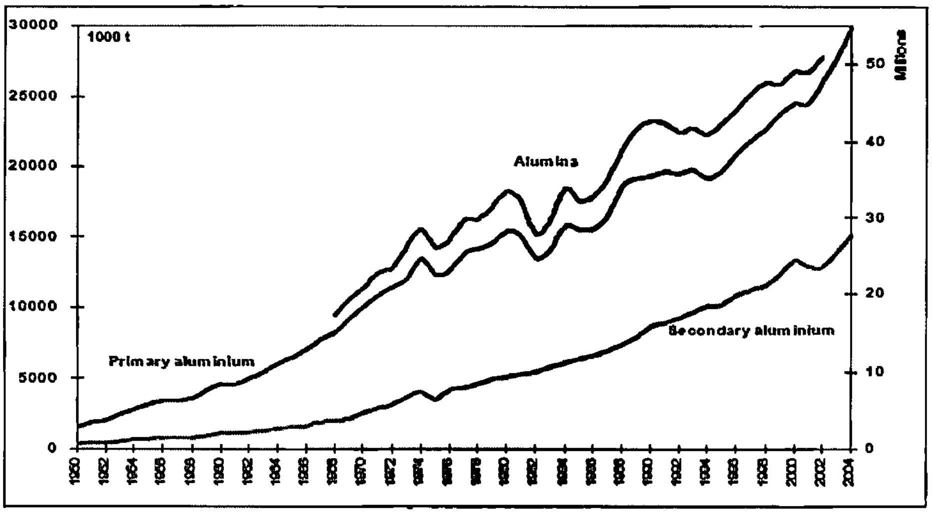


Figure 2.5: Production of alumina and aluminium 1950-2004

Source: Luo and Soria, 2007

2.5 RECYCLING OF ALUMINIUM CHIPS

The demand for aluminium products is increasing because of their positive contribution to the modern life. Various technologies have been developed to recycled excessive waste material because of different processing operations (Gronostajski et al., 1999). In traditional way, aluminium scrap recycling method is re-melting but the materials loss during this process is high where it could reach as 20-25%. Recycling of aluminum has many advantages due to its low production cost factors and very significant implications on the economy, energy, environment, and resource savings. The industry confronted by various issues regarding sampling scrap, scrap purchasing, metal recovery and yield, production cost and hence profit margins, product quality, environmental issues and regulation. They need to completely recycle the metals efficiently in order reducing the current problems (Xiao and Reuter, 2002). There two type of recycling methods which are conventional and direct recycling process.

Gronostajski (2006) have presented on bearing composites made from aluminium and aluminium bronze chips. The energy used to recycle aluminum is 5% in the production of this metal from bauxite ore. There are several disadvantages regarding conventional recycling method by reason of energy and material waste and consist of time consuming operations such as pre-compaction, melting, casting, cutting of ingot, hot extrusion and cutting to final size.

Samuel (2003) has pointed out burning and mixing of aluminium with slag occurs during conventional recycling cause material lost up to 38% as a result of oxidation but depending on the process itself. In the melting process, requiring more than 70% of the energy for conventional recycling including consequences of this phenomenon, such as slag treatment and refining. Usually conventional recycling aluminum uses energy of 16-19 GJ/t per ton (Gronostajski et al., 2000).

In a study by Lazzaro et al. (1992), they analyzed the metal losses in conventional recycling of aluminium turnings. Figure 2:6 shows the flow chart of the conventional process for recycling of aluminium turning. The flow chart consisted of ten steps from aluminium turning chip until it became extruded products. Throughout the manufacturing of extruded product, the metal losses during melting and dross at the liquid aluminium phase harm to environment. At the same time, many scrap is produced during casting and sawing phase. Figure 2.7 shows metal yields in recycling aluminium turnings by the conventional recycling process: products, extrusion scraps, metal losses, drosses, casting scraps, and extrusion butts. From this figures, approximately 45% of aluminium metal will be either lost or carried into a new scrap phase. New direct recycling process without re-melting might result in much higher metal yield than conventional recycling process. Finally, conventional recycling of aluminium chips are categorized as environmental pollution caused by fumes and drosses during melting phase, high energy consumption and the efficiency of recovery is low due to melt loss and post melting scraps processing (Gronostajski et al., 1999).

2.5.2 Direct Recycling Process

Recycling of aluminium chips by direct recycling process is relatively simple because this method only consumed a small amount of energy and no harmful effects on the environment. However, the correct size and shape of chips is essential for good compaction during the compression operation to get a good quality of finished product. It has been found that direct recycling process of aluminium chips into final products results in materials characterized by low porosity and a relative density, exceeding 95%, the hardness and tensile properties of the recycled materials, however, being slightly lower than those of metallurgically-produced materials (Gronostajski et al., 1998).

According to Gronostajski et al. (2000) a lot of metal is lost during recycling of waste as a result of oxidation and the costs of labour and energy. In recent years, there is a different way of recycling metal chips where consisting in the direct conversion of chips into compact metal. The method involved consists of cutting chips into granulated product that then cold pressed and hot extruded or hot forged, whereby melting is eliminated. The energy consumed for the direct conversion of aluminium into compact materials only 5-6 GJ per ton is needed. The operating number is less than conventional recycling allows labor to be reduced to 2.5-6.5 man-hours per ton of the product. The advantages of direct conversion of aluminium into compact metal shows a possible reduction in the funds spend on environment protection as a result reduced the ores consumption and energy carriers, and less degradation of the natural environment due to reduced air pollution emission. There are numerous of researchers have presented recycling aluminium metals by using direct recycling processes in order to eliminate the melting procedure as well as reduce energy and materials consumption.

In a study of Zhou et al. (2005), they are using rotary furnace due to its ability to process dross and low-grade scrap. The rotary furnace functions simultaneously as a smelter and a phase separator at the same time it is able to deal with a lot of contaminated scrap. Figure 2.8 shows the complex phenomena inside the furnace. The rotary furnace process contains following operations: the scrap feed is charged into a rotary furnace, passing through a salt layer, melting, mixing and being cleaned in the furnace. Heat source that use by furnace is a burning natural gas with oxygen, and it is normally operated at a temperature around 800°C.

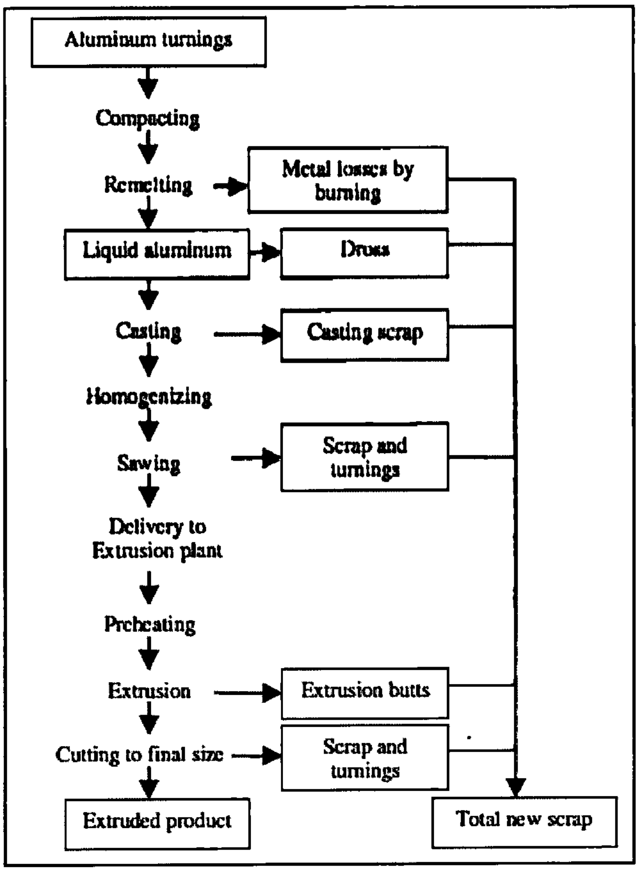


Figure 2.6: Flow chart of the conventional process for recycling of aluminium turning

Source: Lazzaro and Atzori (1992)

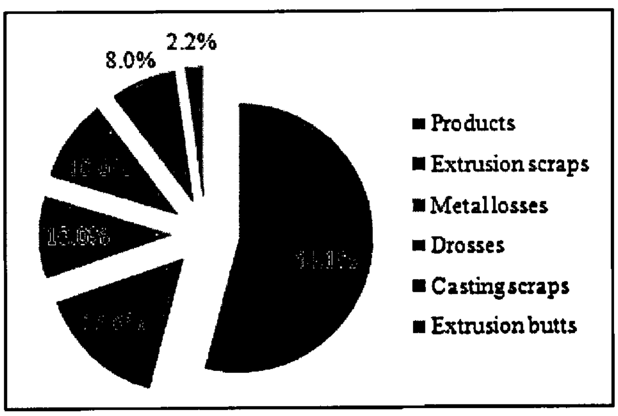


Figure 2.7: Metal yields in recycling aluminium turnings by the conventional recycling process

Source: Lazzaro and Atzori (1992)

They also stated aluminium liquid that produced from previous step then tapped into a holding furnace, further refined and directly transported to the industrial partners or forms the liquid into ingots using casting. The salt slag with various contaminants should be further processed and reused. High temperature effect and the complex chemical reactions contribute to the complexity in the process. This complexity also due to highly complex of scrap feed with a distributed nature of aluminium types, sizes, shapes, compositions, paintings and other contaminants. There are a few drawback in this process in which low efficiency, requires a higher maintenance and production of huge salt cake that must be disposed of as a hazardous waste.

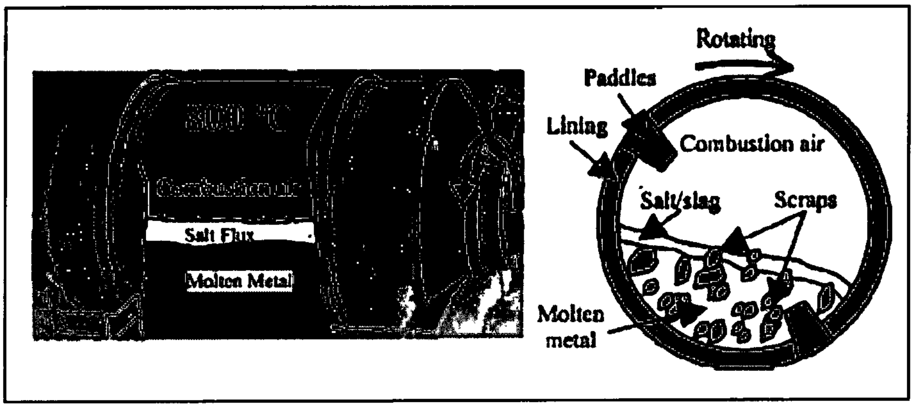


Figure 2.8: Illustration of the rotary furnace and phenomena inside the furnace

Source: Zhou et al. (2005)

Hot extrusion is another direct recycling process for aluminium. Aluminium Extrusion Technology (2000) has put forward hot extrusion is plastic deformation process in which a solid billet pushed through a forming die into a profile bar using a ram with specified extrusion force and the solid billet preheated to facilitate plastic deformation at fairly high temperatures, approximately 50 to 75 % of the melting point of the metal as shown in Figure 2.9. The hot extrusion process is done above the material's recrystallization temperature to keep the material from work hardening due to its hot working process. It is done on horizontal hydraulic press with a range from 230 to 11,000 metric tons. Lubricants required which can be oil or graphite for lower temperature extrusions, or glass powder for higher temperature extrusions because of the pressure applied from range 30 to 700 MPa (Oberg et al., 2000).

Fogagnolo et al. (2003) have presented on recycling aluminium alloy and aluminium matrix composite chips by pressing and hot extrusion to prevent the chip transform into powder. They proved the hot pressed sample of hot extrusion process as the best route from the point of view of mechanical properties but required higher cost profit. Guley et al. (2010) pointed out approximately 10% of energy is required to recycle both aluminium chips and scrap materials directly by hot extrusion.

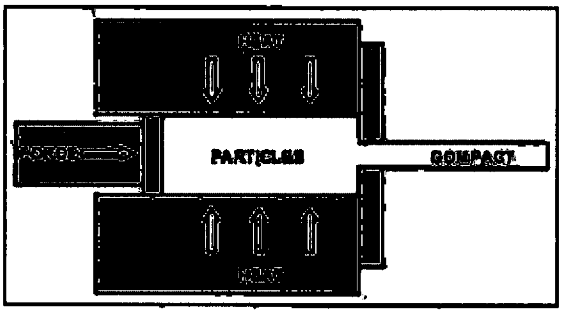


Figure 2.9: Illustration of preheated solid billet into a profile bar

Source: umms.sav.sk

In a study by Upadhyaya (2002), compaction methods are known widely and this process one of the most important steps in powder metallurgy process where they cover a large range of applied pressures. The main function of using compaction is to consolidate the powder into desired shape. In cold compaction, the bulk powders contained with small amounts of lubricant to eliminate friction between particles and particles also with die wall. Presses that involved may be either mechanical or hydraulic and the powder is compressed inside a die between upper and lower punches. Figure 2.10 illustrated the basic tool motions of compaction process.

Meluch (2009) has presented a studied on warm compaction of aluminium alloy alumix 123. He stated the basic tool motion during cold compaction cycle when the upper punch retracted to the fill position during powder filling at the same time the lower punch is being termed. A specified amount of powder in an external feed shoe is vibrated into the die. The lower punch position during pressurization differs from the fill position to position which allow pressing in the centre of the die. After filling, the lower punch is dropped to the pressing position and the upper punch is brought into the die. Both punches are loaded to generate stress within the powder mass. At the end of the compaction stoke, the powder experiences the maximum stress. Finally, upper punch is removed and the lower punch is used to eject the compact.

The recent studied by Pepelnjak et al. (2012) have performed a recycling of AlMgSi1 aluminium chips by cold compaction. They study the influence of chip geometry on the billet's final density. The density is measured until 97% at extruded aluminium was obtained for one type of chips. Several pre-compaction were performed prior to major compression because of the chips have low initial density during filling procedure and chips with smallest volumes required more pre-compaction operation. Results show that the chip's shape and size especially their thickness have a great impact on the integrity of billets. Lee et al. (2009) pointed out the punch speed influenced the uniformity of the finished product where the decreasing speed of punch give more uniform distribution for powders relative density than increase the punch speed.

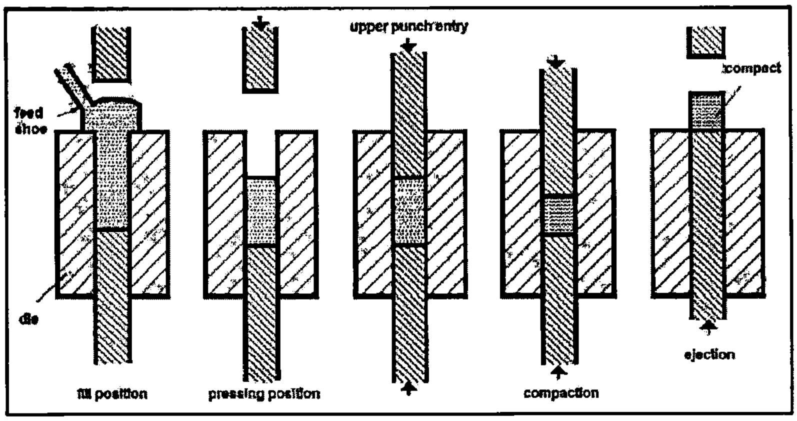


Figure 2.10: Tool motion during compaction process

Source: (Meluch, 2009)

Kalpakjian and Schmid (2006) showed that forging is a process where the workpiece is shaped using compressive forces through various dies and tooling. This operation produced discrete parts because the metal flow in a die can be controlled as well as the material's grain structure; the forged parts have good strength and toughness, and are very reliable for highly stressed and critical applications. Hot forging carried out at elevated temperature and requires lower forces. In Figure 2.11, the basic tool motion is shown during hot forging process.

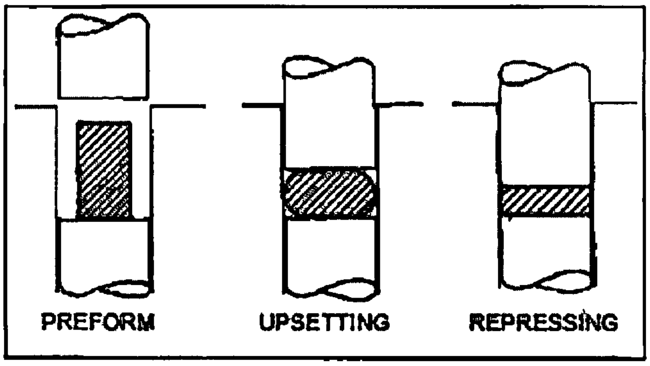


Figure 2.11: Basic tool motion by hot forging
Source: Upadhaya (2002)

Pepeljak et al. (2012) pointed out that direct recycling of aluminium chips solidification faces a major issue where the layer of aluminium oxide (alumina) forms on aluminium surface becomes very hard layer after expose instantly to oxygen with a thickness of 4 mm. In obtaining a good solidification, high pressures exerted on chips are needed to crack the alumina. To ensure that no chips decomposition occurs, high hydrostatic and good lubrication is needed. Because of that, direct recycling process is suitable as a recycling method in conducting to recycle the aluminium chips waste without melting process.

2.6 HARDNESS MEASUREMENT

The hardness of aluminium is relatively low due to its low density means that this material is easier to scratch than other metals like steel are. According to The Metal Handbook, it defines hardness as "Resistance of metal to plastic deformation, usually by indentation. However, the term may also refer to stiffness or temper or to resistance to scratching, abrasion, or cutting. It is the property of a metal, which gives it the ability to resist being permanently, deformed (bent, broken, or have its shape changed), when a load is applied. The greater the hardness of the metal, the greater resistance it has to deformation".

Zamri and Yusoff (2009) have performed a study an influence of particle sizes and compaction pressure in surface roughness of aluminium composite fabricated via powder metallurgy. The method used to measure the changes of hardness with increasing reinforcement content by the indentation method with a Vickers hardness tester (Mitutoyo). Based on the experiment results, the surface hardness depends on the particle size ratio of matrix and reinforcement. Within a limit range, the greater the size ration, the higher the maximum packing density tends to improve surface hardness.

2.7 MICROSTRUCTURE

In a study by Schikorra et al. (2007), microstructure analysis aluminium extrusion is performed to investigate the grain size distribution in AA6060, AA6082 and AA7075 alloys. This paper deals with the microstructure during extrusion process of these alloys type as references for microstructure prediction based on material flow, with it strains and strain rate history. The microstructure was analyzed based on etchings and light optical microscopy and finite element simulation for certain position. Figure 2.12 shows the original microstructure of both AA6061 and AA7075 aluminium alloys billet before machining operation.

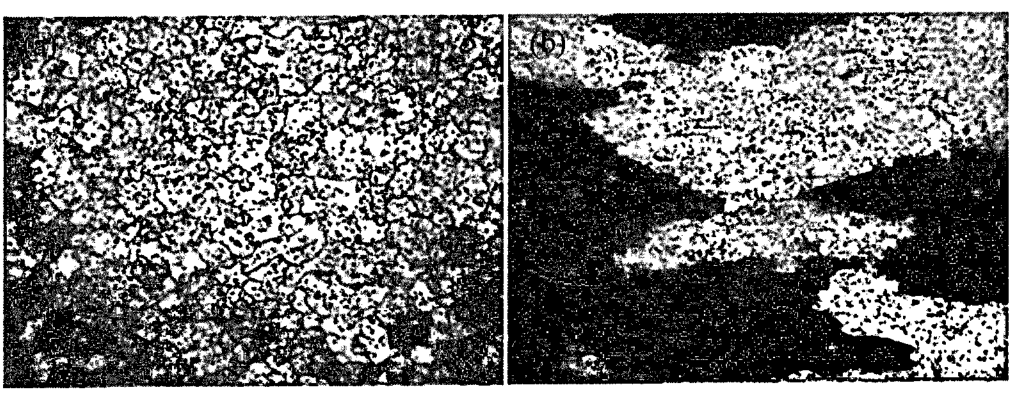


Figure 2.12: Microstructure of aluminium alloys billet. (a) AA6061 (b) AA7075
Source: Metallographic.com

Hu et al. (2008) have performed an effect of chip size on mechanical property and microstructure of AZ91D magnesium alloy prepared by solid state recycling. The study focused on mechanical properties and microstructure of the recycled specimens. From the observation of microstructural, it is revealed that all the recycled specimens consisted of fine grain due to dynamic recrystallization. The equiaxed grains (*polygonal crystallite*) formed high angle boundaries and the deformation processing features are clearly seen. Recrystallize did not happen on afew grains but they exhibited and elongated fiber-like structure.

Misiolek et al. (2012) presented a study of high quality extrudates from aluminium chips by new billet compaction and deformation routes. In the study, the multi-layer billet compaction technique is used to achieve higher billet density and therefore lower porosity in the extrudates in order to investigate the microstructure of extruded profiles. The microstructures are different between the cast and chip based billets and between profiles extruded through different extrusion dies. The extruded chip billet through the porthole die has a smaller peripheral coarse grain zone with characteristic seam weld line equiaxed and elongated grains in weld vicinity and equiaxed grains elsewhere. The porthole die did lead to sufficient chip bonding and to an advantageous microstructure, which explains the increase in ductility compared to the reference extrudate.

2.8 SUMMARY

In this study, the experiment will be conduct based on the literature review found by various sources. The study will focus on direct recycling process of aluminium chips waste as secondary materials. Aluminium chips are difficult to recycle due to their unusual characteristic and mixed with lubrication, at the same time they are generated from the manufacturing industry day by day. Without a proper disposal, the aluminium chips will cause both environmental and economic issues. AA6061 and AA7075 aluminium alloy will examine as the specimens and cut into chip shape by turning operation without cutting fluid. These materials were chosen because it is widely used in their respective fields and produces the most aluminium chip during the machining operations. The experimental study will be carried out on closed cylindrical die by compressing the chips in room temperature to form as solid secondary materials and the finished products will be examined on their density, the percentage of porosity and structure of the compacted billets by calculation.

CHAPTER 3

METHODOLOGY

3.1 EXPERIMENT SETUP

3.1.1 Fabrication of Aluminium Chips

For the analysis of aluminium chip waste for secondary materials using direct recycling process, chips are produce with different type of sizes by machining operation on ROMI C420 CNC turning machine (Figure 3.1) at Faculty of Manufacturing Engineering, UMP laboratory. The maximum center height for this machine is 215 mm and distance between centers is 0.5 m. The chips are fabricated in a lathe machine by turning operation on conventional cast extrusion billets of the aluminium wrought alloy AA6061 and AA7075 (Figure 3.2). AA6061 was chosen because of its wide application in mechanical and electrical industries where AA7075 was selected due to extensively used in the aerospace industry. Besides, the chip of the two types of material is continuously forms during the machining operation leads to typical industrial chips type condition.

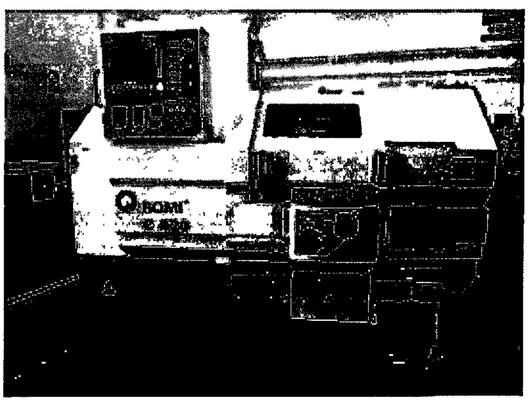


Figure 3.1: CNC Lathe Machine

The AA6061 and AA7075 chemical composition have been included in Table 3.1 and Table 3.2 respectively. To obtain the required chips from turning operation, aluminium turning indexable inserts (uncoated cemented carbide) with the specification CCGT 120408-AK and a positive rake angle were used. This inserts are suitable for cutting aluminium and aluminium alloy materials because it has 25-125H_B hardness. Both materials are machining under dry condition in which without lubricant to prevent any contaminant in the compacting process.

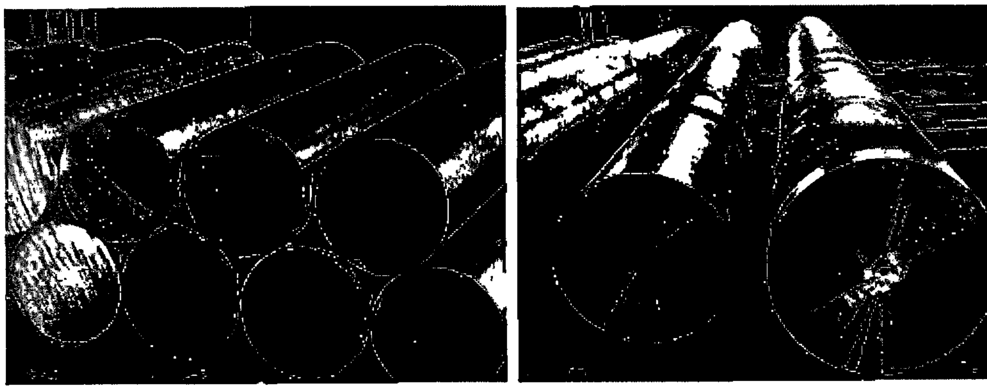
Table 3.1: Chemical composition of AA6061 aluminium alloy

Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al
0.4-0.8	0.7	0.15-0.4	0.5	0.8-0.12	0.04-0.35	0.25	0.15	Rest

Table 3.2: Chemical composition of AA7075 aluminium alloy

Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al
0.4	0.5	1.2-2.0	0.3	2.1-2.9	0.18-0.38	5.1-6.1	0.2	Rest

For the preparation of the compacting process, a certain combination of turning parameter is made for each operation with different types of materials are shown in Table 3.3; it presents the parameter for turning operation used in producing the chips. Chips of the sample S1 and S4 are machining under the same turning parameter because the material use is different. The spindle speed (rpm) used to produce this sample is 800 rpm and the feed rate , f is 50 mm/min with the depth of cut, a_p by 1.0 mm for S1 and 0.1 mm for S4. This parameter indicates the maximum and minimum value in turning operations to compare the chips produced the least and highest thickness of the chips. The second parameter for S2 and S5 specimens are spindle speed is 1000 rpm and f were 100 mm/min with a_p of 0.7 mm. The last parameter in order to produce the chips is 1200 rpm for spindle speeds; feed is 150 mm/min with a_p of 0.5 mm for S3 and 0.8 mm for S6. For an experimental of the direct recycling process, these chips are use in the next step of experiment to be place in the provided die device for the compaction process. These chips will acting as the solid waste materials indicates the aluminium chips waste that was produced by the industries. In the machining operation, the extruded casting bar has a diameter of 50 mm and 150 mm length so it will not exceeding the requirement limitation of the length used in CNC lathe machine tool working area.



(a) (b)

Figure 3.2: Materials use to produce the chips sample. (a) AA6061 (b) AA7075

Table 3.3: Turning parameter for production of aluminium chips

Material	Type	Spindle Speed (RPM)	Feed Rate (mm/min)	Depth of Cut (mm)
AA6061	S1	800	50	1.0
	S2	1000	100	0.7
	S3	1200	150	0.5
AA7075	S4	800	50	0.1
	S5	1000	100	0.7
	S6	1200	150	0.8

3.1.2 Die Device

The die device was designed for the use on a universal testing machine (UTM). Figure 3.3 shows a CAD modeling of die device used in the compaction operation. The dimension of the complete assembly showed in Figure 3.4 where details measurement gives clear description in fabricate the die device. SKD11 material is used in fabrication of the cylinder for die device because it consists of 12% of Cr. In other word, the SKD11 material is suitable as tools for the compressed operation because it can resist the wear excellently and good hardenability; the most often used tool steel and belong to the group of alloy tool steel. The die punch and die base are also made of SKD11 materials and machine on a CNC lathe machine. The die cylinder has a diameter of 100 mm with 100 mm length shows in Figure 6.6. The diameter of the cylinder hole is 30.02 mm because it must have a clearance of +0.02 mm so that the die punch can get into the hole without difficulty. The die punch shows in Figure 6.4, the outer diameter is 50 mm where inner diameter 30 mm. The thickness of outer diameter is 20 mm and the inner diameter has 50 mm of length. Both punch and die base have radius of 1° and 2°at their sharp edges also in between outer and inner diameter to prevent them from breaking or crack during the compaction operation. Figure 6.5 shows the dimension of die base. Die base and punch have the same dimension of outer and inner but different thickness and length. The die base has three sections where the top part mount on die cylinder and the bottom part will mount on the machine base plate. The middle of the die base act as supported for both parts. Top bottom has a diameter of 50 mm and 20 mm of length where the bottom part has a diameter of 32 mm with length of 50 mm. The die punch will move in a downward direction to enter the die cylinder hole then compress aluminium chips while die base will stay in a stationary condition.

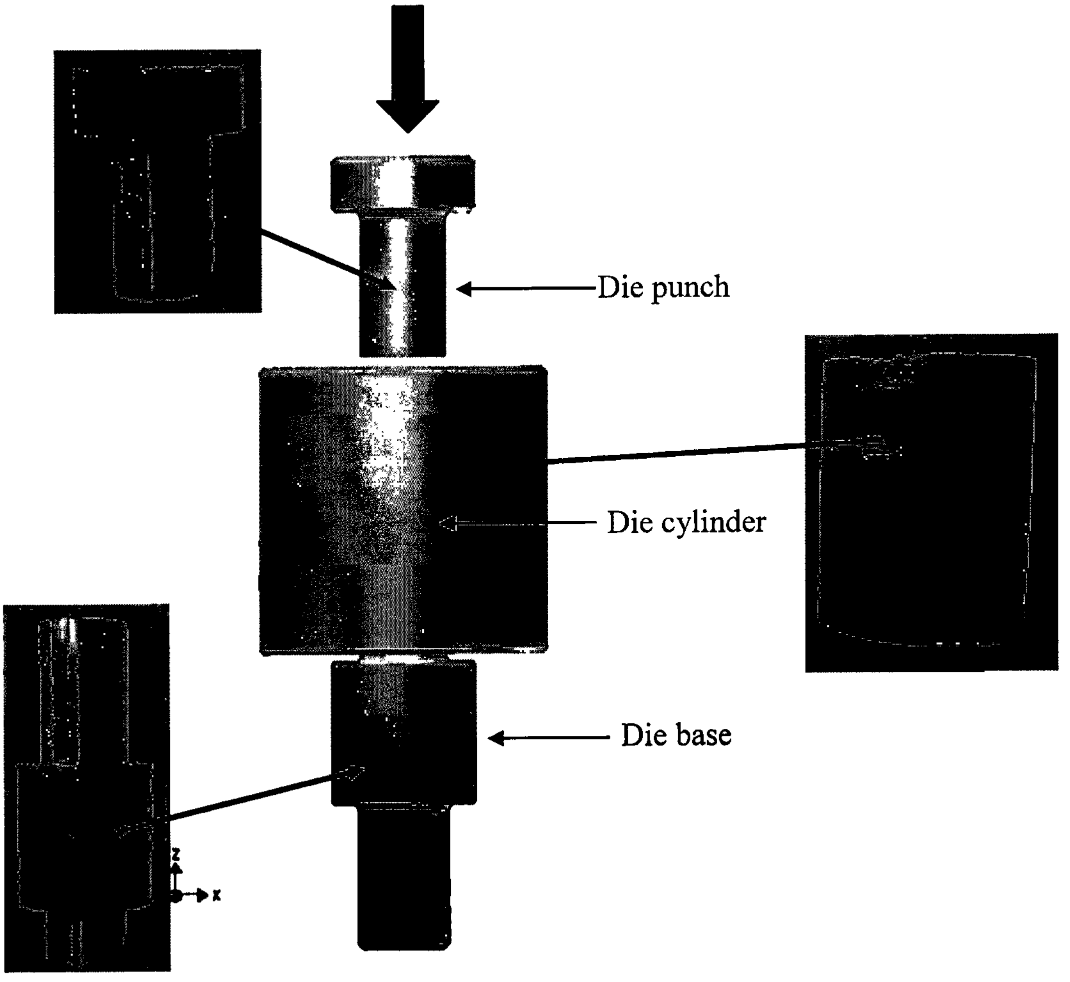
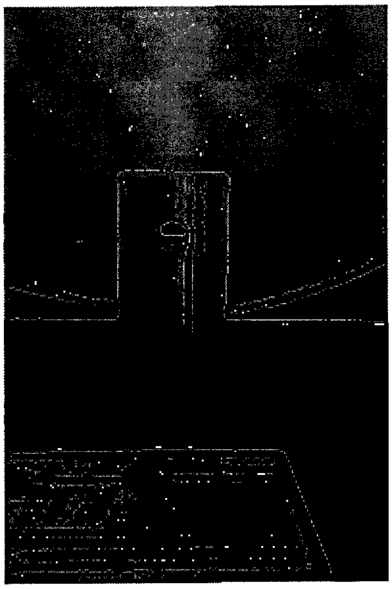


Figure 3.3: Die device by CAD modeling

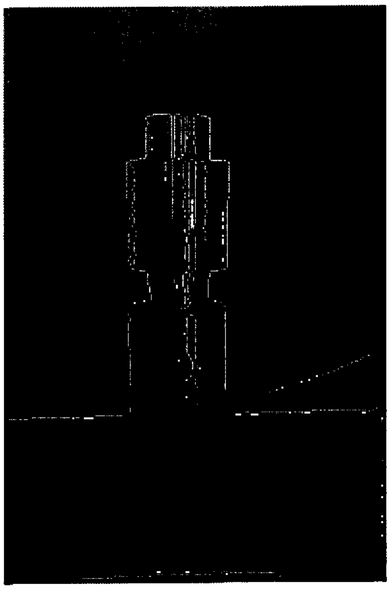
3.1.3 Compaction Operation

Compaction experiment is performed on a Universal Testing Machine (UTM) Instron 3369 (Figure 3.9) placed at Material Laboratory, FKP. The chips from the machining operation are collected and isolated them according to shape and size. The chips are placed in different compartment to differentiate them and easier to take during the operation. Then, the die device is set up on the UTM base cylinder like in the Figure 3.8 and the above grip is changed into cylinder plate to do the compression method. After installation completed, key in all the data needed in the Bluehill software to perform the compression. The UTM cylinder plate will compressed onto the die punch until the chips pressed compact. The machine itself can record the displacement between its cross heads on which the sample is held. The drawback in this method is its can record all other expanding or elastic components including any slipping of the sample in the grips. This Instron 3369 UTM has a maximum of 50 kN capacity with maximum speed of 500 mm/min and provide 1193 mm of vertical test space (Instron.co.uk).

Figure 3.8 shows the die device is set up on UTM base plate. Figure 3.4 (a) is the hollow cylinder fixed on the UTM base plate diameter of 32 mm and functioning as a holder for the die base of die device. Die base were mounted on the hollow cylinder (Figure 3.4 (b) and it will not move during the compaction operations (static state). Next, the die cylinder is mounted on the top of die base so that the chips will not come out

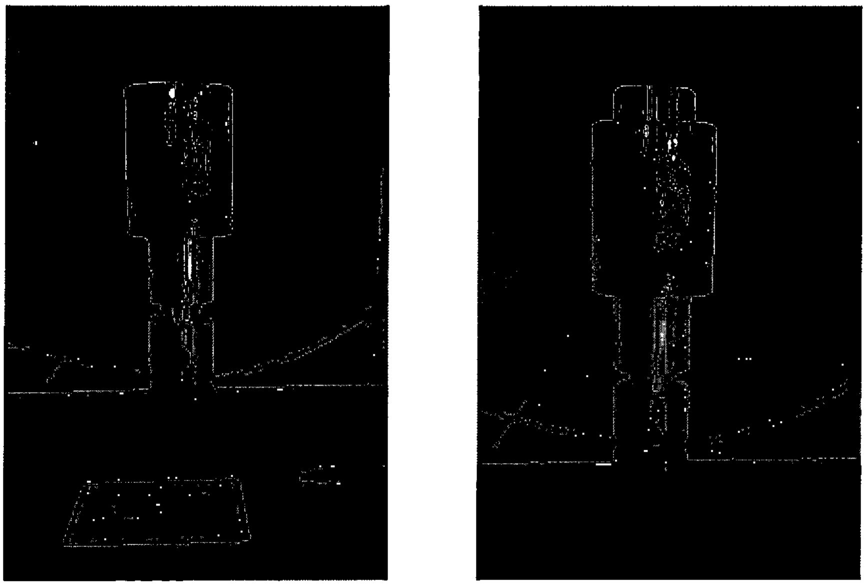


(a)



(b)

during the operations. The chips were filled up inside the die cavity until it full and then closed the cavity like in Figure 3.4 (d) with the upper punch die for the next process. Figure 3.5 show the finished installation of the die device on UTM. The UTM's grip has been change into compression cylinder to perform the compression process. The cold compaction operations were applied the same force of 40 kN for all the chips.



(c) (d)

Figure 3.4: Die device set up on Universal Testing Machine (UTM)

Figure 3.5: Universal Testing Machine (UTM) after die device installation

3.2 ANALYSIS ON COMPRESSED BILLETS

3.2.1 Hardness Testing

Hardness can be performing by penetration operation that enables it to resist plastic deformation. In this experiment, Vickers 402 MVD was used to measure the hardness of aluminium alloys solid bar before and after the compaction method. The Vickers (HV) test was formerly known as Diamond Pyramid Hardness (DPH) test and developed in England in 1925. The Vickers test has two distinct force ranges which are micro (10g to 1000g) and macro (1kg to 100kg), to cover all testing requirements. The indenter is the same for both range therefore Vickers hardness values are continuous over the total range of hardness for metals (typically HV100 to HV1000).

With the exception of test forces below 200g, Vickers values are generally considered test force independent. In other words, if the material tested is uniform, the Vickers values will be the same if tested using a 500g force or a 50kg force. Below 200g, caution must be used when trying to compare results. Figure 4.0 shows Vickers 402 MVD hardness test placed at Material laboratory, FKP. In the Vickers test method, all Vickers ranges use a 136° pyramidal diamond indenter that forms a square indent. Firstly, the indenter is pressed into the sample by an accurately controlled test force.

Then, the force is maintained for a specific dwell time, normally 10 – 15 seconds. After the dwell time is complete, the indenter is removed leaving an indent in the sample that appears square shaped on the surface. Lastly, the size of the indent is determined optically by measuring the two diagonals of the square indent. The strength of using Vickers test are one scale covers the entire hardness range; a wide range of test forces to suit every application; and nondestructive which is the sample can normally be used.

Both of the aluminium alloys 6061 and 7075 extruded casting billet was measured their hardness on the Vickers Hardness tester to compare the hardness of different materials. The extruded billets were cut into thin specimen cylinder like a coin measurement for easier the testing is performed because the gap between the test table and microscopic lens are limited. The averages of the hardness values are taken.

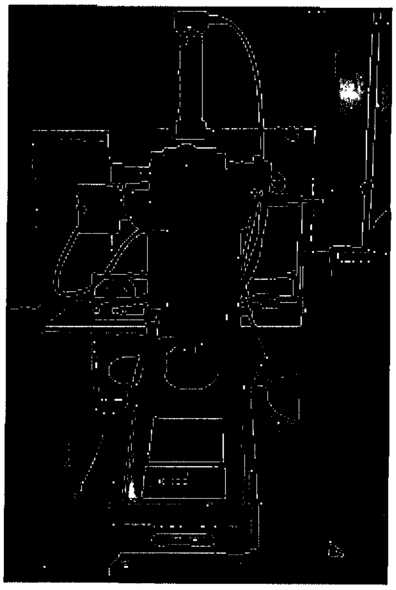


Figure 3.6: Vickers Hardness Test

3.2.2 The Density of Compressed Billets

Aluminum alloys have many outstanding attributes that lead to a wide range of applications, including good corrosion and oxidation resistance, high electrical and thermal conductivities, low density, high reflectivity, high ductility and reasonably high strength, and relatively low cost. Aluminum alloys display a good combination of strength and ductility among the easiest of all metals to form and machine.

Aluminium is a lightweight material compared with other metals. Cast extruded aluminium alloys of AA6061 and AA7075 have different value of density due to their characteristic of the materials itself. AA6061 is one of the most common alloys that widely used in the industry where it has a density of 2.70 g/cm^3 contained magnesium and silicon as the major composition. While, AA7075 alloys has a density of 2.81 g/cm3 slightly higher than AA6061 because this material is strong with zinc as the primary alloying element. AA7075 are often used in transport applications, including marine, automotive and aviation due to their high strength-to-density ratio.

In order to obtain the density for the final products after completing the compaction operations, the diameter and height of each specimen is measured to acquire the volume for each compressed billets. Volume (V) equation is defined as:

$$V = \pi r^2 h \qquad (3.1)$$

followed by the equation to gain the density value of the final product shows in (3.2) where specimen's density (ρ_s) is determined by measuring the weight of the specimens and its geometry.

$$\rho_s = \frac{m_s}{V_t} \qquad (3.2)$$

Relative density was used to compare and qualify compaction processes by the study of Pepelnjak et at., (2012). Relative density (ρ_{rel}) is defined as:

$$\rho_{rel} = \frac{\rho_b}{\rho_{extruded\,Al}} \text{ x } 100\% \qquad (3.3)$$

3.2.3 The Percentage of Porosity

Porosity or void fraction is a measure of the void (empty space) spaces in a material, and is a fraction of the volume of voids over the total volume, between 0 – 1, or as a percentage between 0 – 100 %. Porosity usually used in geology, hydrogeology, soil science, and building science, the porosity of a porous medium such as rock or sediment describes the fraction of void space in the material, where the void may contain, for example, air or water. In this study, the percentage of porosity is used to determine on how much is empty space generated by the compressed billets after compacting operations is performed. It is because the chips have a large surface area and make them difficult to handle and transportation. The porosity percentage is defined as:

$$\text{Porosity percentage} = [\,1 - (\frac{\rho_s}{\rho_{extruded\,Al}})\,] \text{ x } 100 \qquad (3.4)$$

3.3 SUMMARY

In this chapter, details explanation of the experiment methodology for recycling aluminium chips by compaction process is discussed. The production of aluminium chips from solid billets by machining operation is important in order to carry out the compaction operation. Different kind of turning parameter is stated to produce various types of chips. From the compaction process, results a final product in a forms of solid billet. The final product is analyzed for its density and relative density for qualifying compaction process. Then, performing the porosity percentage calculation on the compressed billets and the results will be compared with the existing billets.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 ALUMINIUM CHIPS PREPARATION

In the result of the turning operation, chips were produced under three types of parameter to get different shapes and size. Figure 4.2 and 4.3 show the chips obtained from the machining without applying lubrication carried out on AA6061 and AA7075 alloys have classified according to their specifications. It is very important that only chips that follow the specifications are accepted for the next process of compaction. In Figure 4.1, undesirable chips are occurred in each process machining during the turning operation. It happened when the workpiece continuously working without rest since the aluminium alloys is not very good in dissipate the heat generated by cutting and friction. Furthermore, it takes a lot of time to machine the round bar of aluminium alloys in order to eliminate undesirable chips formation that does not follow the required specifications.

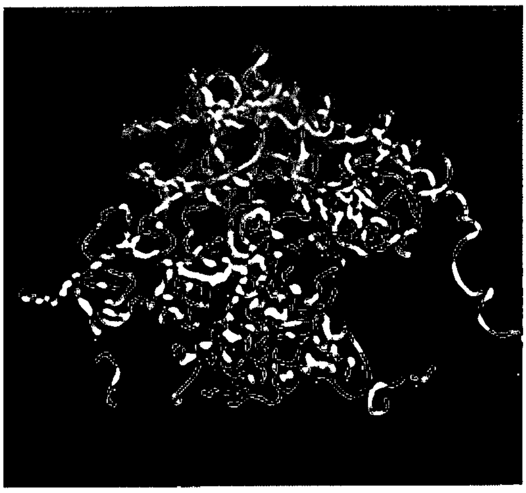
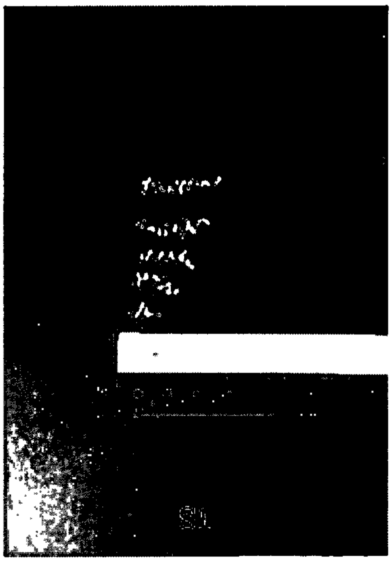
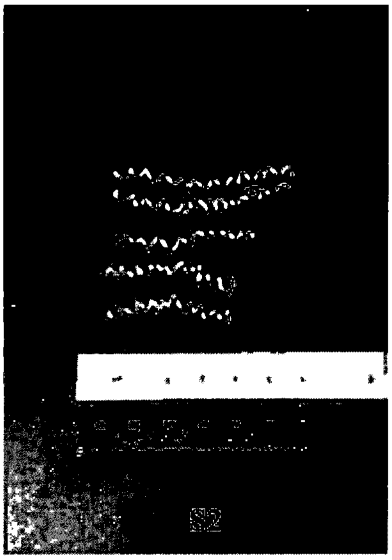


Figure 4.1: Unfavourable chips

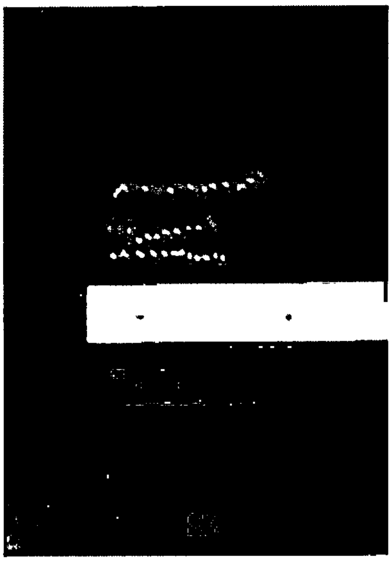
Figure 4.2 shows chip's type of AA6061 after turning operation. S1 chips have a measurement of 0.5 – 3.0 centimeter. It is categorized as short size of washer type chip with depth of cut 1.0 mm. This chip's width is the thickest compared with other chip types. S2 chip's measurement is longer than S1 which is in a range of 4.0 cm until 6.0 cm and they are classified as washer type chips for long size. Lastly, S3 chips have the same type as S1 for a short size of washer type chips but the difference between them is size of the S3 chip is relatively longer than S1that is 2.5 cm until 3.5 cm.



(a)



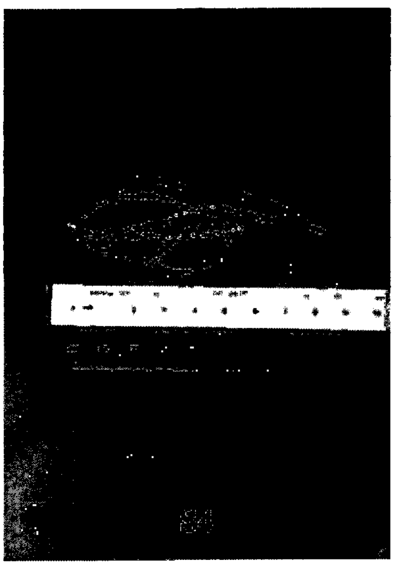
(b)



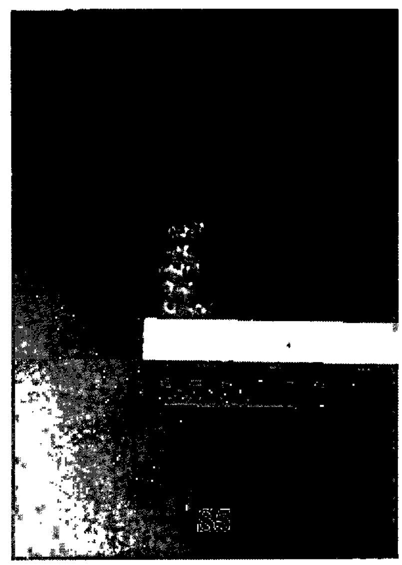
(c)

Figure 4.2: Chips of AA6061 (a) 0.5 – 3.0 cm (b) 4.0 – 6.0 cm (c) 2.5 – 3.5 cm

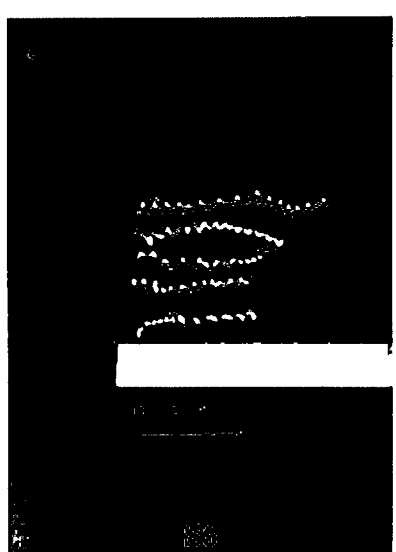
Meanwhile, in Figure 4.3, it can be seen specimen 4 (S4) has long size of ribbon chip (4.0 – 8.5 cm) type also as the most lightweight chip compared with others since its depth of cut is only 0.1 mm. However, S5 is very different from S4 chips because it has shorter size in a range of 0.5 until 1.5 cm and categorized in washer type chips for short size. Finally, S6 chips almost equal as chip from S2 even though their depth of cut slightly different by 0.1 mm. The S6 chips have a measurement of 3.5 – 6.0 cm and categorized as washer type chips for a long size.



(a)



(b)



(c)

Figure 4.3: Chips of AA7075 (a) 4.0 – 8.5 cm (b) 0.5 – 1.5 cm (c) 3.5 – 6.0 cm

The data has been analyzed according to speed of the spindle and feed rate versus depth of cut during the operation. From this data, the trend lines are obtained after chips through the machining process without lubrication oil. Depth of cut plays an important role in producing the desired chip thickness, in the meantime, spindle speed and feed rate are set up as constant (800 rpm – 50 mm/min; 1000 rpm – 100 mm/min; 1200 rpm – 150 mm/min) parameter for chip's shape and sizes. The graphs below show both speed and feed rate versus the depth of cut to produce the chips from extruded casting bar aluminium alloy of 6061 (Figure 4.4) and 7075 (Figure 4.5) formed by different parameter.

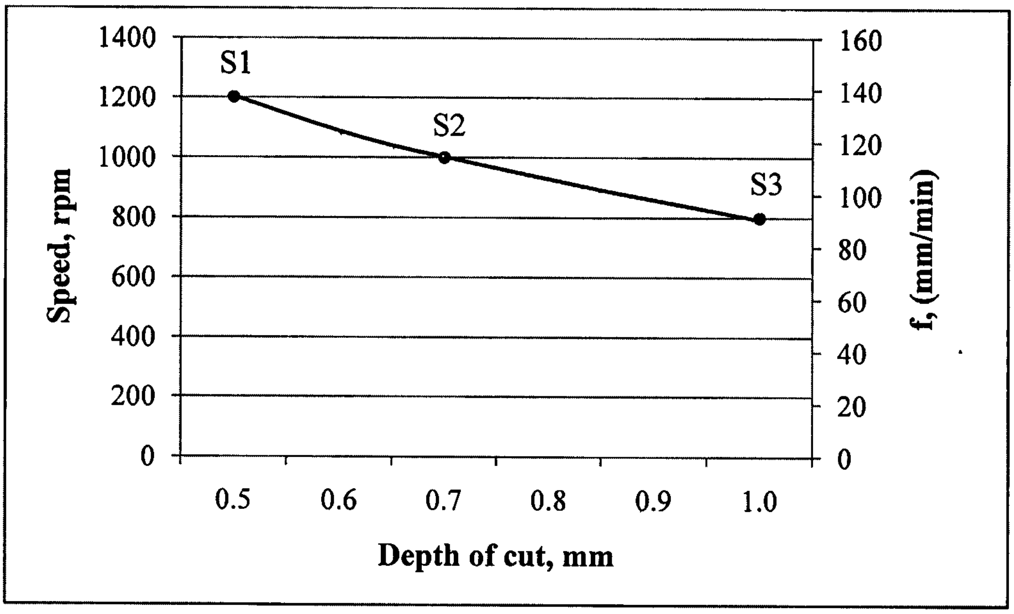


Figure 4.4: Graph of AA6061 chips obtained from turning operation

As a result, graph in Figure 4.4 shows the decreasing type of trend line made by AA6061 chip's thickness where graph in Figure 4.5 has an increasing type of trend line for AA7075 chip's thickness. These trend lines are based on the thickness for each type of chips and have demonstrated a huge difference in chip's characteristic between both aluminium alloy 6061 and 7075. It can be seen that the lower the depth of cut, the thicker chips produced through the process of turning by AA6061 alloy's material. However, AA7075 has the opposite results with AA6061 alloy. Type S1 and S6 express significantly highest thicknesses than S2, S3 and S5 while, S4 chips shown the lowest thickness compared with other type. This is because increasing the depth of cut on the material, the thicker chips produced. This difference is maybe influenced by the hardness of each material as shown in Table 4.1 tested on Vickers Test.

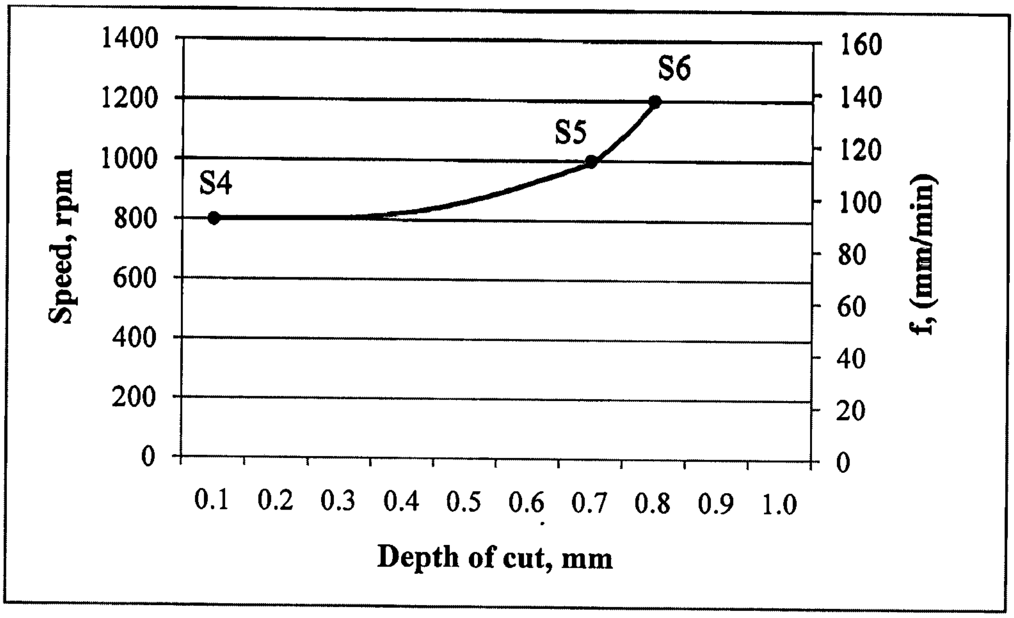


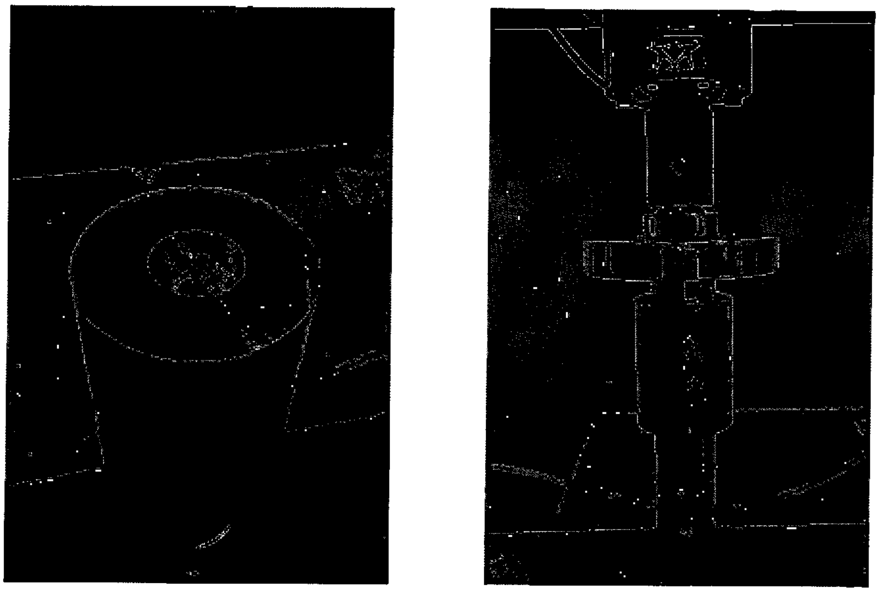
Figure 4.5: Graph of AA7075 chips obtained from turning operation

Table 4.1: The average value of aluminium alloys on Vickers Test

Material	Value 1	Value 2	Value 3	Value 4	Value 5	Average (H_B)
AA6061	111.8	117.3	127.1	121.1	114.8	118.42
AA7075	132.9	133.8	129.0	127.0	121.0	128.74

4.2 COMPACTION METHOD

The compaction process of the chips was carried out on Universal Testing Machine (UTM) in a Ø30 mm closed die. Figure 4.6 (a) and 4.6 (b) respectively show the compaction method when the chips are filled up inside the die device cavity and then compressed by using compression cylinder. All the chips used in this compaction are differ both in length and width as well as in thickness



(a) (b)

Figure 4.6: Compaction operation

4.2.1 Pre-compacting Operations

An approximate amount of chips was used for each compaction to ensure the final specimen's height of 34 mm depending on the chip type. The total amount of chips prepared for each specimen could not fit into the die cavity at once because the relative filling density of the chips is low. Hence, a number of pre-compacting operations required to form the final shape. Numbers of compacting for every chip type are presented in Table 4.2. There are total of 3 to 5 pre-compacting operations that was performed during the filling of the chip in the die cavity depends on the type itself. S3 and S5 have the highest pre-compaction as they have the smallest thickness and therefore lowest filling densities. Meanwhile, S6 has the largest volume required only three times of compaction process, although S4 categorized as S6, it began to crack when reached the 3rd compacting operation. It may be due to its size longer than other types and very thin thickness not suitable for compaction process.

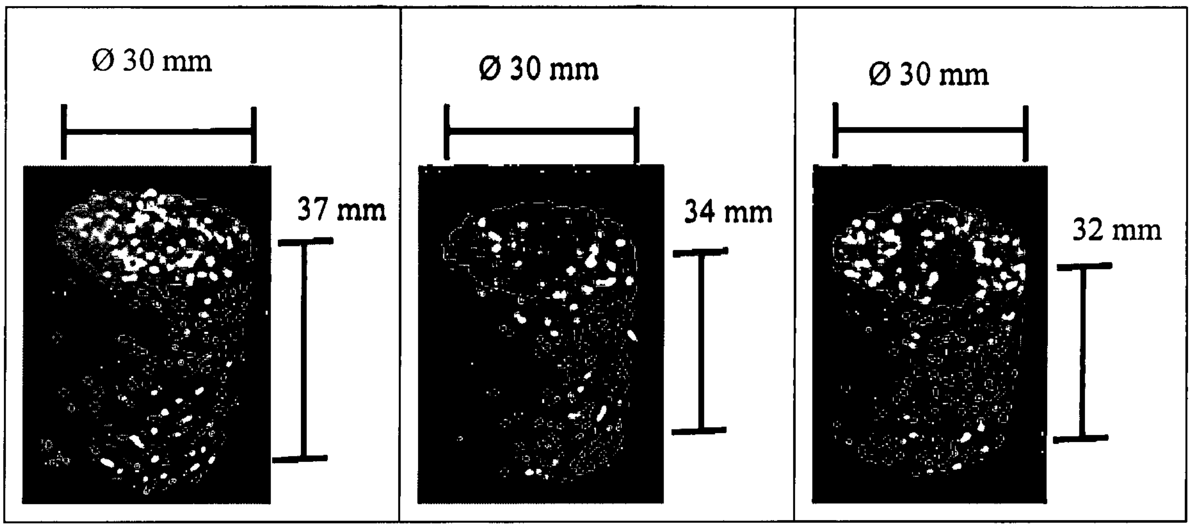
Table 4.2: Pre-compacting operation for each chip type

Number of compacting	1st	2nd	3rd	4th	5th
S1	√	√	√	(√)	
S2	√	√	√	(√)	
S3	√	√	√	√	(√)
S4	√	√	(√)		
S5	√	√	√	√	(√)
S6	√	√	(√)		

( ) Compacted billet cracked after reached maximum number of compacting

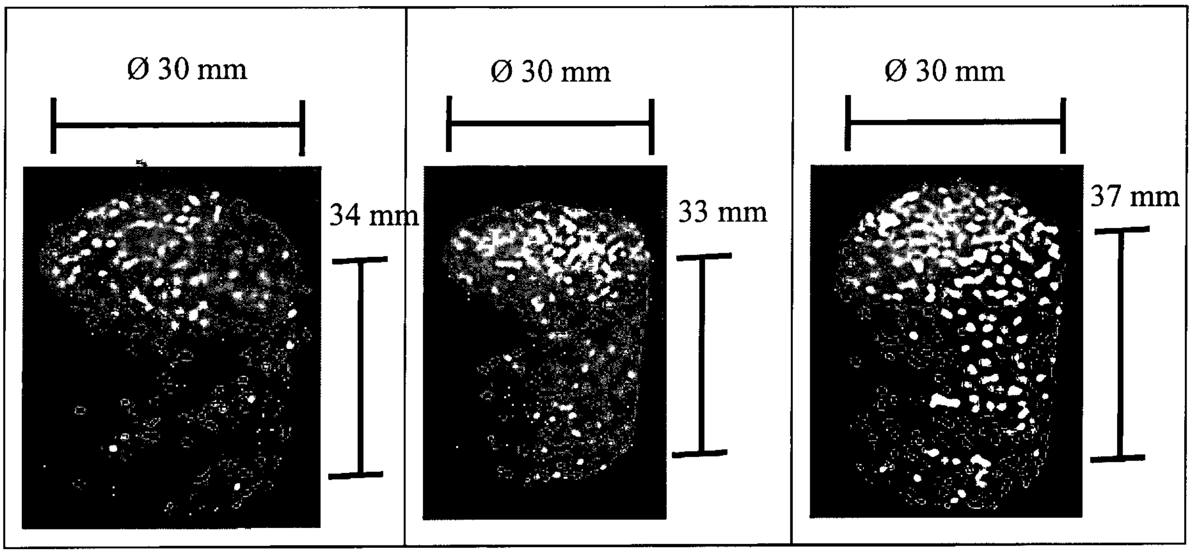
4.2.2 Compressed Billets

Figure 4.7 shows the compressed billets owned by AA6061 alloys after compacting operations. It can be seen, they have slight differences in term of the final compressed billets height. According to the die device design in chapter 3, cavity of the die device has 34 mm height but from the results show in Figure 4.7 and Figure 4.8 only S2 and S4 specimen follow the exact measurement based on the die device design. Other specimens have a height in the range of 32 – 37 mm. However, the specimens have the same diameter of 30 mm. S1 and S6 have the same height by 37 mm. Therefore, the pre-compacting operating does affected the height of each specimen. It can be seen, S4 has the worst condition of its form where most of the chips are out of the shape and its condition is very unstable. For a short time, S4 specimen is break easily even though the force applied is the same as other. Specimens of S2, S3 and S5 show a strong form.



(a) (b) (c)

Figure 4.7: Compressed AA6061 chips (a) S1 (b) S2 (c) S3



(d) (e) (f)

Figure 4.8: Compressed AA7075 chips (d) S4 (e) S5 (f) S6

4.3 DENSITY OF COMPRESSED BILLETS

The density of compressed billets was used to compare each type of billets after the compaction operations. Every specimen's volume (V) is calculated by using equation (1) where specimen's density (ρ_s) is determined by measuring the weight of the specimens and its geometry.

Figure 4.9 shows the graph of AA6061 density versus number of compacting. It can be seen that S1 and S2 have the same number of compacting but they acquired different value of density where S1 has 0.803 g/cm^3 and S2 with 1.248 g/cm^3 of density. Even though their number of the compacting operation is different where S3 require more number of compacting due to its thickness is smaller than S2. Meaning that, the number of compacting operation does affecting the specimen's density.

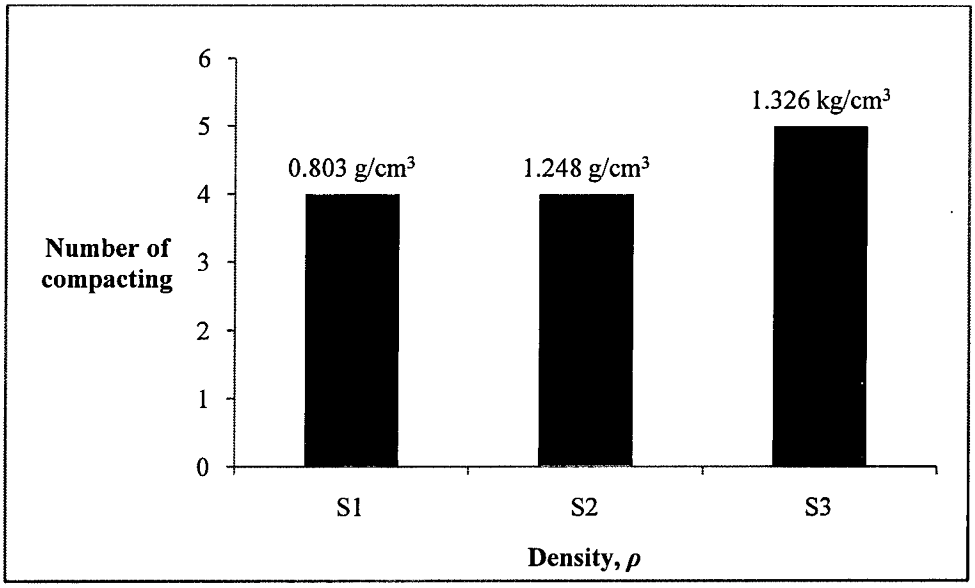


Figure 4.9: Graph of AA6061 density versus number of compacting

While in Figure 4.10 shows the graph of AA7075 density versus the number of compacting operation. S4 and S6 required three operation of compacting but their density (0.208 g/cm^3 and 0.831 g/cm^3) is different due to a significant difference in thickness of the chips. S5 shows the highest density for this material but it ranked at the second highest overall but still cannot compete with the density of S3. S4 placed as last as it obtained the least density compared with other billets. It can be concluded that the chip's thickness can affect the density of compressed billets.

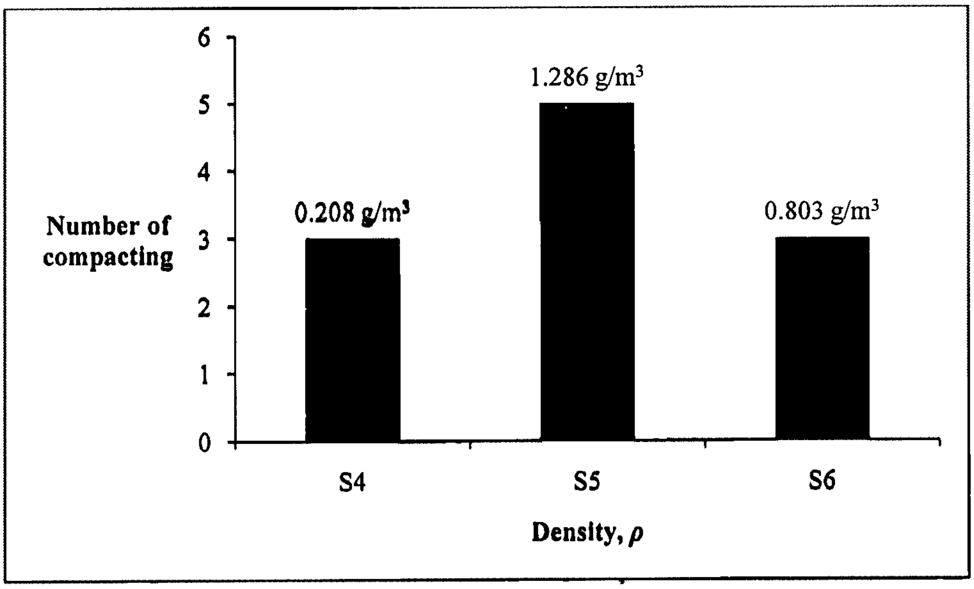


Figure 4.10: Graph of AA7075 density versus number of compacting

In order to compare and qualify compaction process, relative density was used to find the percentage of each specimen whether they can meet with the density of extruded aluminium alloys. Extruded aluminium alloys ($\rho_{extruded\ Al}$) density for AA6061 is 2.70 g/cm^3 and 2.810 g/cm^3 for AA7075. Relative density is defined as in equation (3)

Graph presented in Figure 4.11 shows the relatively density for both AA6061 and AA7075 alloys. S4 has the lowest relative density (7.86%) since it weight is only 5 grams. The S4 relative density is far behind from the cast extruded aluminium alloy. Although S2, S3 and S5 have the same density but they are different in terms of relative density due to the difference between the extruded density of AA6061 and AA7075. The same thing happened on the S1 (34.37%) and S6 (33.02%) where the relative density differ between them. Thus, the chip's type influences the relative densities of the final billet. Furthermore, the percentage of specimens relative density does not achieved as high as percentage of study by Pepeljak.T et al., 2012. The low relative density for each specimen shows the poor quality of their solidification.

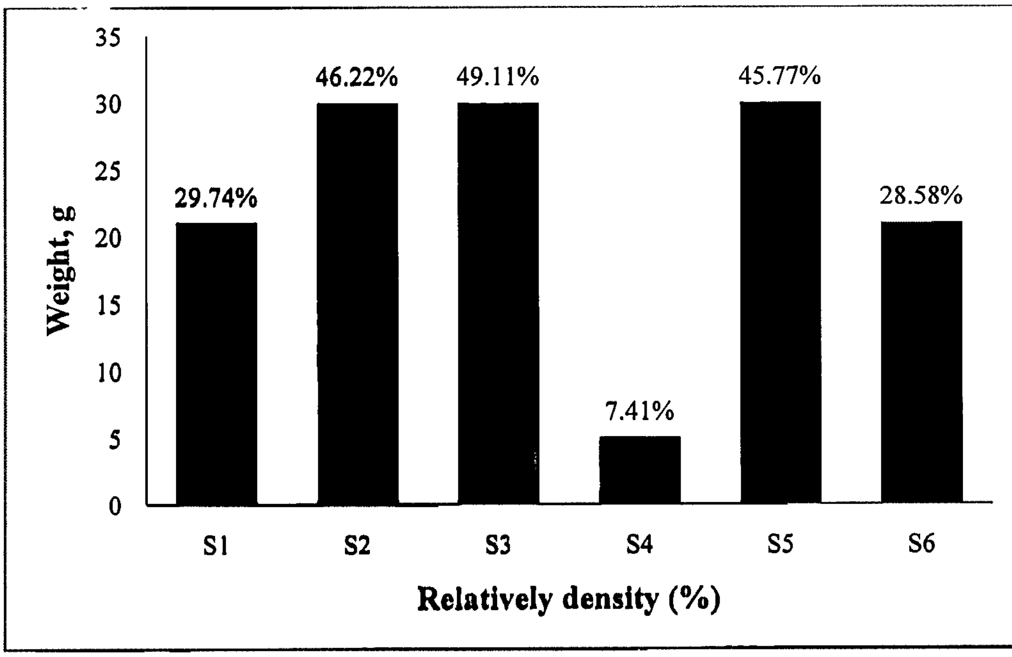


Figure 4.11: Relatively density for AA6061 and AA7075 alloys

In Table 4.3 shows each specimen's properties after applying the calculations provided in Chapter 3. All the values are included in the graph to compare the differences between all the compressed chip's densities.

Table 4.3: The specimen's properties

Specimen	Mass (kg)	Volume (cm^3)	Density (g/cm^3)	Relative Density (%)
S1	21	26.15	0.803	29.74
S2	30	24.03	1.248	46.22
S3	30	22.62	1.326	49.11
S4	5	24.03	0.208	7.410
S5	30	23.33	1.286	45.77
S6	21	26.15	0.803	28.58

4.4 POROSITY OF COMPRESSED BILLETS

Porosity is obtained after the density of each specimen found. The percentage of specimen porosity is calculated using equation (4). From Table 4.4, it can be seen that S4 has the highest percentage of porosity as much as 92.14% nearly to 100% porosity. Thus, S4 specimen is far away in comparing the cast extruded billets and easily to crack even with a small force on it. S4 exhibited high volumes of chips resulted poorest specimen porosity after cold compaction operations since the thickness of it chips is thin, 0.1 mm.

While, S3 has the lowest porosity percentage by 50.89 % compared with other specimens and its average size of the chips also in a good range. Meaning that, S3 is the most successful compacted specimen compared with others after compacting operations are performed and S4 is the worst compacted specimen in this study. On the other hand, S2 and S5 have slight difference with S3 where S2 has 53.78 % and S5 with 54.23 % of porosity. Although S5 has the lowest porosity percentage in AA7075 alloys family it is because of the differences in cast extruded billet densities of the AA6061 and AA7075 alloys causes differ porosity between all the specimens. In the case of S1 and S6, they happen to have the same density of compressed billets but due to different size of chip and aluminium alloys density, S1 has porosity of 70.26 % and the porosity percentage of S6 is 71.42. It can be conclude that materials type affected the porosity percentage for each type of the specimens.

Table 4.4: Percentage of specimen's porosity

Specimen	Porosity Percentage (%)	Average size of the chips (cm)
S1	70.26	1.75
S2	53.78	5.00
S3	50.89	3.00
S4	92.60	6.50
S5	54.23	1.00
S6	71.42	4.75

Figure 4.12 presents the fluctuation type of graph for porosity percentage of AA6061 alloys. S1 has the highest porosity (70.26 %) compared with S2 and S3. The average chip size of S1 shows the second smallest among all types. Followed by S2 as the second highest porosity percentage has 53.78 % but its average size of chip is longer than S3. While S3 has the lowest percentage of porosity by 50.89 % with 3 mm average size of chips in this AA6061 type. From this graph, it can be seen the fluctuation of the point happened because the average size of the chips are influence the porosity percentage where the lower the average size of the chips leads to the higher percentage of porosity for the compressed billets depending on the sizes of the chip.

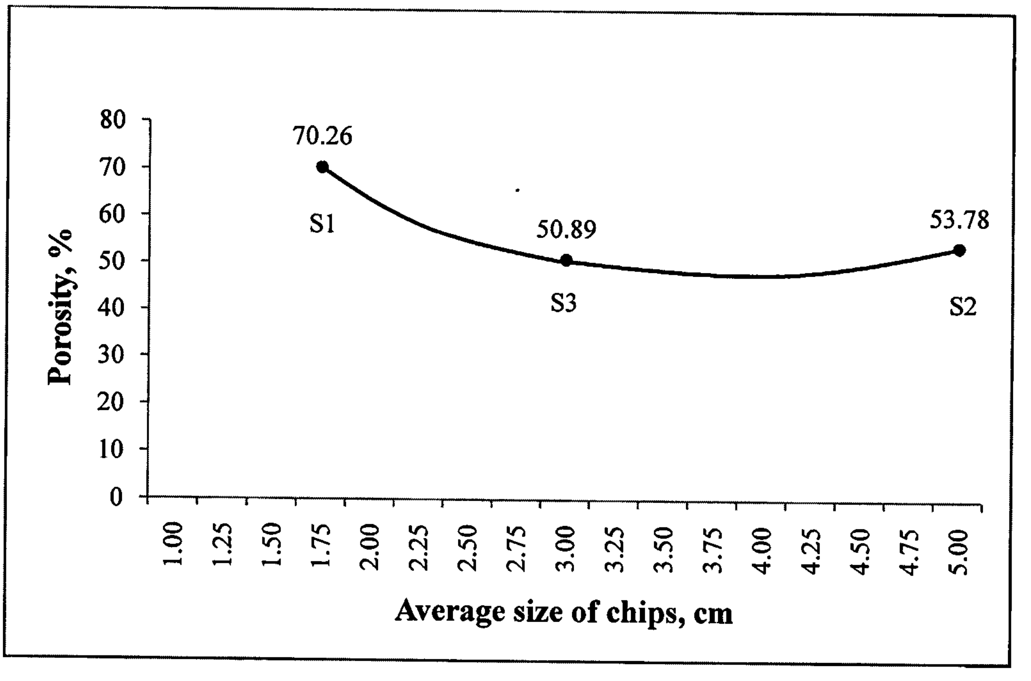


Figure 4.12: Graph of porosity percentage for AA6061 alloy

In Figure 4.13 shows the increasing type of graph for porosity percentage of AA7075 alloys. S4 has the highest percentage of porosity by 92.6 % due to the smallest average size of chips and can be seen from this percentage that the compressed billet of S4 is not stable in term of its structure. Percentage porosity for S5 by 54.23 % is slightly lower than S6 (71.42%) even though they have a large gap in term of the average size of chips. For AA7075 alloy, the lower the size of the chips, the lower percentage of porosity for each compressed billets.

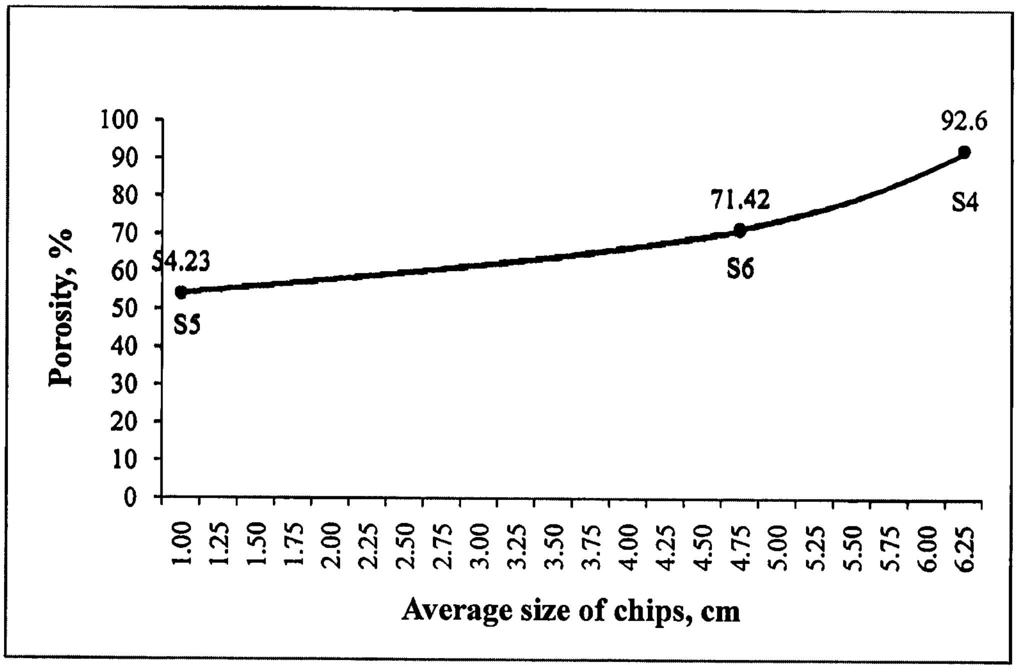
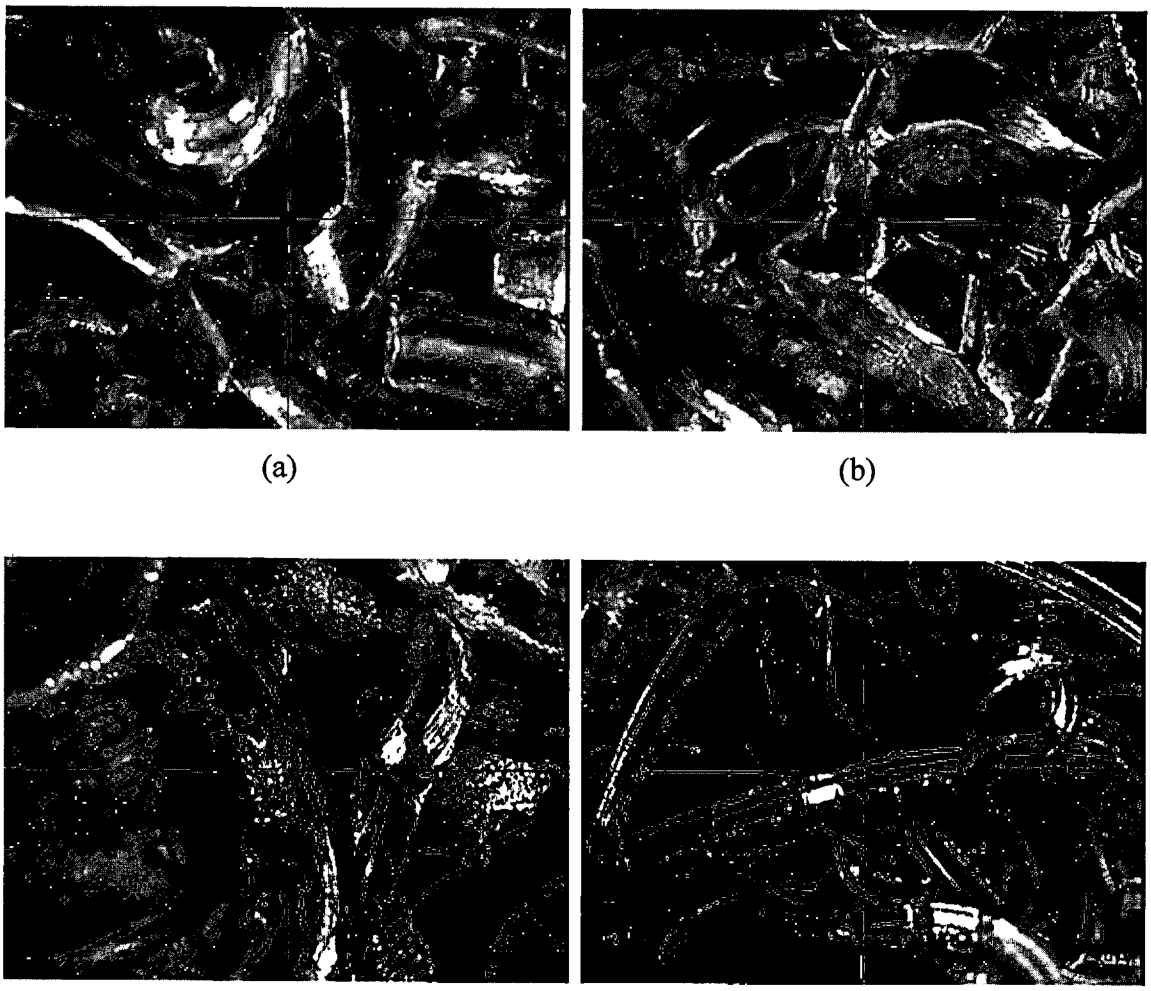


Figure 4.13: Graph of porosity percentage for AA7075 alloy

4.5 THE STRUCTURE OF COMPRESSED BILLETS

In this project, there is unexpected result on the structure of compressed billets where the surface should flat to facilitate the analysis and the bonding between the chips must be strong. In the previous study by various researchers, they have been proved the compacted final products nearly reached the exact cast extruded billets microstructure. However, the structure of each specimen for this study have been observed by using video measurement to get the accurate view since the chips are not a fine grain size and also the bonding of chip influences the images. From Figure 4.14, it can be seen that all of the specimen's structure does have an empty or voids. This voids in other term mean porosity, usually occurs on soil or water but for the aluminium alloys condition it is more to analyze the spaces between the compressed chips. The empty space makes the form of the compressed billets is not strong enough to withstand other forces directly on it after completing the compaction process because they can be characterized as fragile and break easily.

Figure 4.14 (a) until (c), show the structure of AA6061compressed billets and the rest are owned by AA7075 alloy's specimens. For AA6061 family, S2 and S3 have the most firm shape of billets based on the image because their porosity percentage is not high as S3 structure where its empty space is more visible. The bonding of the S2 and S3 is more accurate and showed that they have been compacted properly compared with S1. While for the AA7075 specimens show that the S4 billet structure has largest volume of the empty space. In Figure 4.14 (d), the chips are not properly compacted due to insufficient force applied during the operations plus with their long size of ribbon chip type makes them difficult to compress without proper adhesive. The structure of S5 billet shows that it also has least empty space like S2 and S3. S6 has the same condition like S1 where the empty spaces is visible but still cannot compared with S4 structure due to its percentage of the porosity is too high nearly to 100 % meaning that this type of chip is not suitable for this experiments.



(a) (b)

(c) (d)

(e)

(f)

Figure 4.14: Structure of compressed billets (a) S1 (b) S2 (c) S3 (d) S4 (e) S5 (f) S6

4.6 SUMMARY

In this chapter, results obtained from the experiments have been discussed. The generated chips are classified according to their shape and size. From the compaction method, several pre-compacting operation is performed due to their low filling density of the chips and the compressed billets obtained the same volume. From the volume of the compressed billets, the density and the porosity percentage is analyzed in order cömparing their characteristic after the cold compaction operations.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATION

5.1 CONCLUSIONS

Direct recycling process is a technique for recycling metal waste generated by industry. This paper focused on investigates the influence on different type of aluminium chip shape and sizes as secondary materials of billet using cold compaction operations. Various types of chips were obtained by different turning parameters on extruded AA6061 and AA7075 alloys. All the chips were cut on a CNC Turning machine without using lubrication oil. Chips classifications in favourable and unfavourable have been detected after turning operations was performed. Chips were separated according to type of material with their size and shape into labeled container for easily identified. For this chips machining, specimen S2 and S5 have the shortest chip where in the range of 0.5 to 3.0 mm length. They are the most favourable chips in this classification produced by turning operations compared with other specimens and show a good quality of chips.

The compaction process of the chips was carried out on Universal Testing Machine (UTM) in a Ø30 mm closed die. An approximate amount of chips was used for each compaction to ensure the final specimen's height of 34 mm depending on the chip type. There are total of 3 to 5 pre-compacting operations that were performed during the filling of the chip in the die cavity. S3 and S5 have the highest pre-compaction as they have the smallest thickness and therefore lowest filling densities. Meanwhile, S6 has the largest volume required only three times of compaction process.

After compacting operations, the compressed billets have a height in the range of 32 – 37 mm the same diameter of 30 mm. S4 has the worst condition of its form where most of the chips are out of the shape and its condition is very unstable. For a short time, S4 specimen is break easily even though the force applied is the same as other but for S2, S3 and S5 specimens show a strong form of compressed billets.

The density of compressed billets was used to compare each type of billets after the compaction operations. It can be seen that S1 and S2 have the same number of compacting but they acquired different value of density where S1 has 0.803 g/cm^3 and S2 with 1.248 g/cm^3 of density. Even though their number of the compacting operation are different where S3 require more number of compacting. S4 and S6 required three operation of compacting but their density (0.208 g/cm^3 and 0.831 g/cm^3) is different due to a significant difference in thickness of the chips. Meaning that, the number of compacting operation and thickness does affecting the specimen's density.

Relative density was used to compare and qualify compaction process. S4 has the lowest relative density (7.86%) since it weight is only 5 grams. Although S2, S3 and S5 have the same density but they are different in terms of relative density due to the difference between the extruded density of AA6061 and AA7075. Thus, the chip's type influences the relative densities of the final billet. Furthermore, the percentage of specimens relative density does not achieved as high as percentage of studied by Pepeljak.T et al. (2012).

Moreover, S4 has the highest percentage of porosity as much as 92.14% nearly to 100% porosity. Thus, S4 specimen is far away in comparing the cast extruded billets and easily to crack even with a small force on it. S4 exhibited high volumes of chips resulted poorest specimen porosity after cold compaction operations since the thickness of it chips is thin, 0.1 mm. On the other hand, S2 and S5 have slight difference with S3 where S2 has 53.78 % and S5 with 54.23 % of porosity. It can be conclude that materials type of AA6061 and AA7071 affected the porosity percentage for each type of the compacted specimens.

In this project, there is unexpected result on the structure of compressed billets where the surface should flat to facilitate the analysis and the bonding between the chips must be strong but an empty space between the compressed chips occurs due to thickness of the chips after the machining operations. The structure of S5 billet shows that it also has least empty space like S2 and S3. S6 has the same condition like S1 where the empty spaces is visible but still cannot compared with S4 structure due to its percentage of the porosity is too high nearly to 100 %.

5.2 RECOMMENDATION

For future work, a comparative study should be performed by comparing the performance of the cold compaction processes with chips from dry and wet condition. The chips from machining operation should have the shortest length as it can with correct forces apply on it during the process lead to a fine surface. The study also can include of comparing the obtained chips shapes under different parameter combinations according to the ISO 3685 (refer 2.2.1 Aluminium Chips), specific standard for steels and cast iron.

The chips tend to transform into a snarled shape when the extruded billet became too hot which make it difficult to handle. Therefore, utilize a new insert turning for producing each type of the chips and size during machining operation is important to avoid unfavourable chips occur every time the workpiece is use for a long time since the experiment does not use lubricant to cool down the extruded casting billet on the spindle. The insert turning also will take the color of the aluminium alloys where the color is stick on the insert's surface affected its performance during cutting operation.

Cold compaction is a preliminary process in the direct recycling process. After the compaction process, the compacted billets should go through the hot extrusion operation to improve their mechanical properties. But, due to the hot extrusion machine is not available at the FKP laboratory causes this process cannot be continued. So, for future work the hot extrusion operation need to be done in order to analyze the hardness and microstructure of compacted billets. The results obtain are then compare with the existed extruded casting billets on the market whether the recycling product can meets the actual extruded specifications.

A larger force is needed to compact these chips to get a uniform shape of compacted billets in a range of 400 kN to 500 kN or otherwise it will lead to low integrity of compacted specimens due to insufficient load apply.

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APPENDEX A1

TASK		W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14
Understanding the problem of the project. Determine the objective and scope	P	■	■												
	A	■	■												
Literature Review	P		■	■	■	■	■	■	■	■					
	A		■	■	■	■	■	■	■	■					
Develop die design for the experiment process procedure	P						■	■	■						
	A								■	■					
Acquisition data for the experiment procedure setup	P							■	■						
	A							■	■						
Preparation of the methodology for experimental procedure	P								■	■	■	■			
	A								■	■	■	■			
Preparation of draft report (Chapter 1-3)	P											■	■		
	A											■	■		
Submission of final year project report 1 (Chapter 1-3)	P													■	
	A													■	
Final year project presentation 1	P														■
	A														■

Figure 6.1: Gantt chart for Final Year Project 1

APPENDIX A2

TASK / WEEK		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Production of aluminium chips using turning machine	P	■	■													
	A	■	■													
Production of die set for compaction process	P		■	■												
	A		■	■												
Perform the cold compaction operations	P				■	■	■	■								
	A				■	■	■	■								
Perform hardness test on the actual extruded casting billet	P							■	■							
	A							■								
Analyze the compacted billet	P							■	■							
	A							■	■							
Data collection	P							■	■	■						
	A							■	■	■						
Result analysis and discussion	P										■	■	■			
	A										■	■	■			
Final report preparation	P											■	■	■		
	A											■	■	■		
Submission of draft report	P														■	
	A														■	
Final year project 2 presentation	P															■
	A															■
Submission of final year project report	P															■
	A															■

Figure 6.2: Gantt chart for Final Year Project 2

APPENDIX B1

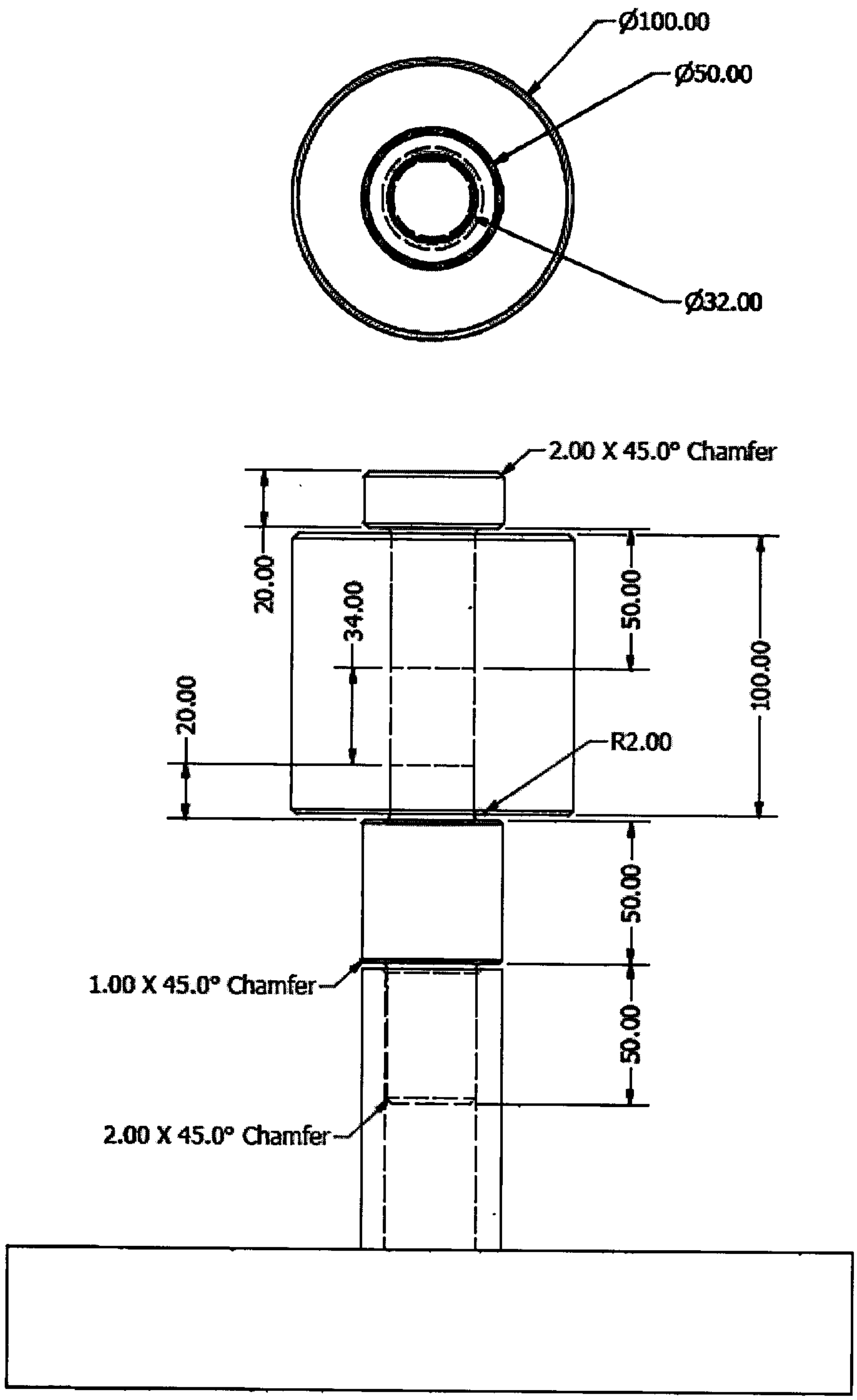


Figure 6.3: Schematic drawing of die device assembly

APPENDIX B2

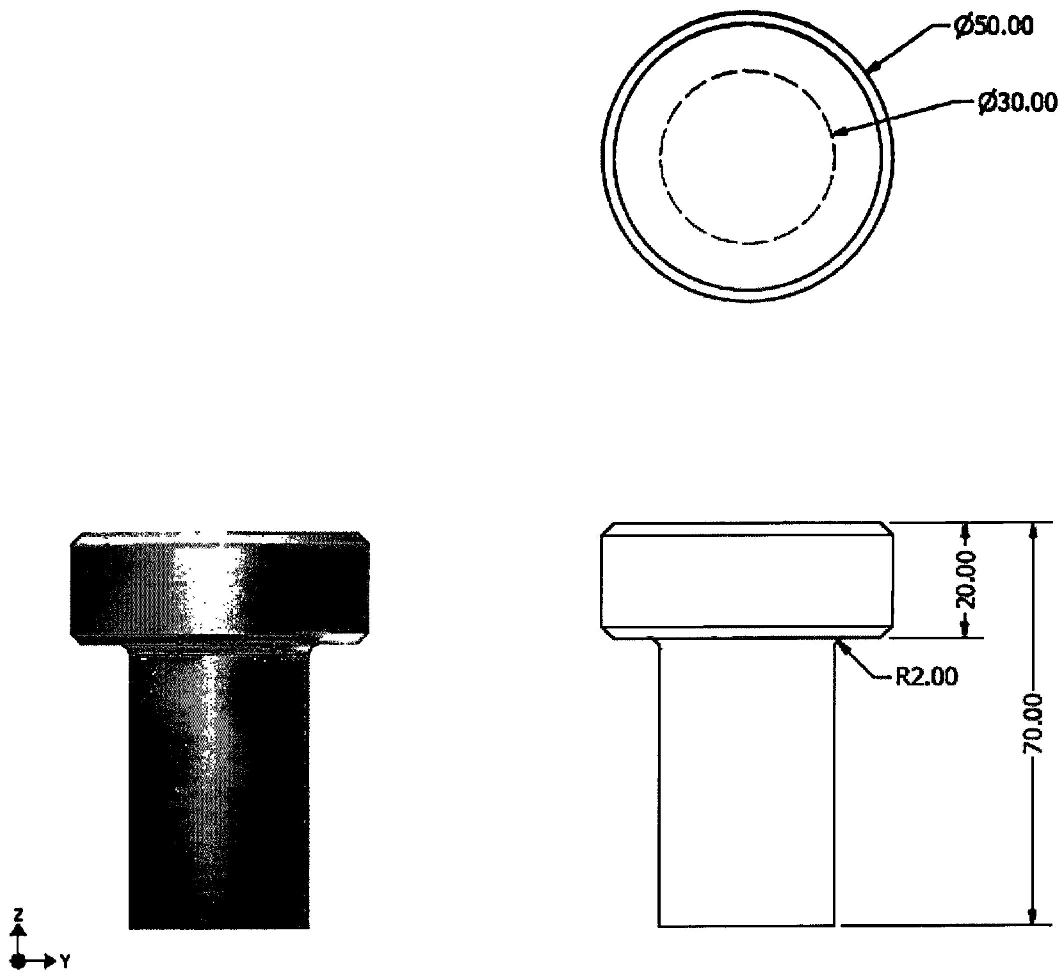


Figure 6.4: Dimension of punch die

APPENDIX B3

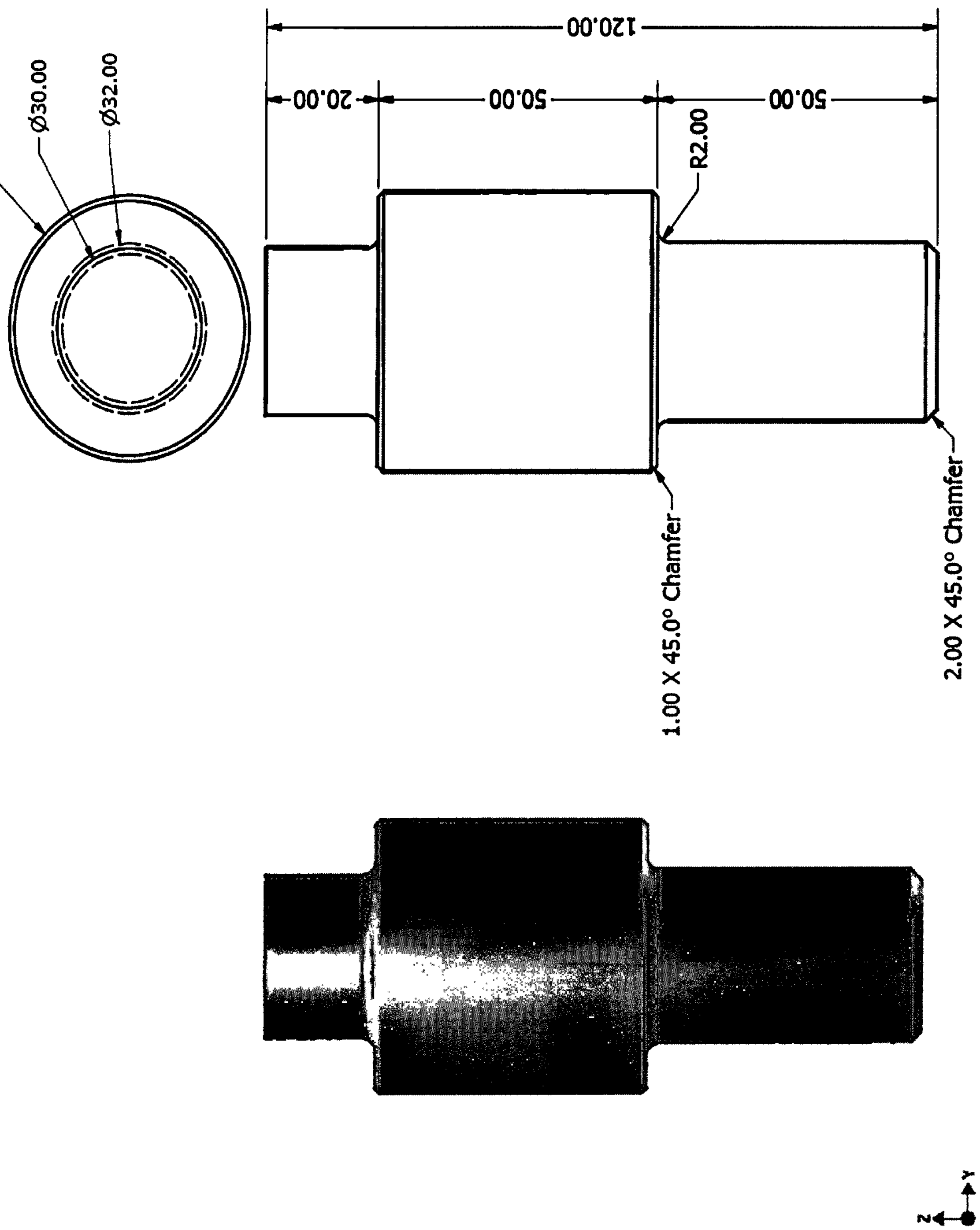
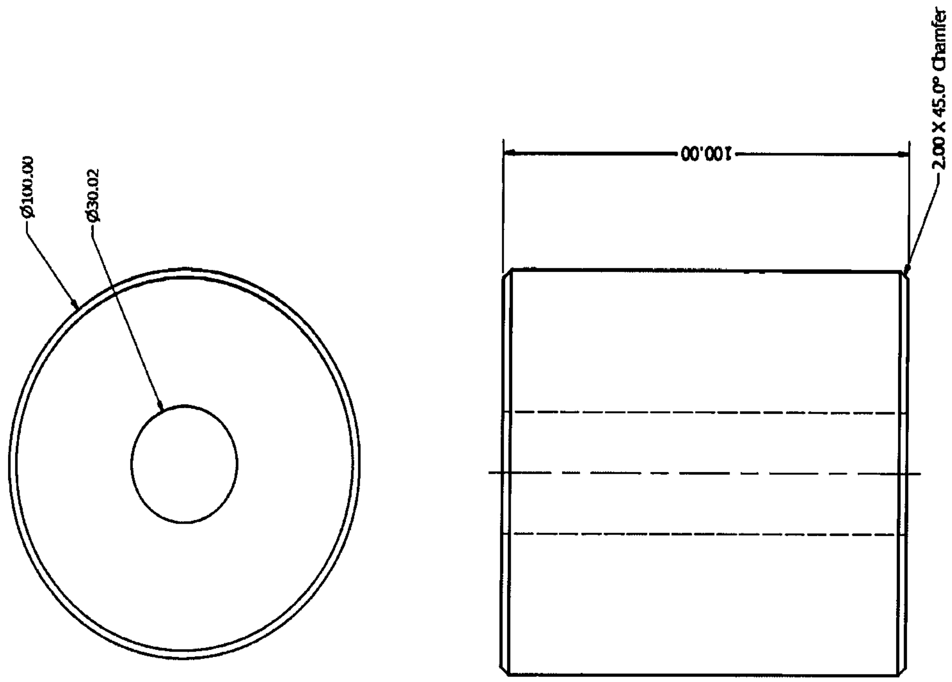


Figure 6.5: Dimension of die base

APPENDIX B4



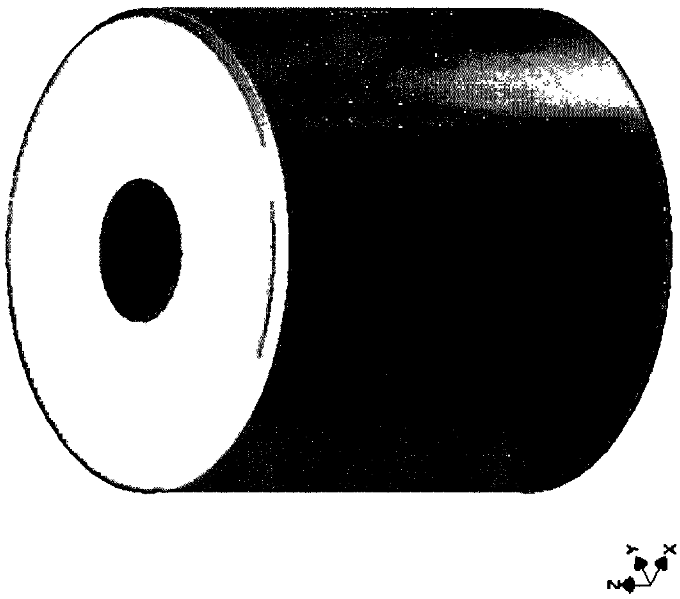


Figure 6.6: Dimension of die cylinder