EFFECT OF HOT PRESS FORGING PROCESS ON DIFFERENT CHIP SIZE, PRE-COMPACTION CYCLE, AND HOLDING TIME IN DIRECT RECYCLING OF ALUMINIUM ALLOY AA6061

SITI SALWA BINTI KHAMIS

A thesis submitted in
fulfilment of the requirement for the award of the
Degree of Master of Mechanical and Manufacturing Engineering

Faculty of Mechanical and Manufacturing Engineering
University Tun Hussein Onn

AUGUST, 2015

To my beloved family and friends,

And if whatever trees upon the earth were pens and the sea (was ink to write), with seven seas behind it to add (supply), yet the word of Allah would not be exhausted. Indeed. Allah is All Mighty and All Wise.

[Luqman: 27]

ACKNOWLEDGEMENT

In the name of Allah, the Most Merciful and the Most Gracious. Alhamdulillah, all praises to the almighty Allah S.W.T for His blessings which has giving me patience, strength and ability to complete this thesis. My highly appreciation and respect to my supervisor Assoc. Prof. Dr. Mohd Amri Lajis for his exceptional guidance, continuous support and encouragement throughout this research. Thank you for the valuable recommendations, ideas and advice which contributed immensely to the successful completion of this research work.

A special thanks to my family especially to my husband, my mother, mother-in law and father-in-law, for all of the sacrifices that you've made on my behalf. Your prayer for me was what sustained me thus far.

I would also like to thank all of my friends who supported me in writing, and motivated me to strive towards my goal especially to PhD's student Nur Kamilah Yusuf who always guide me throughout completing this research. Not to forget to my understanding and supportive roommate, Ainorhayat Hamidon.

Heartfelt appreciation to main financial support, the Ministry of Higher Education (MOHE), Malaysia for funding every semester registration fees under MyMaster MyBrain15 programme. Also the additional funding support provided from the Fundamental Research Grant Scheme (FRGS) for one and half years of my research.

Last but not least, the technical staff, Mr Mohamad Faizal Jasman, Mr Zahrul Mr Hisham Othman, Mr Mahyan Nasoha, Mr Yaacub Zaki Ali, Mr Mohd Tarmizi Nasir, and Mr Anuar Ismail whom has helped me in completing this research. At the end, deeply gratitude expressed to every person involved to the successfully of this project whose not been mentioned here, may Allah blessed us all.

ABSTRACT

A new approach of solid-state direct recycling metal chip was examined scientifically by applying hot press forging process technique. The study is to determine the effect of different chip sizes (*S*), pre-compaction cycle (*PCC*) and holding time (*t*) on the mechanical and physical properties of the recycled chip of AA6061 aluminium alloy in hot press forging process. Full-factorial design coupled with response surface methodology (RSM) design was used based on the face centred, central composite design (CCD) to evaluate the effects of three main parameters as mentioned above. The mechanical properties of recycled chips were determined by measuring the ultimate tensile strength (UTS) and yield strength (YS) whereas the physical properties were studied by examining the microhardness, microstructure, and the relative density of the recycled chip. Finally, both results of mechanical and physical properties of the recycled chips were compared with the original AA6061 aluminium billet. The experimental results indicates that, hot pressed AA6061 recycled aluminium alloy using chip size (*S*=larger), pre-compaction cycle (*PCC*=4 times), and holding time (*t*=120 minutes) produced the higher value of UTS and YS at 122.33 MPa and 120.45 MPa respectively, which is 42% of as-received billet. It was also found that larger *S* used with higher number of *PPC* and longer the *t* will produce better mechanical and physical properties of the recycled AA6061 chip where *t* has most influential effect throughout the process followed by *PCC*, and *S*. Those results were supported by RSM optimization technique giving 98% of desirability index as both solution predicted was close to the experimental value of the reference specimen. Therefore, this study can be used as an alternative technique for recycling aluminium chips instead of conventional method which it has been carried out below the melting phase temperature.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

A	Factor 1-Chip size
Adeq precision	Adequate precision
Adj R^2	Adjusted R2
B	Factor 2-Precompaction
C	Factor 2-Pre-heating time
CCD	Central composite design
Cor total	Totals of all information corrected for the mean
DOC	Depth of cut
DOE	Design of experiment
f	Feed per tooth
HSM	High speed milling
N	Rotational per minute
OM	Optical Microscope
PCC	Pre-compaction cycle
Pred R^2	Predicted R^2
Prob>F	Proportion of time or expected to get the F value
R^2	Coefficient of determination
RSM	Response Surface Methodology
S	Chip sizes
t	Holding time
UTS	Ultimate tensile strength
V_c	Cutting speed
YS	Yield stress
D_e	Experimental density
D_r	Relative density
D_t	Theoretical density

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

There has been a lot of discussion about global warming. Many people talk about the pollution but do not concern about it. For instance, human activities make them pour billions of tons of new carbon dioxide (CO_2) into the atmosphere every day. Uncontrolled of human activities that leaves CO_2 emissions can cause of atmospheric warming which is spreading a dangerous gas with toxic although it is odourless and colourless. The pollution does not only give detrimental effects on the environment but even worse to our health. Research done by many scientists shown that worldwide levels of the chief greenhouse gas that causes global warming have hit a milestone, reaching an amount never before encountered by humans (Borenstein, 2013). CO_2 was measured at 400 parts per million at the oldest monitoring station in Hawaii which sets the global benchmark. The last time the worldwide carbon level was probably that high was about 2 million years ago (Tan, 2013).

Carbon emission is produce from many humans and animals activities. Solid waste comprised of municipal garbage and waste sludge gives various poisonous gases resulting from the combustion process. The open burning, forest fires and heating material or melting metal process cause poisons residue gas spread to the air. While it has long been known that carbon emission contribute to climate change, the new study details how for each increase of 1 degree Celsius caused by CO_2. The resulting air pollution would lead annually to about a thousand additional deaths and many more cases of respiratory illness and asthma in the United States, according to the paper by Jacobson (2008), a professor of civil and environmental engineering at Stanford. Worldwide, upward of 20,000 air-pollution-related deaths per year per degree Celsius may be due to this greenhouse gas (Bergeron, 2008). Therefore, the dangerous situation should be an alarm for every one of us.

Nature of recycling must be adapted to all of us in order to reduce the pollution. In fact, European Union proved that the spread of poisons gas in the air will damage the lungs and skin and in long term can cause cancer. From all the percentage above, recycling should be most importance activity in order to save humans and every living thing in this world. The global warming issue is discussed since and every then throughout life. More than 1 ton of CO_2 released for every ton of aluminium produced (Peter, 2008). In fact, many of us noticed that recycling can help to reduce the greenhouse gas emissions, but still, not many of us do recycling.

Bethany (2012) in his article mentioned recycling aluminium would help reduce carbon footprint. Increasing environmental awareness and growing social responsibility have also driven the recent upsurge in aluminium recycling. Recycling aluminium prevents more than 90 million tons of CO_2 from being release into the atmosphere each year. Recycling a single aluminium can avoids CO_2 emissions equivalent to a one-mile car ride and saves enough energy to power a television for about three hours. Putting lightweight, recycled aluminium into cars makes them lighter and more efficient, as well. In 2002, the average car contained 220 to 265 lbs. of aluminium. As of 2011, cars contain an average of 265 to 330 lbs. of aluminium. Lighter, more efficient cars save fossil fuels. For that reason, aluminium needed to be recycled as the demand increasing and to prevent the shortage of the primary sources of aluminium that cause expensive cost of operation. Besides, it concern for protecting the environment too.

Currently, the machining chips discharged from various factory machine tools is directly discarded or re-melted after being retrieve by scrap metal dealers for recycling into ingots or die-casting products (Chiba *et al.*, 2011). However, the recycling efficiency of metal scrap, including machining chips, is very low in existing recycling processes. For example, Lazzaro and Atzori (1992) showed that the metal yield rate in the conventional recycling of aluminium scrap is approximately 55%. A portion of the metal loss, including the dross formed during the re-melting process, is land filled. Because the mixing of non-metal inclusions with molten metal cannot be avoid during the re-melting stage, the purity of recycled ingots reducing, resulting in a degradation of their mechanical properties. Moreover, the re-melting process consumes a large amount of energy, e.g., 16–19

GJ/t for aluminium (Gronostajski *et al.*, 2000), and is therefore unfavourable from an economic standpoint.

Several studies on solid-state recycling processes, that is, the direct recycling of machining chips into the bulk materials using severe plastic working without re-melting, has recently been conducted for the purposes of improving recycling efficiency, energy use and expense. Through the uses of plastic working processes such as extrusion and rolling, which can be use to recycle scrap materials with microstructural control, machining chips can be recycled into materials with excellent mechanical properties. In addition, energy conservation is possible when recycling metals using these processes; Gronostajski *et al.* (2000) estimated that for aluminium, a reduction in energy use of about 70% is possible compared to the existing melting method. Consequently, these processes have considerably lower recycling costs. They are also better for the environment because their yield rate for recycled products is quite high. For aluminium, Lazzaro and Atzori (1992) to be more than 95% estimated the yield rate.

A great majority of existing studies aimed at recycling machining chips into round bars or plates using hot/warm forward extrusion at the appropriate below melting temperatures (Chiba *et al.*, 2011). There have been a limited number of studies on the recycling of aluminium scrap employing severe hot press forging technique. Katsuyoshi *et al.* (2002) hot forged AZ91D magnesium alloy after it was cold pressed and showed that the values after hot forging are superior to the as-cast AZ91D alloy and hot forged AZ91D alloys produced from the wasted chips has a good metallurgical bonding between primary particle boundaries. Whereas, Sayed *et al.* (2011) hot forged AlSi alloy using powder particles to explore the powder metallurgy route of the metal alloy when it is forged. The study indicates that hot forging process shows the best microstructure, largest densities and giving strongest material. However, there are still not yet discover aluminium scrap as the material investigated and it still needed for further studies on hot press forging technique.

The demand for aluminium products is growing steadily because of their positive contribution to modern living. Aluminium is the second most widely used metal whereas the aluminium can is the most recycled consumer product in the world. Aluminium finds extensive use in air, road and sea transport; food and medicine; packaging; construction; electronics and electrical power transmission. The excellent recyclability of aluminium, together with its high scrap value and low energy needs during recycling make aluminium highly desirable to all. The global aluminium demand forecasted to soar to nearly 70 million tons by 2020 from around 37 million tons currently. The contribution of recycled metal to the global output of aluminium products has increased from 17 % in 1960 to 34 % today, and expected to rise to almost 40 % by 2020. Global recycling rates are high, with approximately 90 % of the metal used for transport and construction applications recovered, and over 60 % of used beverage cans are collected (Salman, 2012). The standard structural alloy AA6061 is one of the most versatile of the re-treatable aluminium alloys that is popular for medium to high strength requirements and has good toughness study characteristics. Applications range from transportation components to machinery and equipment applications to recreation products and consumer durables. Alloy 6061 has excellent corrosion resistance to atmospheric conditions and good corrosion resistance to seawater. Yusuf *et al.* (2013) studied on a method of solid-state recycling aluminium alloy using hot press forging process and the possibility of the recycled chip to be use as secondary resources. The paper presents the results of recycled AA6061 aluminium alloy chip using different operating temperature for hot press forging process. The result of the recycled specimens shows a good potential in the strength properties. As well as Lajis *et al.* (2013), that discussed on the effect of different chip sizes and operating temperature in recycling the AA 6061 aluminium chip.

1.1 Background of study

The study introduces new approach of direct recycling using the hot press forging process that eliminates the two intermediate processes of cold-compact and pre-heating. The recycled specimens exhibit a remarkable potential in the strength properties where it increase with increment of total surface area of chips. The present study investigated the possibility of recycling AA6061 aluminium alloy machining chips using hot press forging technique. After milling the chips, it was direct-recycled by hot compacted into dog bone shaped, the mechanical and physical properties was then examined and compared with the original AA6061 aluminium billet. Finally, the possibility of solid-state recycling of aluminium alloy machining chips at room temperature discussed.

Aluminium alloy AA6061 that has been most widely used in the category of the 6000 Series chosen as a material investigated in this study. The scope of this study introduces the direct technique for recycling aluminium chips instead of conventional method, which carried out without melting phase. Hot press forging technique characterized by lower number of steps and gives benefit on low energy consumption and operating cost. It could elaborate technological process details and a systematic characterization of hot forged profiles properties for the recycled of AA6061 aluminium alloy chip of different geometries and have shown the technological potential regarding yield behaviour and microstructure. It will reveal the performance of recycled aluminium chip on their mechanical properties and microstructure by comparing them with the original aluminium-base composite. Moreover, it is expected that to review the possibility of this recycled aluminium chip as a secondary resources as an alternative to overcome the shortage of primary resources in which it utilizes the metal optimally and able to lower the usage of raw metal. Furthermore, it will help to reduce the land use for mining and provides very low air pollutant emission. This will be an initiative to machining practitioners and industry as a way to support our government on green technology and waste management activities.

1.2 Problem statement

AluminiumAA6061 has outstanding applications. However, primary resources have become shortage day by day and an alternative for secondary resources is needed in order to overcome it. In fact, in conventional recycling there are more metal loses due to oxidation, high in management cost and high-energy consumption and high carbon emission.

Aluminium chips produced in the machining laboratories followed the industrial machining practitioners will be collected from industries before it is re-melting and again reform in the billet shape as recycled chip aluminium. In industries, usually the chips produced in very small sizes and sometimes in a spiral form according to the machining parameter used. A smaller chip thickness has larger surface area, therefore higher amount of aluminium oxide need to be dissolve. Chips sizes produced after machining is too small that contain high percentage of aluminium oxide. In addition to that, it is very difficult to recycling chips due to its shape and size. The chips may be covered with oil emulsion that not suitable for conventional recycling through re-melting approach. Waste AA6061 chips in spiral form can cause void and may give defects to the recycle material.

Instead of void appearance cause by compacted of the different chip sizes, the main issue in direct aluminium chips solidification is the layer of aluminium oxide (alumina) that forms on aluminium surface. The aluminium chips has a unique combination of problems such as high surface area, severe inter-particle friction and has very hard layer forms almost instantly after exposure to oxygen about 4 nm thick. The difficulties of consolidation process when aluminium chips are exposed to high temperature during the forging process. In order to crack alumina and obtain good solidification, several pressed cycled imposed on chips are needed to ensure that no decomposing of chips takes place. Compressive deformation with suitable loads and right pre-heating temperature during the forging process may help in eliminating the void. Therefore, several times of compaction may give opportunity of obtaining extremely dense compacts product with superior mechanical and physical properties.

In addition to that, pre-compaction cycle is not enough to have good consolidation of the aluminium chips. Aluminium chips cannot merge each other due to each chips having own interface that need to be break by heating. Leaving the material in the furnace for some time required to soften the material before the press forging process and produce excellent bonding due to recrystallization during the pressing. Holding time or so called time the material soaking also needed, as it is one of the factors that affect final properties of alloy to minimize the coarsening microstructure and recovery of matrix to make sure the overall interface of each chip become thoroughly melt so they can grip firmly each other.

1.3 Purpose of study

The main specific objectives in this study are includes such as following:

i) To determine the effect of different chip size (*S*), pre-compaction cycle (*PCC*) and holding time (*t*) on the mechanical and physical properties of the recycled chip of AA6061 aluminium alloy in hot press forging process with the following outcomes:

a) Ultimate tensile strength (UTS) and yield stress (YS)

b) Subsurface layer changes consist of microhardness

c) Microstructure analysis includes grain size, grain boundary, voids, phase transformation, etc.

d) Relative density

ii) To make comparison and recommendation based on mechanical and physical properties between recycled and as-received AA6061 Aluminium alloy billet.

iii) To estimate the significance of recycling parameters to the performance of mechanical properties such as UTS and YS by employing response surface methodology (RSM).

1.4 Scope of study

The scopes of this study are focused on the following points:

i) Using AA6061 aluminium-base composite chip (from high-speed end milling) and as-received AA6061 aluminium-base composite billet (reference) for comparison.

ii) Running high speed end milling (Sodick-MC430L) machine to produce three different chip size with the following parameters and conditions:

   a) Tool: 10.0 mm 2 flute diameter uncoated solid carbide
   b) Dry cutting operation without coolant
   c) High cutting speed: 1100 m/min
   d) Depth of cut, DOC: (0.50, 1.00, 1.50) mm
   e) Feed, f: (0.02, 0.05, 0.10) mm/tooth

iii) Conducting the solid-state direct recycling techniques of aluminium alloy by utilizing hot press forging process with constant operating temperature and pressure of 480^{o}C and 15 tonnes respectively based on the following parameters and conditions:

   a) Three different pre-compaction: (2, 3, 4) cycle
   b) Three different holding time: (60, 90, 120) minute
   c) Three different chip size: (small, medium, large)

iv) Examining the responses on mechanical and physical properties as below:

   a) Ultimate tensile strength (UTS) and yield strength (YS) using Universal Testing Machine

b) Microstructure analysis including grain size, grain boundary and voids, using Optical Microscope (OM)
c) Subsurface layer changes consist of microhardness using Vickers Hardness Tester
d) Relative density of the recycling AA6061 using Density Weight Balance

1.5 Research contribution

Direct recycling hot press forgings is a new approach proposed as an alternative recovery for secondary aluminium resources since the aluminium demand is keep increasing. The process also helps prevent global warming as well as supporting the government in the solid waste management. This effort can be describe as a sustainable manufacturing because the process did not leave any harm effects to the environment, conserve energy and natural resources and it is very economical. Therefore, direct recycling is very important in order to make sure everything is under the sustainable condition even the development of the country run smoothly. Usually, chip sizes of aluminium produced after machining is too small and in spiral form, which contain high percentage of aluminium oxide (alumina) that cause void and may give defect to recycled material. In order to establish the influence of chip geometry on the final density of billets, different types of chips were cut by using various milling regimes. The layer of alumina that forms on aluminium surface is the main issue in direct aluminium chips solidification. Several pressed cycled (pre-compaction) imposed on chips needed to crack alumina and obtain good solidification, ensures no decomposing of chips takes place. Finally, the aluminium chip cannot merge each other due to each chips having own interface that need to be break by heating. Therefore, holding time needed before pressing the chips for excellent bonding due to recrystallization during the pressing.

1.6 Significance of study

All manufacturing aluminium products involve the first step obtaining raw materials from bauxite mining. Alumina that extracted from the bauxite will go through electrolysis process to produce primary aluminium and finally will be use in the manufacturing process producing aluminium product. That entire route needs transportation, which is for sure an energy consuming process. The processes not just costly but causes global warming and pollution to the earth.

This study is very significant in order to minimize the harmful effects of producing the primary aluminium so that energy consuming and cost of production will be decreased, at the same time helps reduce global warming and pollution.

Solid-state direct recycling techniques of aluminium will lower the energy consumption and lesser the cost of production. Hot press forging chosen as a process, which can decrease the potential air pollution, compared to the conventional and semi-solid-state recycling technique of aluminium. It is a simple metal forming process that ignoring any metallurgical process involved.

Hence, hot press forging could be one of the alternative metal waste recycling processes, which contribute to a sustainable manufacturing process technology in the future. The utilization of primary metal could be fully utilized by direct recycling technique introduced in this study and at the same time developing a sustainable manufacturing process technology.

CHAPTER 2

LITERATURE REVIEW

This chapter is mainly focused on the literature review which is very important chapter that provide a justification of the proposed research project. The main purpose of the literature review chapter is to review and identify gaps and problems while at the same time to classify the rational for doing the proposed study on what has been or partly been researched before. Firstly, recycling in general and it benefits which is based on the literature reviewed will be discussed to show the overall view of the importance of recycling to be implemented these days. Then, the chapter briefly explains on the recycling aluminium, the process available to recycle the aluminium and what is the best recycling process and technique chosen in particularly of aluminium AA6061. Finally, the last section discusses the summary of overall view throughout literature reviewed to give the clear picture about this study.

2.1 Recycling in general

Recycling is a process of collecting materials and undergoes certain process that turning them into new products. It is also allow saving money in addition to keep the Earth clean, so the materials would not easily be thrown away as trash after it is been used. Pearsall (1999) defined recycle as convert waste into reusable material to used it again or return material to a previous stage in a cyclic process. Provided, recycling turns trash into valuable resources (Wilcox, 2008).

2.1.1 Recycling process

Jedlicka (2010) highlighted three major steps in the recycling process that recognized around the world. Moreover, Frampton & McPoland (1998) mentioned that the three chasing arrows in the recycling symbol reflect the three elements of the recycling system-collection, processing and buying recycled content products. The three chasing arrows are to tell that there are three main steps to recycling materials.
Basically, in recycling materials there are three main steps which are:

1. Separating and collecting recyclable materials
2. Processing and manufacturing these materials into new products
3. Purchasing and/or using recycled products

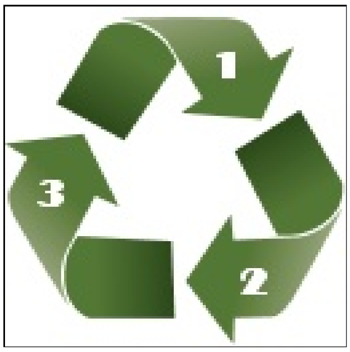

Figure 2.1: The three steps combination of recycling process

While there are several companies created and use their own unique recycling symbols specific to their industries and having their own trademark, but most of them understand and used of three chasing arrows as the basis of their design. Therefore, public and the whole world are aware that they are a recycling company.

As long as people understand that the combination of these three steps are creating a continuous loop represents the recycling process as a whole.

2.1.2 Benefits of recycling

Aluminium recycling is so important. Pendergrast (2011) asserts that people do not think about trash very often, but it is a major issue for humanity to deal with. People do not really know how much of it is actually trash, where do exactly they put their trash and to manage it properly without having damaging effects on the environment. Recycling is one of the best solution and answer for those questions obviously.

Schlesinger (2007) highlighted the benefits of aluminium recycling clearly. According to him, production of aluminium from ores requires considerable inputs of energy. Energy requirements to produce primary aluminium can be seen in Figure 2.2. Rombach (1998) stated that most of the energy used is due to the molten salt electrolysis of alumina. Fossil fuel is required to produce the carbon electrodes and re-melt the ingots produced by electrolysis, and large inputs of electrical energy are required to overcome the resistance of the electrolyte and break down the dissolved alumina in the bath. The 113GJ per metric tonne described in Figure 2.2 is that used in the production of alumina metal itself; when inefficiencies in the production of electricity are factored in, total energy consumption rises to 174 GJ/tonne. Direct energy usage in the production of secondary (recycled aluminium) is much smaller as in Figure 2.3. The largest energy user is the melting step, which can be done using either fossil fuel or electricity. In either case the direct energy use is reduced by 88% from that required to produce primary aluminium. If electrical generation inefficiencies are figured in, total energy consumption per tonne of secondary aluminium increases to 20GJ; this too is 88% lower than that needed for primary aluminium proved that much energy can be save.

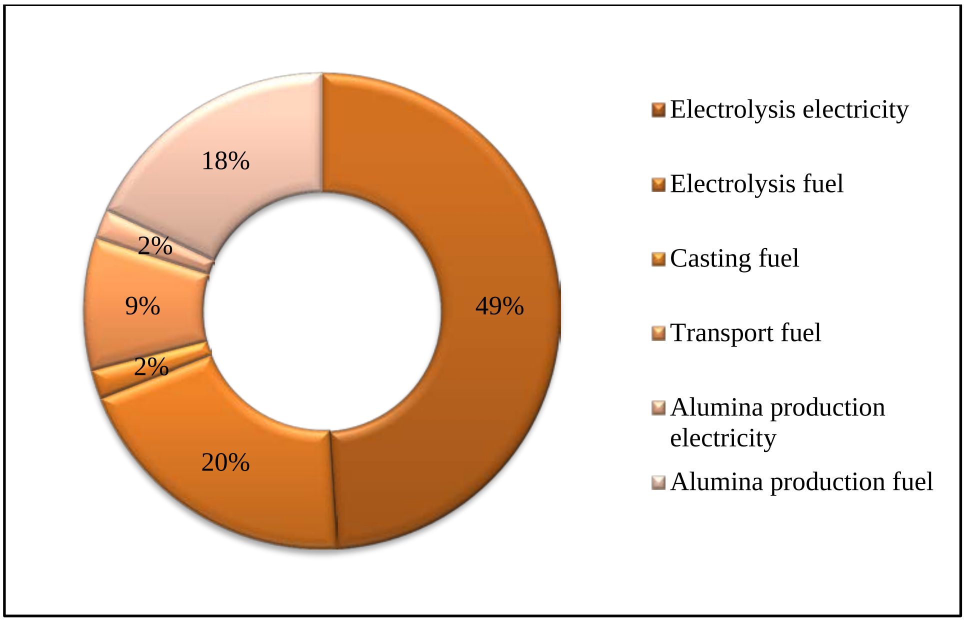

Figure 2.2: Energy requirements (113 GJ total per metric tonne) for the production of primary aluminium (Rombach, 1998)

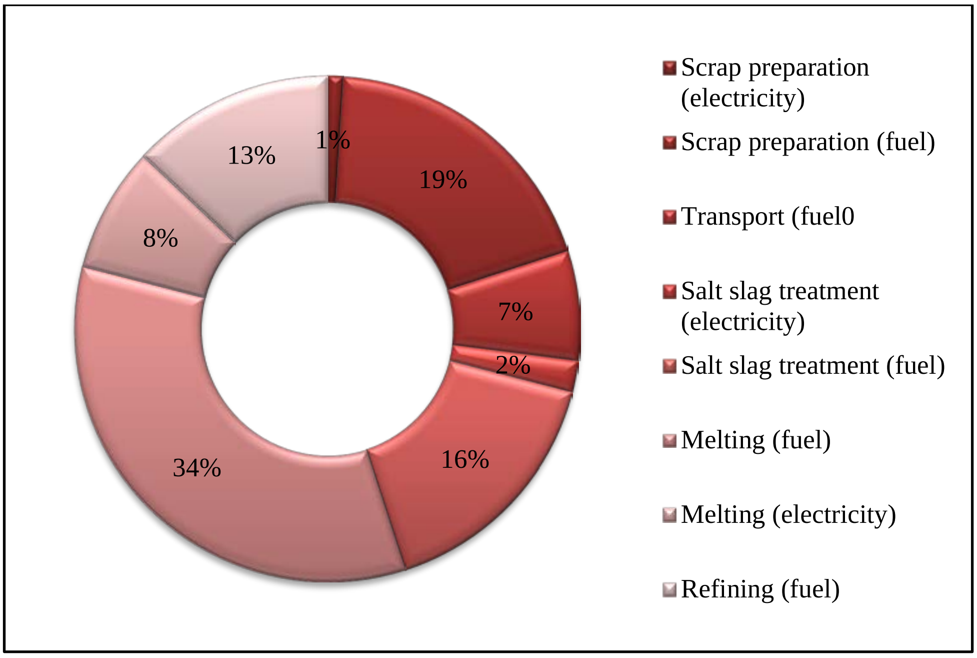

Figure 2.3: Energy requirements for the production of aluminium scrap (13.6 GJ/tonne total) (Rombach, 1998)

Recycling is very important in order to reduced waste disposal. Primary aluminium production generates solid waste at every step in the process. The most significant of these are mine wastes; the red mud residue created during alumina purification, and spent pot liner from the electrolytic cells (Wolf and

Hoberg, 1997). While, aluminium recycling generate solid wastes as well (primarily the dross and salt slag created during re-melting), the volumes are much smaller. European estimates suggest that the mass of solid waste generated per tonne of recycled aluminium is 90% lower than that for primary metal (Martchek, 1997). Lave *et al.* (1999) estimate that recycling aluminium reduces hazardous waste generation by over 100kg per tonne of metal produced.

Emissions can be reduced when aluminium is produced by recycling rather than by primary production from bauxite ores. Primary aluminium production generates both hazardous (fluorides, sulphur dioxide) and nonhazardous (carbon dioxide) emissions. While aluminium recycling presents its own air-quality challenges, the numbers are again much reduced. The amount of CO_2 and total air emissions are both reduced by over 90% per tonne when aluminium is produced by recycling rather than primary processes (Martchek, 1997).

Recycling aluminium reduced capital cost. Primary aluminium production requires a mining operation, a Bayer Process plant to produce purified alumina, and an electrolytic pot line to extract aluminium metal from the alumina. The capital equipment used for recycling is less complex and thus less expensive. A 1976 estimate suggests that producing aluminium by recycling rather than by primary methods reduces capital cost per tonne by 80 to 85% (Mahi *et al.*, 1990).

Incinerator system become more popular nowadays since so much solid waste produced by society per day making less space to dispose the waste in the landfill. The waste will be directly incinerated rather than segregated according to material type to recycle it. This cross cut action will effected clean environment and cause pollutions. Collecting used materials can reduces incinerators and lesser the amount of waste sent to landfills in order to conserves the natural resources. At the same time it helps sustain the environment for future generations. Instead of saves energy consumption, the need to collect new raw materials can be reduces and lesser greenhouse emissions that contribute to global climate change. It will also create employment opportunities for people if recycling is practiced in the country.

2.2 Overview of aluminium recycling

Aluminium is a sustainable metal that can be recycled over and over again. Raw aluminium from bauxite extraction is generally will go to the primary smelting through alumina refining. After went through some manufacturing processes, people will consume the aluminium until it becomes waste. The aluminium waste is then recycled and turned into a new product.

Martchek (2000) mentioned that significant to the life cycle profile of metal products is recent confirmation that recycling has the potential to reduce the materials production energy consumption by 95% for aluminium. Green (2007) supported the statement by reported that recycling of aluminium is vitally important to the sustainability of the aluminium industry. In fact, as the life cycle and sustainability studies indicate that recycles of aluminium saves about 95% of the energy used as compared to making the metal from the original bauxite ore and scrap aluminium requires only 5% of the energy used to make new aluminium. For this reason, approximately 31% of all aluminium produced in the United States comes from recycled scrap (minerals.usgs.gov, 2007).

Schlesinger (2007) listed the successful recycling of aluminium that only is effective due to the several main factors. Most importantly, a plentiful and recurring supply of the metal, concentrated sufficiently in one area to justify the cost of collecting it. In line with it, a mining infrastructure for collecting the scrap metal, removing impurities, and delivering it to a recycling facility. A well recycling aluminium process must have a method for recycling the metal that is economically competitive with production of the metal from primary ores and finally, a market for the recycled metal, should its composition or quality differ from that of primary metal.

2.2.1 Recycling aluminium alloy 6061

Aluminium alloy 6061 (AA6061) is having general characteristics and uses. AA6061 is an excellent joining metal with a good acceptance of applied coatings. It is widely available hence have relatively high strength, good workability, and high resistance to corrosion. The AA6061-T8 and T9 tempers offer better chipping characteristics over the T6 temper and has a density of 2.70 g/cm^3 (0.0975 $lb./in^3$).

Table 2.1: The alloy chemical composition of AA6061(ASM Aerospace)

Composition	Maximum	Minimum
Silicon	0.4%,	0.80%
Iron	0	0.70%
Copper	0.15%	0.40%
Manganese	0	0.15%
Magnesium	0.80%	1.20%
Chromium	0.04%	0.35%
Zinc	0	0.25%
Titanium	0	0.15%
Other elements	0.05%	0.15%
Aluminium	95.85%	98.56%

AA6061 commonly available in pre-tempered grades such as 6061-O (annealed) and tempered grades such as 6061-T6 (solutionized and artificially aged) and 6061-T651 (solutionized, stress-relieved stretched and artificially aged).

Magnesium and silicon are the major alloying elements inside the AA6061. The two majoring elements have excellent mechanical properties and in fact exhibit good weldability. For that reason, AA6061 is chosen as one of the most common alloys of aluminium for many applications such as in fitting of marines, aircraft, cameras, electrical appliances and much more.

AA6061 is easy to be worked and having very high resistant to corrosion even when the surface is abraded. AA6061 is widely used in the construction of valves, hydraulic pistons and aircraft structures. It is used for yacht construction, including small utility boats (Stephen, 1993). Besides, AA6061 is very useful in manufacturing automotive parts, such as wheel spacers and broadly used in the manufacture of aluminium cans for the packaging of foodstuffs and beverages.

Instead of the application of the AA6061 in manufacturing process, it has highly weldable characteristics. According to Finch (2005) typically, the properties near the weld are those of 6061-O, a loss of strength of around 80% after welding. The material can be re-heat-treated to restore -T4 or -T6 temper for the whole piece. After welding, the material can naturally age and restore some of its strength as well.

Meanwhile, a notable use of weldable 6061-T6 aluminium is in the crew compartment of the United State space shuttle. In order to pressurize a compound-curved structure the size of the space shuttle, welded seems in 6061-T6 aluminium were selected as the best way to achieve a strong, leakproof structure. Therefore, AA6061 aluminium is shown as a good choice for weldable material.

Forging process needed for malleable material in order to be easily worked during the pre-heating to make sure the metal follow the shape of the die. Therefore, AA6061 is an alloy that is suitable for forging operation especially in hot forging. Whilst, in extrusion, AA6061 will be an appropriate metal in order to have long constant cross-section structural shapes produced where the metal will be far push through a shaped die.

From the review on overall aluminium recycling, the aluminium chips can be recycled in three techniques. There are three main techniques available to recycled aluminium such as by conventional recycling, semi-direct recycling and direct recycling. Figure 2.4 shows a comparison of the basic steps for the three main recycling techniques.

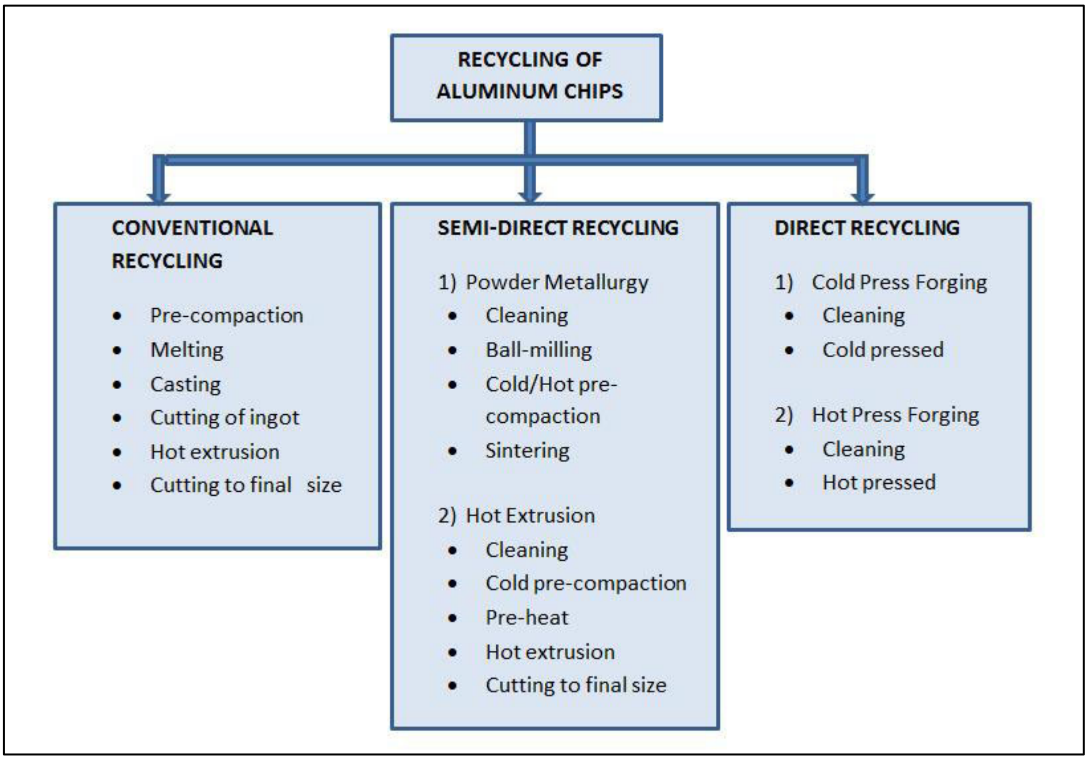

Figure 2.4: A comparison of conventional, semi-direct recycling and direct recycling techniques of aluminium alloy chips

2.2.2 Conventional recycling

Conventional recycling is one of the common ways to recycling aluminium alloy that is widely used in all over the world. It is the most easy and less expensive process that involves crushing or milling and simply re-melting the metal, instead of creating new aluminium through the electrolysis of aluminium oxide (Al_2O_3), which must first be mined from bauxite ore. Green (2007) stated that, when the metal has been separated from its oxide in the smelting process, it can be re-melted and recycled into new products numerous times, with minimal metal losses each time. In line with Schmitz (2006), valuable alloys can be produced in the secondary smelter where in different process steps the aluminium is separated to the most possible extent from the accompanying materials and finally the remaining scrap is melted to get access to the metal for further refining and processing. The conventional aluminium recycling process of chips is carried out with a melting phase as a fundamental step at the same time requires pre-processing of the scrap aluminium to remove impurities. To maintain sufficient purity, the re-melted aluminium can be mixed with pure aluminium produced in a primary smelting plant typically about 50-50 mix. Prior to melting various mechanical, thermal, chemical, and magnetic techniques are used to separate contaminants and non-aluminium materials from the scrap.

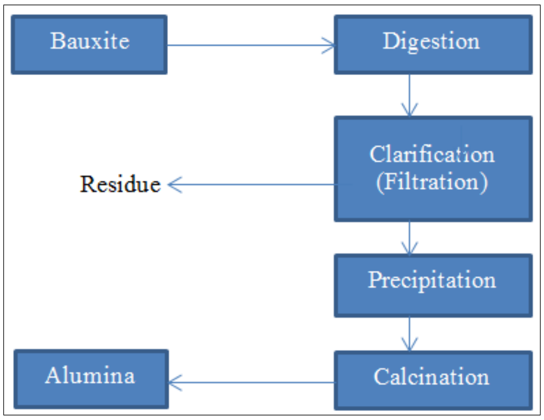

Figure 2.5: Bayer Process

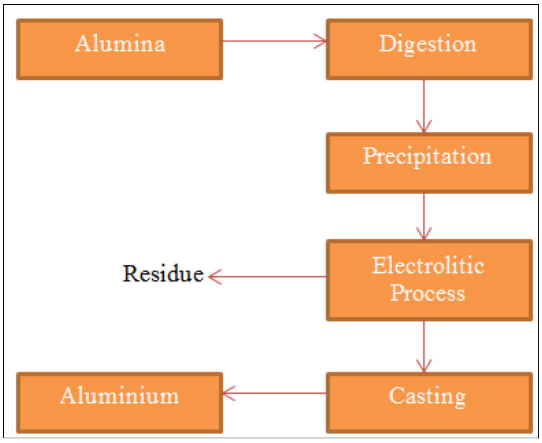

Figure 2.6: Hall-He'roult Process

Aluminium production starts by refining bauxite through the Bayer process, from which alumina is obtained. As in Figure 2.5, refining alumina by the Bayer process leaving residue on the clarification during the filtration before the aluminium can be sent to precipitation process. Then, from the Hall-He´roult process in Figure 2.6, the alumina is electrochemically processed and metallic aluminium is produced (Shinzato & Hypolito, 2005). Due to the metal capacity of becoming oxidized during its fusion, even in the presence of cryolite (Na_3AlF_6), a large amount of residue or dross is generated. Dross resulting from this process usually contains about 80% (wt) of metallic aluminium (Carvalho, 1991), which can be recycled by secondary industries.

Before proceed to the melting process, chips must be cleaned, dried and compacted. Traditionally re-melters use a degreasing fluid to clean the machining fine chips followed by a heating operation to dry it, which often leads to the development of new oxide films. However, there are losses at every stage of the recycling process, such as losses caused by metal oxidation during melting, some losses thought mixing with the slag from the surface of the melt, and the rest are the scraps resulting from casting and further processing of the aluminium ingots (Gronostajki *et al.* , 1997). Not only that, Gronostajki *et al.* (2000) has continued the research and found out, there is about an average of 10% of the metal is burnt and another 10% is lost as the aluminium mixes with the slag removed from the surface of the ladle in the process of melting aluminium and aluminium-alloy waste and scrap. These losses are irreversible and able to reach up to 35% if melting takes place in gas or oil-fired furnaces instead of induction furnace. The main cause of the substantial losses of aluminium and aluminium-alloy waste during conventional recycling is its low density (even after the pressing operation) due to which it stays rather long on the surface of the molten metal and oxidizes intensively. There are further losses during casting such as risers, shrink holes and so on, which reach about 8%. Later, during the processing of aluminium ingots, there are losses amounting to about 18%. Therefore ultimately not more than 54% of the metal is recovered.

Lazzaro and Atzori (1992) analyzed the metal losses in conventional recycling of aluminium turnings. It shown approximately about 45% of the aluminium metal will be either lost or carried into a new scrap phase. Furthermore, high generation of new scrap is about 25% produced during re-melting and needed about 6000 kcal/kg energy consumption. The melting operation is usually performed in high energy consumption fossil fuel rotary furnaces, using up to 20% addition of low melting point salts based in equimolar mixtures of potassium and sodium chlorides to improve de-oxidation, as well as fluorides in the form of CaF_2 and Na_3AlF_6 (Tenorio and Espinosa, 2002). The liquid salts break the oxide structure and transform the oxide net in a great number of small fragments that turn into the shape of plates or small clusters of plates. The aluminium freed from the oxides starts to coalesce generating small drops of liquid that start to coalesce themselves and grow. The oxide-salt reaction generates a by-product, known as “salt-cake” (Gruzleski and Closset, 1990), which is considered a hazardous waste. Almost 800,000 ton of salt cake is annually landfilled in the United States and this number continues to grow with the increase in aluminium consumption, mainly recycled metal (Sreenivasarao *et al.*, 1997). In Europe the landfill disposal of this waste is forbidden because of the slag soluble (Gwinner, 1996). Salts represent a potential source of pollution to surface and groundwater supplies. (Shinzato & Hypolito (2005) concluded that melting techniques generate dangerous residues that require elimination usually at high cost, even some vaporization techniques are arising. As for Samuel (2003), aluminium loss can easily reach 50% and it is in line with Puga *et al.* (2009), at the end, the aluminium loss is very high, making this traditional recovery procedure highly inefficient.

However, there are several treatment to recover the loss of aluminium after the melting process, the liquid metal is degassed and refined using suitable products for each type of alloy, normally TiB_2 and $Al_{10}Sr$ (Gruzleski and Closset, 1990), and poured into metallic moulds. Although melting techniques generates dangerous residues that the re-melting companies must eliminate, usually at high cost, even if some vaporization techniques are arising (Shinzato and Hypolito, 2005), the salt-cake can be eliminated, the liquid metal is degassed and refined using suitable products for each type of alloy, and poured into metallic moulds. So, the addition of other material is needed to be included into the process for the treatment. In addition to that, the research investigated the potential used of the waste which contains non-metallic product (NMP) and salt cake in the production of other useful product. Otherwise, all the waste will be sent to landfill or disposed without treatment that causing many environmental damages as in Figure 2.7. In their research, they found out that the NMP and salts is very useful as one of the important source to accelerate the strength rate development of the concrete blocks when this compound is combined with cement and sand. The commercial use of the so called “waste” can decrease the working time and reduce the amount of discarded wastes, thus contributing to environmental preservation.

Besides, research done by Mashhadi *et al.* (2009) has used salt flux to recover aluminium alloy. From recyclability stand point it is shown that using protective salt flux gave the best route to recycle the aluminium alloy turning scrap, from the point of view of recyclability which is done by cold pressing and melting the compressed aluminium alloy with salt flux. Mechanical properties and chemical analysis of samples were approximately the same as the primary material produced by conventional casting process. Another alternative of melting technique that can preserve the environment was done by Puga *et al.* (2009). Traditionally re-melters use a degreasing fluid to clean the machining swarf followed by a heating operation to dry it, which often leads to the development of new oxide films. The study discovered an environmental friendly aluminium swarf recycling technique avoiding the use of salts during melting, by using induction melting and performing degassing by a novel ultrasonic technique. Those techniques and procedures are the major advantages in the current industrial practice. In order to attain considerable decreasing into manufacturing costs, the final recovered product is introduced in the production cycle together with remaining raw materials. The result shows that the recycling efficiency depends on the swarf conditioning for melting, the melting technique and the metal treatment methodology. Chips moisture reduction, induction melting under protective atmosphere and a specially developed degassing technique were found the most important factors influencing the recycling process. By using the developed technique, cast ingots with microstructure, sanity and chemical composition similar to commercially available melt raw material were successfully obtained with minimum dross formation and metal recovery rates around 90%, without using traditional salts and fluxes.

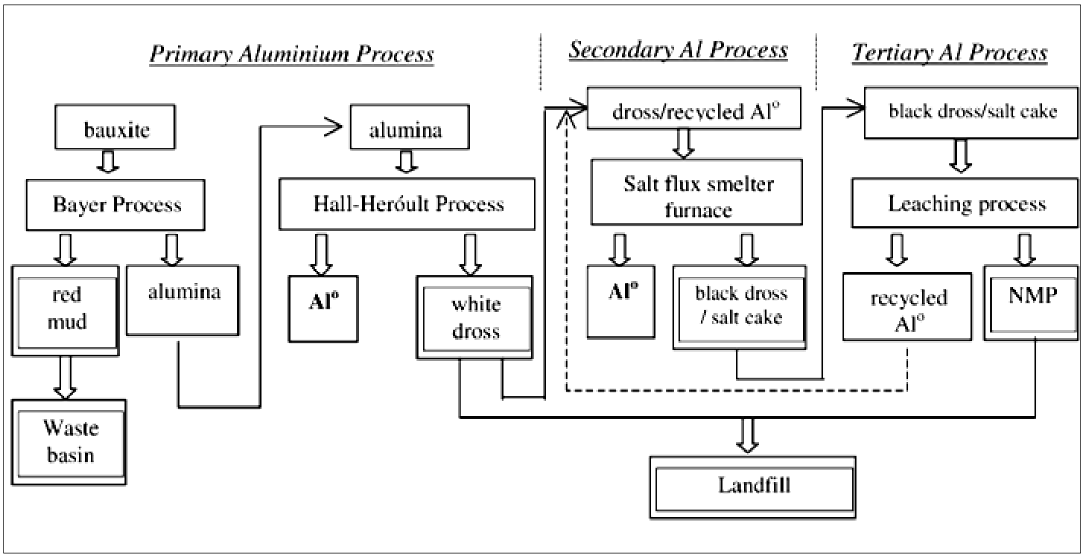

Figure 2.7: Aluminium schematic recycling process in Brazil shows all the waste will be sent to landfill or disposed without treatment and causing many environmental damages (Shinzato and Hypolito, 2005)

2.2.3 Solid-state recycling

Solid state recycling of aluminium chips is an alternative to re-melting. As compared to conventional aluminium recycling, a lot of metal is lost as a result of oxidation and the addition of other material is needed to be included into the process for treatment to recover the loss of aluminium after the melting process. The costs of process, labour and energy as well as the expenditures on environmental protection is increase during the recycling of the waste.

Gronostajski *et al.* (2000) emphasized that there is a different way of recycling metal chips, consisting in the direct conversion of chips into compact metal. The method contains the cutting of chips to a granulated product that is then cold pressed and hot extruded or hot forged, whereby melting is eliminated. It was then supported by Fogagnolo *et al.* (2003) who studied a method for recycling aluminium alloy chips by cold and hot pressing followed by hot extrusion. Solid state recycling is divided into two main techniques which are:

a) Semi-direct recycling
b) Direct recycling

2.2.3.1 Semi-direct recycling

With the global warming of concern, recycling of wrought aluminium alloys by new technique which is semi-direct recycling instead of conventional re-melting that concern on very high temperature for the aluminium to reach the melting point. High energy consumption for conventional aluminium recycling and subsequent refinement has been taken into account. Semi-direct recycling method is defined as partially-direct recycling processes that require additional steps before the recycling process is completed. Two techniques of semi-direct recycling involved powder metallurgy and extrusion technique at room or moderate temperature can result in significant energy savings. In both techniques, one additional step is required for the recycling process to be completed. Powder metallurgy technique utilizes ball mill before the cold compaction to grind the scraps of aluminium chip whilst hot extrusion technique needs for pre-heating step after the cold compaction to produce the cold billet.

a) Powder metallurgy technique

Powder metallurgy is a manufacturing process where a desired shape is created from metal powder by compacting it in a die (Parashar & Mittal, 2004). The metal powder is made to flow to fill the die just similar as liquid metals fill the mould in the casting process. The metal that in powdered form will be compacted under high pressure in a die having the shape of the product and then it is sintered.

Rao (2002) explained the steps involves in powder metallurgy process which include of production of the metal powders, blending and mixing of the powders, compacting either in hot or cold compaction, sintering and finally finishing operations. The production of the metal powders is depending on the type and nature of the metal itself. There are various methods available in order to produce the powders which are:

a) Atomization
b) Machining
c) Crushing and milling
d) Reduction
e) Electrolytic deposition
f) Shooting
g) Condensation

Gronostajki *et al.* (2000) in their research was employed ball mill to blend and mix the aluminium alloy granulated chips product with the reinforcing agent. Powder metallurgy process can eliminates or minimizes machining with the maximum utilization of the material. It is a simple process which can produce good surface finish and enables to give close dimensional tolerances (Angelo & Subramanian, 2008). However, Balsaraf (2009) found that there still many limitations in the powder metallurgy process. Powder metallurgy process cannot be applied to many complicated shapes. More volume of the metal powder produced more oxidized material that lead to lower physical properties and will be difficult to be stored. Furthermore, the cost of equipment is high and it is not economical for small-scale production.

b) Extrusion technique

Hot extrusion is an innovative process chain, combining optimized primary material usage and a reduction of process steps. It is combination of hot profile extrusion with subsequent turning or machining and hot extrusion of the produced machining chips for semi-finished parts. This concept was introduced and patent by Stern in 1945 (Misiolek, 2012). This method is possible due to the joining of the aluminium under high pressure, high strain and temperature just below the melting temperature. The occurring strains results into a cracking of oxide layer, and the high pressure and temperature lead to a joining caused by a contact of the surface of the pure aluminium. This process chain requires a small amount of energy compared to conventional process chain which is only 5-6 GJ/ton that is only 5-6% of that needed for the conventional process chain. During the whole process of direct conversion of aluminium chips into compact metal by extrusion, the waste is a part of the chips

REFERENCES

Allwood, J.M., Huang, Y., & Barlow, C.Y., (2005). Recycling scrap aluminum by cold-bonding. In: Proceedings of the 8th ICTP, Verona.

Altan, T., Ngaile, G. & Shen, G. (2005). Cold and Hot Forging: Fundamentals and Applications**.** ASM International, page 161.

Aluminum Aluminium | Advancing each generation | Alcoa Inc.

Angelo, P. C. & Subramanian, R. (2008). Powder Metallurgy: Science, Technology and Applications Phi Learning Pvt. Ltd, page 8.

ASM Aerospace Specification Metal Inc.

Balsaraf, V. M. (2009). Applied Chemistry. I. K. International Pvt Ltd., page 53.

Barros, A. M., Tenorio, J. A. S., & Espinosa, D. C. R. (2002). Chlorida Influences on the Incorporation of Cr₂0₃ and Nio in Clinker: A Laboratory Evaluation. Journal of Hazardous Materials, issue 93(vol2), page 221-232.

Beddoes, J., & Bibby, M. J. (1999).Principles of Metal Manufacturing Process. Great Britain, Arnold.

Beno**,** B. (2003). Manufacturing: Design, Production, Automation and Integration. CRC Press, page 181.

Bergeron, L. (2008). Study links carbon dioxide emissions to increased deaths. StanfordWoods Institute for the Environment.Stanford University Stanford, CA 94305, USA.

Bethany Wieman (2012). Benefits of Recycling Aluminum. Demand Media.

Borenstein, S. (2013). Greenhouse gas level at first-ever milestone. Associated Press.

Box, G. E. & Wilson, K. B. (1951). On the experimental attainment of optimum conditions. *Journal of the Royal Statistical Society, Series B (Methodological),* 13 (1), 1-45.

Callister, W. D., & Rethwisch, D. G. (2007). *Materials science and engineering: an introduction* (Vol. 7, pp. 665-715). New York: Wiley.

Campbell, T., Kalia, R. K., Nakano, A., Vashishta, P., Ogata, S. & Rodgers, S. T. (1999). Dynamics of Oxidation of AluminumNanoclusters using Variable Charge Molecular-Dynamics Simulations on Parallel Computers, Physical Review, 82, 4866-4869.

Carvalho, L.S., (1991). Estado da arte da tecnologia do tratamento de esco´ rianaindu´ stria do alum´ınio. In: III Semina´rio de Tecnologia da Indu´ stria doalum´ınio, 20 a 21 de agosto de 1991. Sa˜o Paulo, Brasil. ABAL, pp. 169–192.

Chiba, R., Nakamura, T., & Kuroda, M. (2011). Solid-state recycling of aluminium alloy swarf through cold profile extrusion and cold rolling. *Journal of Materials Processing Technology*, *211*(11), 1878-1887.

Chino, Y., Kobata, M., Shimojima, K., Hosokawa, H., Yamada, Y., Iwasaki, H., & Mabuchi, M. (2004). Blow forming of Mg alloy recycled by solid-state recycling. *Materials Transactions*, *45*(2), 361-364.

Degarmo, E. P. , Black, J. T. &Kohser, R. A. (2003). *Material and Processes in Manufacturing* (9^{th} ed.), USA, John Wiley.

Demirel, M., & Kayan, B. (2012). Application of response surface methodology and central composite design for the optimization of textile dye degradation by wet air oxidation. *International Journal of Industrial Chemistry*, *3*(1), 1-10.

Drasnar, P., Kudlacek, J., Kreibich, V., Kracmar, V., Vales, M. (2011). The properties of electrolytically deposited composite Zn- PTFE coatings, MM Science Journal, 248-251.

Elmagrabi, N.H.& Shuaeib, F.M.& Haron, C.H.C., "An overview on the cutting tool factors in machinability assessment", Journal of Achievements in Materials and Manufacturing Engineering, vol. 23, 2007, p.87-90

Erik, O., Jones, F. D., Horton, Holbrook, L. &Ryffel, H. (2000), *Machinery's Handbook*(26^{th} ed.), New York: Industrial Press, ISBN 0-8311-2635-3.

Finch, R. (2005). Performance Welding Handbook (Motorbooks Workshop), page 109.

Fogagnolo, J. B., Ruiz-Navas, E. M., Simón, M. A., & Martinez, M. A. (2003). Recycling of Aluminium Alloy and Aluminium Matrix Composite Chips by

Pressing and Hot Extrusion. *Journal of Materials Processing Technology, issue 143*, page 792-795.

Frampton, G. & McPoland, F. (1998). Recycling for the Future. ISBN: 0481269031. Washington D. C.

George E. D., Howard A. K., Semiatin S. L. & G. E. Dieter (2003). Handbook of Workability and Process Design. ASM International, page 147.

George, F. & Mcpoland, F. (1999).Recycling, For The Future: It's Everybody's Business. United States. Environmental Protection Agency, page 24.

Green, J. A. S. (2007). Aluminum Recycling and Processing for Energy Conservation and Sustainability.Asm International, page 9.

Gronostajski, J. Z., Kaczmar, J. W., Marciniak, H., &Matuszak, A. (1997). Direct Recycling of Aluminium Chips Into Extruded Products. *Journal of Materials Processing Technology, issue64* (volume 1), page 149-156.

Gronostajski, J., Marciniak, H., & Matuszak, A. (2000).New Methods of Aluminium and Aluminium-Alloy Chips Recycling. *Journal of Materials Processing Technology, issue106*(volume 1), page 34-39.

Groover, M. P. (2010). Fundamentals of Modern Manufacturing (4th ed.), John Wiley & Sons, Inc.

Groover, M. P. (2011). Principle of Modern Manufacturing, SI Version., (4thed.). John Wiley & Sons, Inc.

Gruzleski,J. E. & Closset, B. M. (1990).The Treatment of Liquid Aluminum-Silicon Alloys.American Foundrymen's Society, Inc.

Gwinner, D.S., (1996). Environmental issues in the aluminum reclamation industry. In: II Semina´rioInternacional de Reciclagem de Alumı´ nio, Sa˜o Paulo, SP, Brazil, 8 August 1996, ABAL (Associac¸a˜oBrasileira do Alumı´ nio), pp. 40–51.

Hong, S. J., Koo, J. M., Lee, J. G., Lee, M. K., Kim, H. H., & Rhee, C. K. (2009). Precompaction Effects on Density and Mechanical Properties of Al2O3 Nanopowder Compacts Fabricated by Magnetic Pulsed Compaction. *Materials transactions*, *50*(12), 2885.

Horsinka, J., Kliber, J., Drozd, K. & Mamuzić, I. (2011). Approximation model of the stress-strain curve for deformation of aluminium alloys, Metallurgy, 50(2), 81-84.

Jacobson, M. Z. (2008). Healthy Planet, Healthy People: Global Warming and Public Health. Department of Civil & Environmental Engineering Yang & Yamazaki Environment & Energy Building, StanfordWoods Institute for the Environment.Stanford University Stanford, CA 94305, USA.

Jedlicka W. (2010). Sustainable Graphic Design: Tools, Systems and Strategies For Innovative Print Design. John Wiley & Sons, page 462.

Joseph R. D. (1993). Aluminium and Aluminium Alloys. ASM International, page 247-248.

Kalpakjian, S. (1997). Manufacturing Processes for Engineering Materials, Addison-Wesley.

Katsuyoshi, K., Tachai, L. & Tatsuhiko, A. (2002). Solid-State Recycling Processing for Magnesium Alloy Waste via direct hot forging. *Material Transaction, issue 43*(volume 3), page 322-325.

Kaushish, J. P. (2008). Manufacturing Processes. Estern Economy Edition PHI Learning Pvt. Ltd.

Kim, H. S. (1998). Yield and compaction behavior of rapidly solidified Al–Si alloy powders. *Materials Science and Engineering: A*, *251*(1), 100-105.

Kishawy, H. A., Dumitrescu, M., Ng, E. G., & Elbestawi, M. A. (2005). Effect of coolant strategy on tool performance, chip morphology and surface quality during high-speed machining of A356 aluminum alloy. *International Journal of Machine Tools and Manufacture*, *45*(2), 219-227.

Kliber, J. & Mamuzić, I. (2011).Selected new technologies and research themes in materials forming, Metallurgy, 493,169-174.

George E. Dieter, Howard A. Kuhn, S. Lee Semiati (2003). Handbook of Workability and Process Design. ASM International, page 147.

Lajis, M. A., Yusuf, N. K., Noh, M. Z., & Ibrahim, M. (2013). Mechanical Properties and Surface Integrity of Direct recycling Aluminum Chips (AA 6061) by Hot Press Forging Process. 11th Global Conference on Sustainable Manufacturing, Berlin, Germany, 23rd – 25th September, 2013.

Lange, K. (1985). Handbook of metal forming. University of Stuttgart. McGraw-Hill Company.

Lave, L. B., Hendrickson, C. T., Conway-Schempf, N. M., & McMichael, F. C. (1999). Municipal solid waste recycling issues. *Journal of Environmental Engineering*, *125*(10), 944-949.

Lazzaro, G. & Atzori, C. (1992) Light Metals 41 1379.

Lazzaro, G. & Vittori, S. (1992) Metal and energy saving by direct and continuous extrusion of aluminium scraps, in: Proceedings of the 121st TMS Annual Meeting, San Diego, California.

Legarth, J. B. (1996). Sustainable metal resource management—the need for industrial development: efficiency improvement demands on metal resource management to enable a (sustainable) supply until 2050. *Journal of Cleaner Production*, *issue 4*(volume 2), page 97-104.

Mahi, P., Bland, W. J., Towse, R. J. & Jones, M. R. C., Burshell, K. C. (1990). Trends in Aluminium Recycling in the United Kingdom., page 133-143.

Maoliang, H., Zesheng. J., Xiaou. C, & Zhenkao, Z. (2008). Effect of chip size on mechanical property and microstructure of AZ91D magnesium alloy prepared by solid state recycling. *Materials Characterization*, *59*(4), 385-389.

Martchek, K. J. (1997). Life cycle benefits, challenges and potential of recycled aluminum, in *Proc. Air and Waste Manage. Assoc. 90th Ann. Meet.Exhib.*, paper 97-RP124B.01

Martchek,K. J. (2000). The Importance of Recycling To The Environmental Profile Of Metal Products. The Minerals, Metals & Material Society, USA.

Martchek, K. J., Green, J., &Pomper, S. (2000). *Credible Life Cycle Inventory Data for Studies of Automotive Aluminum*.SAE.

Mashhadi, A. H., Moloodi, A., Golestanipour, M., & Karimi, E. Z. V. (2009).Recycling of aluminium alloy turning scrap via cold pressing and melting with salt flux. *Journal of Materials Processing Technology*, *209*(7), 3138-3142.

Matthew J. D. (2000).Titanium: A Technical Guide. ASM International, page 36.

Minerals. Usgs. Gov (2007).Aluminum.

Misiolek, W. Z., Haase, M., Ben Khalifa, N., Tekkaya, A. E., & Kleiner, M. (2012). High quality extrudates from aluminum chips by new billet compaction and deformation routes. *CIRP Annals-Manufacturing Technology*, *61*(1), 239-242.

Moghaddam SS, AlaviMoghaddam MR, & Arami M (2010) Coagulation/flocculation process for dye removal using sludge from water treatment plant: optimization through response surface methodology. J Hazard Mater 175:651–657

Montgomery, D. C., & Montgomery, D. C. (1997). *Design and analysis of experiments* (Vol. 7). New York: Wiley.

Myers, R. H. (1971).Response surface methodology.Allyn and Bacon, Boston

Myers, R. H. & Montgomery, D. C. (2002). Response surface methodology: process and product optimization using designed experiments, 2nd edition. Wiley, New York.

Özer A, Gürbüz G, Çalımlı A, Körbahti BK (2009) Biosorption of copper(II) ions on Enteromorphaprolifera: application of response surface methodology (RSM). Chem. Eng. Journal 146:377–387

Pantke, K., Güley, V., Biermann, D., &Tekkaya, A. E. (2013). Aluminum Scrap Recycling Without Melting. In *Future Trends in Production Engineering*(pp. 373-377). Springer Berlin Heidelberg.

Parashar, R. K. & Mittal (2004). Elements of Manufacturing Processes. Phi Learning Pvt. Ltd, page 285.

Pasco, R., Przybylski, L. & Slodki, B. (2002). High speed machining (HSM)- The effective way of modern cutting. International Workshop CA Systems and Technologies.

Pearsall, J. (1999). The Consice Oxford English Dictionary (10th ed.), Oxford, England: Oxford University Press.

Phillip J. R. (1996). Taguchi Technique for Quality Engineering. McGraw-Hill International editions. Industrial Engineering Series (2nd ed.)

Pendergrast, B. (2011).Benefits of Recycling.Grin Verlag.

Pepelnjak, T., Kuzman, K., Kačmarčik, I., & Plančak, M. (2012).Recycling of AlMgSi1 aluminium chips by cold compression. *Metalurgija*, *51*(4), 509-512.

Peter Atkins, P. J. (2008). Climate change, Geography Review, 21, 4, 36

Plaza, M. (1995). The prons and cons of high-speed machining. Canadian Metalworking and Machinery.

Puga, H., Barbosa, J., Soares, D., Silva, F., & Ribeiro, S. (2009). Recycling of aluminium swarf by direct incorporation in aluminium melts. *Journal of Materials Processing Technology*, *209*(11), 5195-5203.

Ranjit, K. R. (2001). Design Experiments Using the Taguchi Approach. 16 Steps to product and process improvement. John Wiley & Son, Inc., page10.

Rajput, R. K. (2007) Manufacturing processes. Firewall Media, page 202.

Rao, K. V. (2002). Manufacturing Science and Technology - Manufacturing Processes and Machine Tools.New Age International, page 141-143.

Rao, P. N. (2001). Manufacturing Technology.Foundry, Forming and Welding.Tata McGraw-Hill Education, page 255.

Richard, Verseput, "Digging Into DOE: Selecting the Right Central Composite Design for Response Surface Methodology Applications", 2000 QCI International,

Rombach, G. (1998). Integrated assessment of primary and secondary aluminum production, in *Material for future: Aluminum Product and Processes*, DMG Business media, Ltd., Surrey, UK, chap. 10

Sabroff, A. M., Boulger, F. W. &Harold, J. H. (1968). Forging Materials and Practices.Reinhold Book Corp.

Salman Zafar (2013). Methods for Aluminium Recycling. Aluminium Recycling, Waste Management.

Samuel, M. (2003). A new technique for recycling aluminium scrap. Journal of Material Processing Technology 135, 117-124.

Sayed Moustafa, Walid Daoush, Ahmed Ibrahim & Neubauer, E. (2011). Hot Forging and Hot Pressing of AlSi Powder Compared to Conventional Powder Metallurgy Route, *Materials Sciences and Application*, vol. 2, pg. 1127-1133.

Schlesinger, M. E. (2013). *Aluminum recycling*. CRC Press.

Schmitz, C. (2006). Handbook of Aluminium Recycling.Vulkan-VerlagGmbh, page 74.

Schultz, H. (1984). High speed milling of aluminium alloys. In*Proceedings of the Winter Annual Meeting of the ASME, High Speed Machining, New Orleans* (pp. 241-244).

Schulz, H., Moriwaki, T. (1992).High-speed machining. Annual of the CIRP. 41 (2), 637-642.

Sharma, C. S., Nakagawa, T., & Takenaka, N. (1977).Recent development in the recycling of machining swarfs by sintering and powder forging. *Ann Cirp, issue 25*(volume1), page 121-125.

Sheng, J. Z., & Liang, H. M. (2013, June). Magnesium alloy and aluminium alloy fabricated by solid recycling process. In *Strategic Technology (IFOST), 2013 8th International Forum on* (Vol. 1, pp. 13-17).IEEE.

Shinzato, M. C., & Hypolito, R. (2005). Solid Waste from Aluminum Recycling Process: Characterization and Reuse of its Economically Valuable Constituents. *Waste Management*, *issue 25*(volume1), page37-46.

Smith I. & Hayes P. J. (1992). Proceeding of International Conference on " The Recycling of Metals", Dusseldorf/Neuss-Germany, page 151.

Smith, W. F.; Hashemi, J. (2006), *Foundations of Materials Science and Engineering* (4th ed.), McGraw-Hill, ISBN 0-07-295358-6.

Somayajula A, Asaithambi P, Susree M, Matheswaran M (2011) Sonoelectrochemical oxidation for decolorization of reactive red 195. UltrasonicsSonochem. doi:10.1016/j.ultsonch.2011.12.019

Sreenivasarao, K., Patsiogiannis, F., Hryn, J.N., Daniels, E.J., (1997).Concentration and precipitation of NaCl and KCl from salt cakeleach solutions by electrodialysis. Light Metals 1997, Orlando, FL,USA, 9–13 February 1997, Publication of TMS (Minerals, Metals & Materials Society), pp. 1153–1158.

Stat-Ease Inc. (2000). Design-Expert Software, Version 6, User's Guide, Technical Manual, Minneapolis, MN.

Stephen, P. (2006). Boatbuilding with Aluminum:A Complete Guide for the Amateur and Small Shop.McGraw-Hill Education.

Stephen, F. P. (1993). *Boatbuilding WithAluminum*, ISBN 0-07-050426-1.

Syamal, M. (2011). Metal Fabrication Technology. PHI Pvt. Ltd., page 170.

Tenorio, J. A. S., & Espinosa, D. C. R. (2001). Treatment of chromium plating process effluents with ion exchange resins. *Waste management*, *21*(7), 637-642.

Tekkaya, A. E., Schikorra, M., Becker, D., Biermann, D., Hammer, N., &Pantke, K. (2009). Hot profile extrusion of AA-6060 aluminum chips. *Journal of Materials Processing Technology*, *209*(7), 3343-3350.

Tan, P. (2013), Earth System Research Laboratory. National Oceanic and Atmospheric Administration (NOAA), Boulder, Colorado**.**

Thomas Zwieg (2001). A Universal Method for the Mechanical Preparation of Aluminium Alloy Specimens with High Edge Retention and their Subsequent Colour Etching. Danish Institute of Technology, Aarhus, Denmark.

Verran, G. O., & Kurzawa, U. (2008).An experimental study of aluminum can recycling using fusion in induction furnace, *issue 52* (volume 5), page 731-736.

Wang JP, Chen YZ, Ge XW, Yu HK (2007). Optimization of coagulation–flocculation process for a paper-recycling wastewater treatment using response surface methodology. Colloids and Surfaces A. Physicochemes. Eng. Aspects 302: 204–210

Wang S. C. & W. Wei C. J. (1998). Nanostruct.Mater.10 983–1000.

Wilcox, C. (2008). Recycling. Lerner Publications Group, United States of America.

Wolf, S. & Hoberg, H. (1997).Recycling of aluminium and its effect on sustainable development in *3rd ASM Int. Conf. Recycl. Metals*, ASM International, Brussels, Belgium, p. 257.

Yi Qin (2010). Micromanufacturing Engineering and Technology. Elsevier Inc., page 122.

Youngseon Lee, Yongnam Kwon, Junghwan Lee, Chul Park & Sangshik Kimb (2003). Effects of strain and strain rate on tensile behavior of hot-forged Al 6061-T6. *Materials Science and Engineering* A362 pg. 187–191. Korea Institute of Machinery and Materials &Gyeongsang National University, South Korea.

Yusuf, N. K., Lajis, M. A., Daud, M. I., & Noh, M. Z. (2013). Effect of Operating Temperature on Direct Recycling Aluminium Chips (AA6061) in Hot Press Forging Process. *Applied Mechanics and Materials*, *315*, 728-732.