

MECHANICAL STRENGTH OF AS-COMPACTED ALUMINIUM ALLOY
WASTE CHIPS

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PERPUSTAKAAN TUNKU TUN AMINAH

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ABSTRACT

This research is important to human being because a global reduction of CO_2 emissions is becoming more and more important to prevent global warming caused by green-house gas production. So, recycling of aluminium alloy scraps is important to reduce energy consumption and also a reduction of CO_2 emissions in manufacturing processes. The main purpose of this research is to determine the effect of Aluminium Alloy *AA6061* chips sizes and composition of polycarbonate on mechanical strength prepared by compaction process. Besides that, to investigate the effect of pressure and time compacted on mechanical properties. The research was conducted with different chips size, different composition of binder, different pressure and difference time throughout compacted process. Three difference chips sizes are selected which is 250, 500, and 710 μm , different pressure is 0.5, 1.0 and 2 tonne, meanwhile for different time compaction is 20, 30 and 40 minutes. From the result obtained, the highest strength showed by sample with chips size 250 μm and composition of polycarbonate 30 wt% with value 61.185 MPa. Furthermore for higher hardness also at the lowest chips size 250 μm and higher composition of polycarbonate 30 wt% with 167.752 HV. Meanwhile for the lowest values of strength and hardness are 6.7894 MPa and 72.2052 HV at chips size 710 μm and 10 wt% of polycarbonate. In this research, lower chip sizes, addition of composition polycarbonate, higher pressure and time compaction could improve the mechanical strength of Aluminium Alloy waste chips.



ABSTRAK

Penyelidikan ini penting kepada manusia kerana pembebasan CO_2 adalah banyak dan lebih penting untuk melindungi pencemaran yang akan menyebabkan pembentukan rumah hijau. Jadi kitar semula aluminium aloi sangat penting untuk mengurangkan tenaga dan juga mengurangkan pembebasan CO_2 dalam proses pembuatan. Tujuan utama penyelidikan ini adalah untuk mengenalpasti kesan saiz aluminium aloi *AA6061* and komposisi polikarbonat ke atas kekuatan bahan melalui proses pempadatan. Selain itu, mengenalpasti kesan tekanan dan masa pempadatan ke atas kekuatan mekanikal. Penyelidikan ini dijalankan dengan saiz cip yang berbeza, perbezaan komposisi pengikat, perbezaan tekanan, dan perbezaan masa sepanjang proses mampatan. Tiga perbezaan saiz cip dipilih yang mana 250 μm , 500 μm , dan 710 μm , perbezaan tekanan 0.5, 1.0 dan 2 tan, manakala perbezaan masa mampatan dalam julat 20 hingga 40 minit. Daripada keputusan yang diperolehi, kekuatan tertinggi ditunjukkan oleh sampel dengan cip bersaiz 250 μm dan komposisi polikarbonat 30 wt% dengan nilai 61.185 MPa. Tambahan pula, nilai kekerasan yang lebih tinggi pada saiz cip yang terendah iaitu 250 μm dan komposisi yang lebih tinggi iaitu 30 wt% dengan nilai 167.752 HV. Sementara itu, bagi nilai terendah kekuatan dan kekerasan adalah 6.7894 dan 72.2052 HV pada saiz cip 710 μm dan 10 wt% polikarbonat. Dalam kajian ini, penggunaan saiz cip yang lebih rendah, penambahan komposisi polikarbonat, dan penggunaan tekanan dan masa yang tinggi boleh meningkatkan lagi sifat-sifat mekanikal cip aluminium aloi.



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LIST OF SYMBOLS AND ABBREVIATION

CO_2	Carbon Dioxide
Al	Aluminium
$Al-Si$	Aluminium Silicon
$AA6061$	Aluminium Alloy 6060
$ASTM$	American Society for testing and Material
$AlMg2$	Aluminium Magnesium
$AlCu4$	Aluminium Copper
μm	Micrometer
CNC	Computer Numerical Control
min	Minute
mm	Millimeter
rpm	Rotation per minute
m/s	Meter per second
$^{\circ}C$	Degree Celsius
kN	Kilogram Newton
MN	Mega Newton
g	Gram
MPa	Mega Pascal
UTS	Ultimate Tensile Strength
P	Pressure
F	Force
$\%$	Percentage
SEM	Scanning Electron Microscope
OM	Optical Microstructure



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T	Temperature
PC	Polycarbonate
Δl	Deflection of length
L	Length
T	Thickness
ε	Strain
σ	Stress
mN	Milli Newton
HV	Hardness Vickers
σ_y	yield stress
σ_i	intrinsic yield stress



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CHAPTER 1

INTRODUCTION

1.1 Introduction

Metal chip processing refers to the method of collecting and treating metal machining wastes with the use of metal crushers, oil separators, dryers for drying chips, and other specialized equipment interconnected with metal chip conveyors, so as to comprise a complete metal chip processing system.

Chips from machining operations are wet with coolant and oil, and in this condition cannot be re-melted efficiently and economically. While transportation oil spills all over creating environmental issues. Also the melting loss is huge. Hence chip processing is necessary for obtaining maximum recovery and savings.

A global reduction of CO_2 emissions is becoming more and more important to prevent global warming caused by green-house gas production. Due to this, the need for a decrease in energy consumption in every field of industrial processes as well as transportation and production engineering is a major factor in today's industrial world. Analyses of energy consumption in manufacturing processes have shown that most of the energy is needed for the production of material such as aluminum or steel and not for further manufacturing steps like forming or cutting (Tekkaya *et al.*, 2009).



In the area of cutting and forming technology, typically, the major amount of energy is not used for the manufacturing process, but for the production of the primary material, made from first melting after mining, or secondary material, made from melting after recycling. Therefore, to reduce energy consumption and also a reduction of CO_2 emissions in manufacturing processes, an innovative process chain, combining optimized primary material usage and a reduction of process steps, is highly needed.

Recycling of aluminium alloy scraps and chip are usually performed mostly by the melting method. Using the common recycling methods, aluminium alloy chips and scrap are remelted, whereby some of the alloy is recovered and reutilized in the production process. During the melting/recycling of the chips and scraps, a lot of aluminium alloy is lost as a result of oxidation and the costs of labor and energy required for more efficient recovery.

Expenditures associated with environmental protection further increase the general costs Maoling *et al.*, (2008). To date, several innovative processes have been proposed to recycle aluminium chips using direct hot extrusion Gronostajski *et al.*, (2000). This process chain requires an amount of energy of only 5-10 % of that needed for the conventional process chain including a re-melting step of the scrap to produce new extrusion billets compacted the chips into pure aluminum cans, which were then hot-extruded at various extrusion ratios and temperatures. Recently, Tekkaya *et al.*, (2009) reported on the hot extrusion of chips based on *Al 6060* and also the mixture and extrusion of *Al 6060* chips with SiC particles. This research proposed a new method of direct recycling aluminium chips as shown in Figure 1. In the direct recycling process, chips and scraps are recycled by consolidation using plastic deformation processes such as cold or hot pressing followed by hot extrusion Gronostajski *et al.*, (2000). Direct recycled aluminium alloys show high strength due to grain refinement and homogeneous dispersion of oxide precipitates.

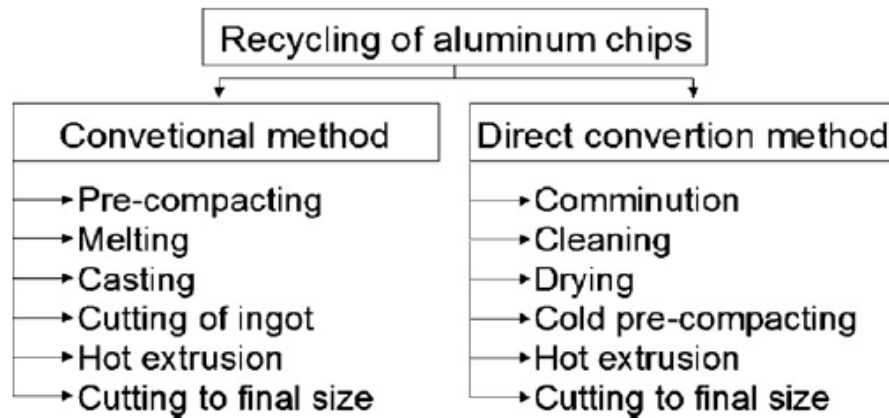


Figure 1: A comparison of conventional and direct recycling techniques of Aluminium alloy chips (Gronostajski et al., 2000)

The recycling of aluminium and its alloys by direct recycling method is relatively simple, consumes small amounts of energy and does not have a harmful effect on the environment. It is which they recycled the material directly from the chips formed by cold or hot pressing followed by hot extrusion which results in a more economic recycling process. Hence, the concern to decrease the energy consumption in industrial process and the need to reduce a carbon dioxide emission in global warming, it will be important to study the direct recycling of Aluminium chips as a secondary resources. This evaluation will be new in this country and it is judged to be important to support our government in Green Technology research. Thus, it will be worth to study the potential of recycling the aluminium chips for secondary resources.

1.2 Background of Research

The researches on recycling chips were conducted by many researchers. There are several journals that studies on recycling chips, Tekkaya *et al.*, (2009), study on hot profile extrusion of *AA6060* aluminium chips, which is re-used of aluminium scrap based on milling and turning chpis by direct hot extrusion. The investigations have shown that using billets made *AA6060* chips can lead to similar mechanical and microstructural properties as using of conventional cast aluminium billets.

Fogagnolo *et al.*, (2003), research on recycling aluminium alloy chips by cold and hot pressing was studied as well as the possibility of using this method to recycle aluminium matrix composite chips. The results obtained from this study were due to the refinement of the microstructure and the dispersion of the aluminium oxide caused by the extrusion process, the ultimate tensile strength and the hardness were higher for the recycled material than for the former composite.

Maoling *et al.*, (2008), research on the effect of chip size on mechanical properties and microstructure of AZ91D magnesium alloy prepared by solid state recycling. Mechanical properties and microstructure of the recycled specimen were investigated. Ambient oxide in the recycled specimen contributes to a higher ultimate tensile strength and a higher elongation to failure, however excessive oxide in the recycled specimen may adversely affect the elongation to failure.

Besides that, Gronostajski *et al.*, (2000) research on a new method of aluminium and aluminium alloy chip recycling. The method that the researcher used is preparation of aluminium chips for the manufacture of products by direct conversion covers, segregation of the chips, the cleaning of the chips of impurities and the comminution of the chips to a granulated product. The method has been applied to the production of composite materials, characterized by good strength properties at room and elevated temperature, as well as for bearing material. Other research by the same author Gronostajski *et al.*, (1997), is a study on direct recycling of aluminium into an extruded product. Also carried out with the same material which uses aluminium chips but with a difference in method and process. The relevant research is high density and good properties of products can be obtained at high extrusion temperature which makes possible the plastic flow of matrix into pores and voids and at a relatively low extrusion rate that gives the time for diffusional transport matter.

Gronostajski *et al.*, (1999), also studied on recycling of aluminium and its alloy chips by using plastic deformation. The method consists in the conversion of the chips directly without melting processes into a finished product. By using powder metallurgy technique followed by an extrusion process, the method has been applied to the production of composite material, characterized by good properties.



1.3 Problem Statement

This research is important to human being because a global reduction of CO_2 emissions is becoming more and more important to prevent global warming caused by green-house gas production. Recycling of aluminium alloy scraps is important to reduce energy consumption and also a reduction of CO_2 emissions in manufacturing processes.

1.4 Objective of Research

The objectives of this project are:

- i. To determine the effect of Aluminium Alloy *AA6061* chips size and composition of polycarbonate on the mechanical strength of as-compacted.
- ii. To investigate the effect of pressure and time compacted on mechanical strength of Aluminium Alloy *AA6061*

1.5 Scope of Research

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

- i. The aluminium alloy *AA6061* chip sizes are used; 250, 500 and 710 μm and the binder that are used is polycarbonate.
- ii. The compositions of polycarbonate are 10 wt%, 20 wt% and 30 wt%.
- iii. In preparation of the sample, the pressure and time compaction are kept in the range of 0.5-2 tonne and 20-40 minutes respectively.
- iv. For mechanical strength properties, the sample is tested using flexural and hardness tests, whereas the fracture surface is observed using optical microscope and scanning electron microscope.



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CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In this research, paper on recycling chip had been used as studied and reviewed to obtain the information related to the study and used as reference for writing the thesis. This information was useful because of involving environment condition and this focused on method, parameter and result.

Usually processing that previous studied used are normally same, include process to production of chip, compacting, extrusion, cold pressing, hot pressing, and others. Process to produce chip are very important because considering metal losses and comparing the cost involved, and can assess the efficiency of the recycling method.

Normally after manufactured processes, considerable amounts of waste in the form of chips and discards that are produced. This waste and scrap is returned to melting, whereby some of the metal is recovered and reutilized in production processes. During the recycling of the waste, a lot of metal is lost as a result of oxidation and the costs of labour and energy as well as the expenditures on environmental protection increase the general cost of the process Gronostajski *et al.*, (2000).



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2.2 Aluminium Alloy

Aluminium alloys are alloys in which Aluminium (*Al*) is the predominant metal. The typical alloying elements are copper, magnesium, manganese, silicon and zinc. There are two principal classifications, namely casting alloys and wrought alloys, both of which are further subdivided into the categories heat-treatable and non-heat-treatable. About 85% of aluminium is used for wrought products, for example rolled plate, foils and extrusions. Cast aluminium alloys yield cost effective products due to the low melting point, although they generally have lower tensile strengths than wrought alloys. The most important cast aluminium alloy system is *Al-Si*, where the high levels of silicon (4.0% to 13%) contribute to give good casting characteristics. Aluminium alloys are widely used in engineering structures and components where light weight or corrosion resistance is required (Palmerin *et al.*, 2009).

Alloys composed mostly of the two lightweight metals aluminium and magnesium have been very important in aerospace manufacturing since somewhat before 1940. Aluminium-magnesium alloys are both lighter than other aluminium alloys and much less flammable than alloys that contain a very high percentage of magnesium.

Aluminium alloy surfaces will keep their apparent shine in a dry environment due to the formation of a clear, protective layer of aluminium oxide. In a wet environment, galvanic corrosion can occur when an aluminium alloy is placed in electrical contact with other metals with more negative corrosion potentials than aluminium.

Aluminium alloy compositions are registered with the Aluminum Association. Many organizations publish more specific standards for the manufacture of aluminium alloy, including the Society of Automotive Engineers standards organization, specifically its aerospace standards subgroups and American Society for testing and Material (*ASTM*) International.

2.3 Recycling Chips

Aluminium alloy chips can be recycle by conventional method, direct conversion method, and others. The direct conversion method, is a characterised by low energy, low cost of manufacture and labour and large material saving. Recycling the material directly from the chips by cold or hot pressing followed by hot extrusion, avoiding the milling step, produce economic recycling process. The most suitable way of recycling the chips is their processing through hot extrusion. This statement is supported by several authors that enclosed in this chapter.

Misiolek, *et al.*, (2012) represented in their research which is recycling *AA6060* aluminium alloy chips with compacted into billets using three techniques. The techniques included traditional compaction of entire chips volume in one stroke, multi layer compaction for powder compaction and using the front-pad for powder extrusion.

Pepelnjak, *et al.*, (2012) in their research recycled of *AlMgSi1* aluminium using direct conversion into solid billet by cold compaction. From the research area, it can be examined the influence of the shape and size of chips on cold compression parameter and final properties of product.

Hafeez, T. M, (2012) presented recycled Aluminium Alloy chips *AA6060* by using hot forging. In their research conducted with difference pressure which is related with strength properties and macrostructure of the specimens.

Sherafat *et al.*, (2010) presented mechanical properties and deformation behaviour of *Al7075* with two-phase material. Two phase a material which is fabricated by mixing commercially pure *Al* powder with *Al7075* chips and consolidating the mixture through hot extrusion process at 500°C. Researcher proposed that to obtain better bonding and as a result improved mechanical properties of the extruded products; author used *Al* powder as a binder in recycling of *Al7075* chips through hot extrusion process.

Guley, V. *et al.*, (2010) used a method for recycling scrap, which is by hot extrusion and direct recycling. The material is aluminium alloy 1050 in the form of pins remained as scrap after lateral extrusion process. Meanwhile, the scrap was mixed with aluminium alloy to produce secondary aluminium, this aluminium was cold compaction and hot extruded.

In case of recycling by cold and hot extrusion, approximately 90-93% of the energy used is needed for the material production, 3% for thermal treatment, and only 1% for the forming process. Due to the energy consuming in production of aluminium, amount of energy needed for the production process is even larger. So that from an economic and point of view reducing the production of primary material the most efficient way to reduce energy consumption. And innovative process chain, combining optimized primary material usage and a reduction of process steps, was analyzed and successfully applied (Tekkaya *et al.*, 2009).

Mashhadi, *et al.*, (2009) used aluminium alloy turning scrap with different cold compaction pressure and melting with salt flux as a recyclability of material. Their research proposed that using protective salt flux ($NaCl-KCl-KF$) is the best route from the point of view of recyclability. Mechanical properties were approximately same as the primary material that produces by conventional casting process.

Maoliang *et al.*, (2008), in their research used magnesium alloy chips prepared by solid state recycling. Using the common recycling method, magnesium alloy chips and scrap remelted, whereby some of the alloy is recovered and reutilized in the production process. During the melting or recycling of the chips and scraps, a lot of magnesium alloy is lost as a result of oxidation and the cost of labour and energy required for more efficient recovery. Expenditure associated with environmental protection further increase the general cost.

Fogagnolo *et al.*, (2003) study on their research which is recycling alloys chips by cold and hot pressing followed by hot extrusion. Author used this method to recycle aluminium matrix composite of alloy chips and compare with the primary material produce by conventional casting process.

Samuel (2003) represented new technique for recycling aluminium scrap. Researcher proposed new technique which is carried out without melting point. Figure 2.1 shows comparison between conventional and new technique for direct scrap convention into extruded product. It can be seen that the new technique is characterized by fewer steps, a higher efficiency of recovery and lower generation of new scrap. Conventional process produces about 52%, whereas the direct conversion process introduced about 96% of the extruded product as shown in Figure 2.1.

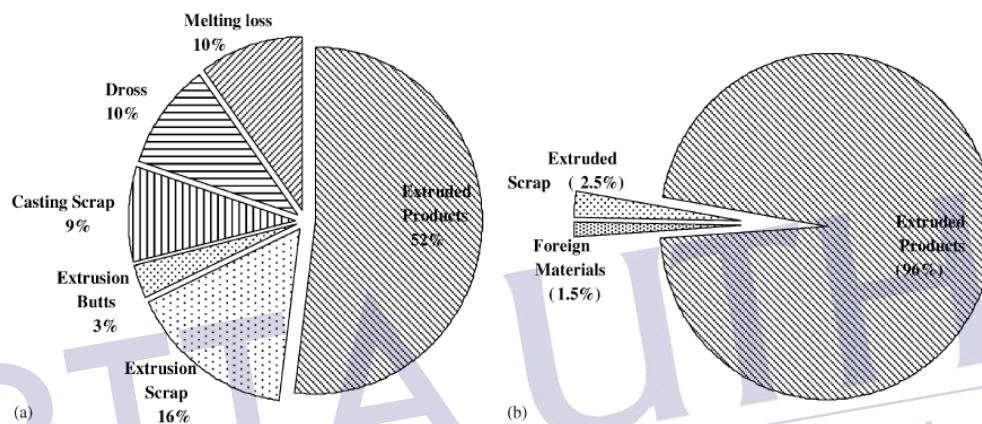


Figure 2.1: Comparison between: (a) conventional process (b) new technique by direct conversion method (Samuel. M 2003)

Chmura and Gronostajski (2000) presented author produced bearing composite by cold and hot extrusion at 520°C of comminute and mixed aluminium and aluminium-bronze chips. The manufacturing and properties of bearing material produced by the recycling of aluminium and aluminium-bronze chips are presented.

Researcher by Gronostajski *et al.*, (2000) was presented in the process of melting aluminium alloy waste and scrap, on average about 10% of the metal is burnt and about 10% of it is lost because aluminium mixes with the slag removed from the surface. The losses are irreversible and can reach about 35% if melting takes place in gas or oil-fired furnaces instead of induction furnaces.

In the case of the direct conversion of aluminium alloy chips into compact metal by extrusion, the waste is the part of the chips from which impurities cannot be removed 2% and the extrusion waste is of up to 30% thus ultimately 95% of the metal is recovered. By reducing the number of operation, the direct conversion method allow labour to be reduced to 2.5-6.5 man-hour per ton of product, while for conventional recycling is much higher ranging from 11 to 15 man-hour per tonne.

In their research, estimated that factor that contribute significantly to the bonding of aluminium and aluminium alloy chips with an introduced consolidating phase include; the amount, form and size of the consolidating phase, the degree of fineness of aluminium and aluminium alloy chips, the cold pressing parameters, the shape of extrusion dies, the degree of reduction, the lubrication method and the lubricant used, and the temperature and rate of extrusion. Aluminium and aluminium alloy chips can be recycled with and without reinforcing phase. As reinforcing phase can be used aluminium oxide, tungsten, silicon carbide, ferro-chromium and aluminium bronze.

During the recycling of the waste a lot of the metal is lost as a result of oxidation and the cost of labour and energy as well as the expenditure on environmental protection raise the general cost of such processes. Recycling of aluminium scrap requires only approximately 5% of the energy needed to produce it from ore. The conventional recycling process is characterized by high energy consumption, high operating cost and a large number of operations (Gronostajski *et al.*, 1999)

In journal paper that represented by Gronostajski *et al.*, (1997), which is study, on direct recycling of aluminium chips. It shows that by using direct recycling of aluminium more effective compare to conventional method. Author estimated that the average metal loss about 20% occurs during the remelting phase and moreover conventional recycling process is characterized by high energy consumption, high operating cost and large number of operations.

From Figure 2.2, it shows that by using the conventional process it can be recycled less than 55% of aluminium scraps. This is very significant because the amount of recycled aluminium has been growing systematically since the sixties and its consumption nowadays is estimated at 27%. The recycling of aluminium and its alloys by direct conversion method is relatively simple, consumes small amounts of energy and does not harmfully the environment.

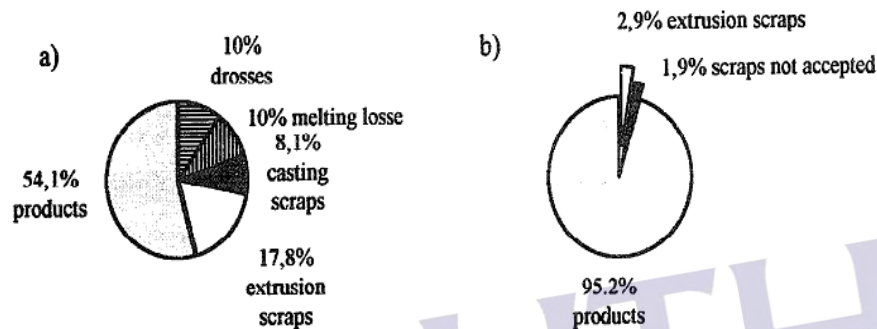


Figure 2.2: Comparison between (a) conventional and (b) direct recycling processes (Gronostajski *et al.*, 1997)

Researcher by Gronostajski *et al.*, (1996) presented directly converted into the final product by hot extrusion process which is addition of small amount of tungsten powder with $AlCu_4$ chips. $AlMg_2$ composites cannot be strengthened by heat treatments, so that author used $AlCu_4$ alloy because they can be heat treated by precipitation ageing. From the recycling chips, author fined how properties can be change by heat treatment at different amount of tungsten powder.

2.4 Preparation of Chips

Pepelnjak, T. *et al.*, (2012) presented in their research which is used different chips size of *AlMgSi1*. The chips were produce by using Computer Numerical Control (*CNC*) machine and conventional machine at the Laboratory for Cutting at the Faculty of Mechanical Engineering Ljubljana. Figure below shows the different type of *AlMgSi1* chips.

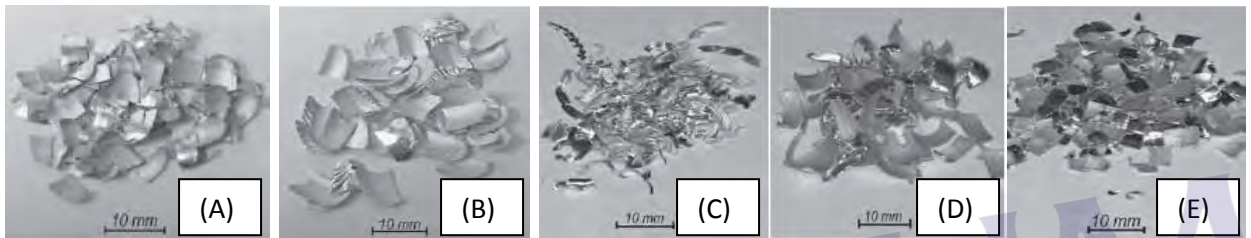


Figure 2.3: Different type of chips (Pepelnjak, T. *et al.*, 2012)

From Figure 2.3 it can be seen the different type of chips obtained from milling operation and milling parameters. All type of chips differs both in length and width as well as in thickness.

Material that are used by Hafeez, T. M, (2012) are Aluminium Alloy *AA6061* that produce by High Speed Milling Machine with cutting speed 1100 m/min, Feed, r 0.02 mm/tooth and depth of cut 0.5 mm. There are used a constant chips size, and considered in pressure on hot forging.

Materials that used by Sherafat *et al.*, (2010) are *Al* powder with *Al7075* chips. Rectangular cube shape *Al7075* chips with an average size of 1 mm x 1 mm x 0.11 mm and air-atomized commercially pure *Al* powder with the average particle diameter of about 45 μm were used as a starting material. The *Al7075* chips were mixed with difference amount of *Al* powder in the range of 20-90 wt% using a simple mixing drum.

Diameter of *AA 1050* about 3-5 mm and length of about 10-40 mm remain as scrap after a lateral extrusion process in production. For *AA6061* chips resulting from a turning operation have an average thickness of 0.1 mm and length of about 25-30 mm (Guley, V. *et al.*, 2010). The characterized of material that are used as shown in Figure 2.4.

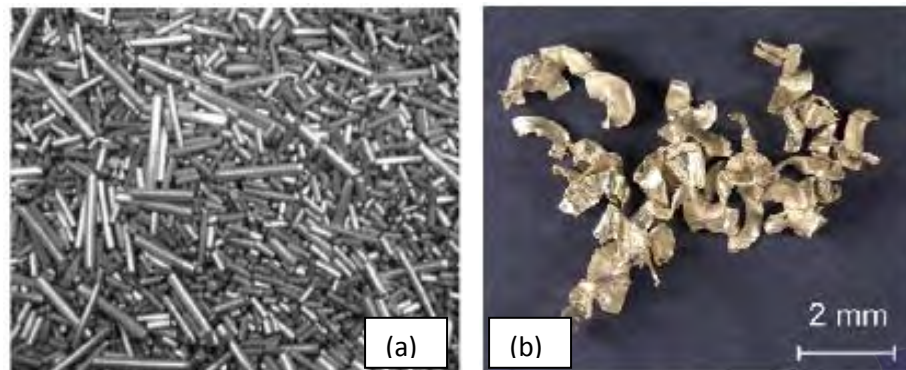


Figure 2.4: (a) AA 1050 pins (b) AA6060 chips (Guley, V. *et al.*, 2010)

Tekkaya *et al.*, (2009) was presented to produce difference shape of chips, investigations on milling and turning operations from three machining operation on conventional cast extrusion billets made of aluminium wrought. For the preparation of recycling chips, three different kinds of typical small and thin chips were produce. Combination of a large cutting depth and small feed leads was to produce the difference chips size. Both cutting operation have been carried out dry machining condition to prevent any inclusion in the extrusion process.

Table 2.1: Chips shape and size related to the manufacturing process
(Tekkaya *et al.*, 2009)

	Type A	Type B	Type C
Production	Turning	Turning	Turning
Length of chips (mm)	>30	>30	<10
With (mm)	6-8	1-2	4-6
Thickness	0.5-1.5	<0.2	<0.2

From Figure 2.5, it can be seen that turning chip of type A had a highly twisted geometry, type B are long but narrow chips have been produced by turning and type C a sufficient chip formation with small and thin shapes.

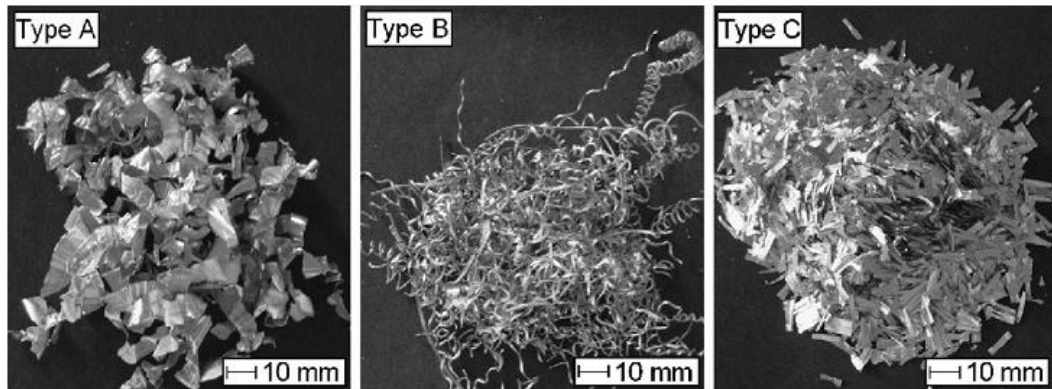


Figure 2.5: Chips related to the manufacturing process. (Tekkaya *et al.*, 2009)

Researcher by Maoliang *et al.*, (2008) in their experimental procedures use AZ91D magnesium alloy as their material recycled. Machined chips of alloy were prepared by machining an ingot in a lathe. Machine chips were kept clean in the turning processes. Figure 2.6 and Table 2.2 shows the size of recycled chips specimens.

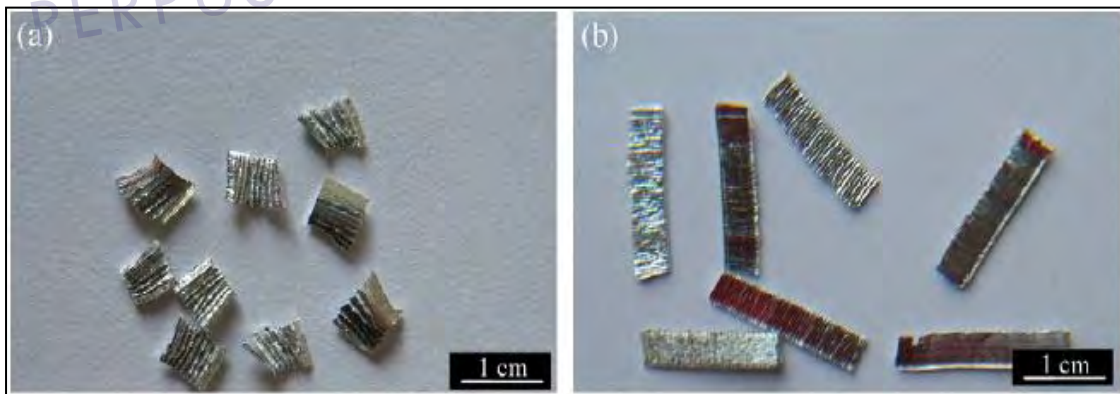


Figure 2.6: Recycle chips size of AZ91D magnesium alloy (Maoliang *et al.*, 2008)

Table 2.2: Size of recycled chips specimens (Maoliang *et al.*, 2008)

Recycle specimen	Length/mm	Width/mm	Thickness/mm
1	4-6	3.5-4.5	1.45-1.55
2	10-16	1.8-2.2	0.48-0.52
3	5-8	1.8-2.2	0.18-0.22

Recycle chips with the sizes of (4-6) x (3.5-4.5) x (1.45-1.55) mm, (10-16) x (1.8-2.2) x (0.48-0.52) mm and (5-8) x (1.8-2.2) x (0.18-0.22) mm are called recycled specimen 1, recycled specimen 2, and recycled specimen 3 respectively as shown in Table 2.2.

Besides that, research by Samuel, (2003) used aluminium as a recycled material that produced from milling machine. Grading of comminuted scrap is performed using standard sieves and only two sizes of granulated aluminium produced, namely from 0.5 to 2.0 mm and <0.5 mm will be used. For each of the sizes, milling is done by an attritor-type machine of high-power ball mill which rotates 300 rpm horizontally. The milling machine dimensions are 130 mm inside diameter and 150 mm long. The 20 mm diameter ball was made of hardened chromium steel. The weight ratio of the milling balls to the granulated aluminium is chosen as 10:1 and loading of the granulated aluminium takes in air.

Figure 2.7 shows the particle sizes that had been used which is have four categories with 6 mm, 4-2 mm, 2-0.5 mm and less than 0.5 mm. Magnets are used for separating ferrous particles. This can be carried out manually using a magnetic separator. This operation is of particular importance to separate the very fine hard oxide particles from the hardened steel balls during milling.

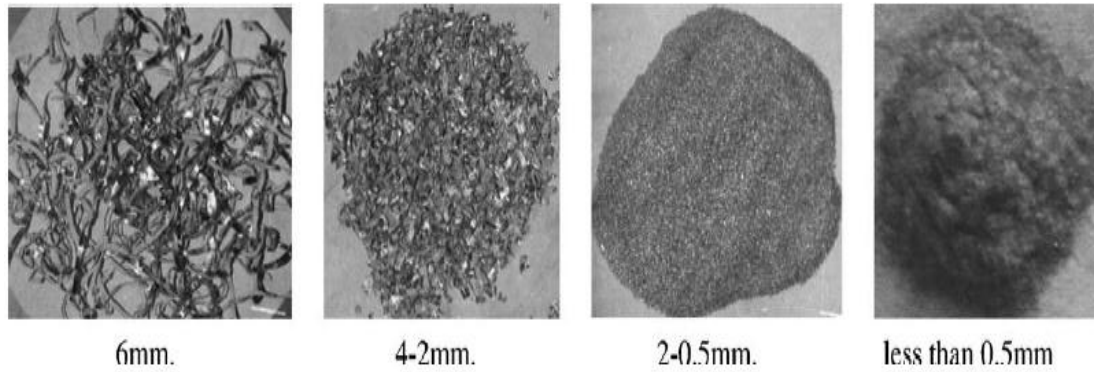


Figure 2.7: Aluminium scrap and milled powder for different size (Samuel, 2003)

AA6061 aluminium alloy reinforced with Al_2O_3 was mechanically characterised, transformed into chip by machining, and recycled in order to compare with the primary composite material. To optimise the process, aluminium alloy chips with unknown composition were employed (Fogagnolo *et al.*, 2003).

Aluminium and aluminium alloy chips are collected and store by the categories, classes, and grade of metal. The chips were comminuted in a cutting mill up into particle of no more than several millimetres length. Aluminium granulated particle size were used below 4mm; from 4 to 2mm, below 2mm; from 1 to 0.5mm, and below 0.5mm (Gronostajski *et al.*, 2000).

Chmura and Gronostajski (2000) have presented that aluminium chips are comminuted to below 2 mm and $CuAl_{11}2$ and $CuAl_{11}3$ chips with 12 and 13% Al content, respectively comminuted to two fractions below 2 and 2-4 mm would be used. After comminution in the cutting mill and the selection of the particular fractions to be the composites components, composite mixtures with 15, 22, 30 and 45% reinforcement phase by weight were prepared and mixed in the two-cone high power mill for 20 min.

Gronostajski *et al.*, (1999) presented in their research that used aluminium and aluminium alloy as material recycled. The preparation of aluminium chips for the manufacture of product by direct conversion. Metal scrap are collected and stored by categories, classes and grades. Segregation of aluminium and aluminium alloy chips according to their chemical composition and also divided depending on their impurities right at the production plant. The segregation of the chips at a later stage is practically impossible. To make the composites, the chips were comminuted in a cutting mill. The following aluminium and aluminium alloy granulated product sizes were used below 0.5 and between 0.5 and 1.0, 1.0 and 2.0, and 2.0 and 4.0 mm.

To mix aluminium and aluminium alloy granulated product with reinforcing phase, initially an attritor-type ball mill employed. The mill has a fixed casing and a rotary mixer (with a vertical axis of rotation) which drives steel ball of diameter 12.5mm. It was used for the mixing of aluminium alloy granulated product with particle of hardening phases.

Other paper with same author which is Gronostajski *et al.*, (1997) prepared chip that produce from machining operation. Characterized by irregular elongated spiral shape which is makes them unsuitable for preliminary pressing and hot particle. So that author used different kind of milling to obtain the correct size.

Figure 2.8 shows the result of comminution of aluminium chips in the cutting mill at the rate of 4.6 m/s. Particle of 2-3 mm dimensions are the most frequently obtained fraction after the first comminution. The second comminution of the granulated product, increase fractions 0-2 mm and 2-3 mm at the expense of the fraction 3-4 mm, 4-5 mm and >5 mm.



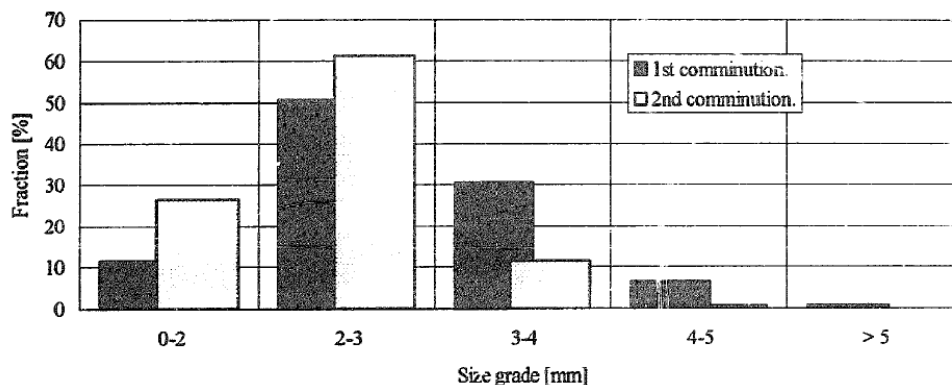


Figure 2.8: The effect of aluminium chips comminution in the cutting mill on the distribution size of their particle (Gronostajski *et al.*, 1997)

After the cutting, the chips were granulated further by milling in an attritor. Water, methyl alcohol and 2% of zinc were used as the milling medium to avoid cold welding. It was found that milling in water produced particle of the smallest size but their surface layer was covered with a thick film of oxide and hydrate. The particle size distribution of the granulated chips used for further processing is given in Table 2.3. Particle size with larger than 5mm were eliminated.

Table 2.3: The particle size distribution of the chips used for further processing (Gronostajski *et al.*, 1997)

Material	Size of particle in mm			
	0-2	2-3	3-4	4-5
	Distribution of particle in %			
<i>Al</i>	26.0	61.5	11.0	1.5
<i>PA2 (Al-2 % Mg)</i>	4.7	25.6	41.8	27.9
<i>PA6 (Al-4% Cu-1 % Mg)</i>	12.4	28.1	32.6	26.9

Other research by Gronostajski *et al.*, (1996), have presented the process which is granulation of chips was performed by using cutting speed of 4.6 m/s. Aluminium chips were cut twice according to their high plasticity and chips of $AlCu_4$ alloy were cut once. These processes are conducted with chips smaller than 4 mm. In this research, $AlCu_4$ alloys chips or aluminium mixtures are granulated with tungsten powder. Aluminium and aluminium alloy chips belong to a group of reclaimed raw material, metal scrap to be processed metallurgically. Such scrap should be collected and stores by categories, classes and grades.

2.5 Chips Cleaning

Chips cleaning are one of the processes which are to preparation of aluminium chips for the manufacture of product by direct recycling. Usually Aluminium chips are fouled chiefly with the coolants and lubricants used in machining, with oil emulsion. The emulsion can be removed from the chips by a chemical method or a thermal method.

Hafeez, T. M, (2012) used the Ultra Sonic Cleaning to cleaned the chips. This Ultrasonic cleaning are used high frequency sound wave to agitate in a liquid. Acetones are used as cleaner that ensure there are no impurities and oxide layer attaché on the chips.

In research by Samuel (2003), his used chemical cleaning for removing surface oxides from annealed granulated aluminium. This cleaning operation were often performed as; a bath of sodium hydroxide ($NaOH$) at 65-77°C, hot water rinse, chromic acid bright dip, and last hot water rinse. The cleaned granulated aluminium is dried at temperature of 80-100°C in ovens and preserved in desiccators.

Gronostajski *et al.*, (2000) used thermal method without the deposition of carbonisation product on the surface of the chips as the most appropriate method in cleaning the chips from oil emulsion.

2.6 Compaction

Compacting process is important in the direct recycling of aluminium method. Compacted chips affect the mechanical properties and microstructure of aluminium alloy.

Misiolek *et al.*, (2012) used a multi-layer billet compaction technique which is constant mass of 550g of aluminium chips were compacted in one stroke on hydraulic press in a steel tube with an inside diameter of 60 mm using compacting 500 kN. This is the highest compaction force allowing ejection of a chip based billet without damaging it on our compaction press.

Pepelnjak, T. *et al.*, (2012) used cold compaction which is carried out on a 2.5 MN double-stroke hydraulic press in a diameter 32 mm closed die. Amount of approximately 33 g was used for each compression to ensure the final specimen height of 15-17 mm depending on the chips type.

Table 2.4 presents compression for different chips type. Pre-compacting was performed with the same tool-set and on the same hydraulic press while different number of pre-compacting varied on type of chips.

Table 2.4: Number of compression operation for each chip type
(Pepelnjak, T. *et al.*, 2012)

Chip type	A	B	C	D	E
First pre-compressions	3	3	1	2	2
Second pre-compressions	4	4	4	2	4
Third pre-compressions	1	1	1	1	1

Hafeez, T. M (2012) used hot forging that difference pressure applied in their research. Hot forging also have a same concept with compaction which is applied temperature and pressure. In their research, difference pressures are applied in range 4-7 tonne and constant value of temperature is 520°C.

Guley, V. *et al.*, (2010) presented the *AA1050* pins and *AA6060* chips were mixed in an 1:1 weight ratio and compacted to billet inside a thick-walled steel tube with an inner diameter of 60 mm and a punch by using universal testing machine. The billet are repeated the compaction with additional chips until a billet length of approximately 175 mm.

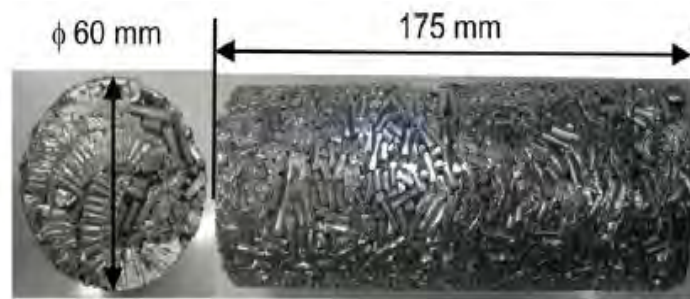


Figure 2.9: billet of *AA1050* pins and *AA6060* chips (Guley, V. *et al.*, 2010)

Tekkaya *et al.*, (2009) had present in their paper which is difference compacting forces for the aluminium were test in dependence of the specific geometrical chip properties and compacting pressure of up to 20 MPa. Seven compacting steps were necessary to produce one billet with a larger than the minimum billet length of 88 mm. In this way initial volume of chips was compacted, more chips were filled in the compacted tube and, again, compacting was done. Procedure was repeated until the complete billet length was reached. A punch force with maximum of 60 kN over punch travel for 4 compacting steps is shown in Figure 2.10.

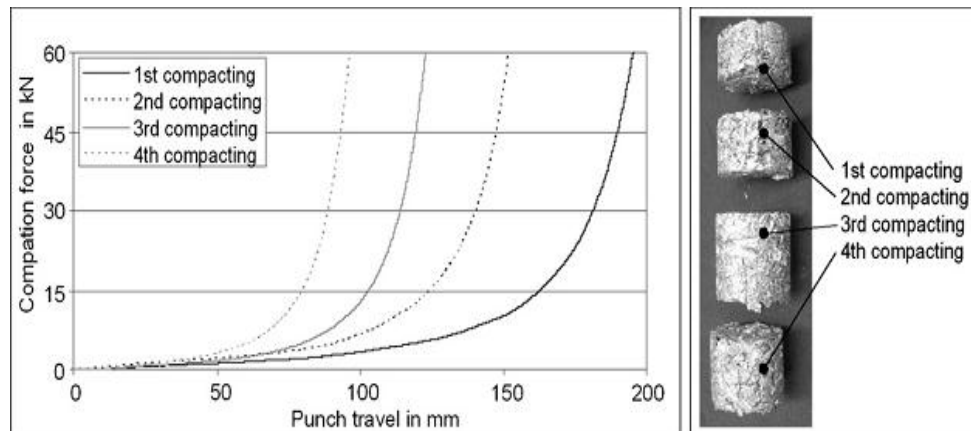


Figure 2.10: Compacting of chips-Left: Compacting force over punch travel for four steps. Right: Billet fallen apart made of milling chips, compacted in four steps
(Tekkaya *et al.*, 2009)

From Figure 2.10, it shows that some of the billets broke at the contact surface of the difference compacting steps, so that the use of a non-planar stepped punch is suggested. The turning chips of type A were placed in an aluminium, 88 mm long covering tube to prevent falling apart of the billet after compacting. The turning chips of type B have been compacted without a covering tube. Due to their length and shape, they compacted to a solid unit by plastic deformation based on interlocking each other. For type C did not develop any cohesion or twisting by plastic deformation during the compacting process.

Mashhadi, *et al.*, (2009) which is aluminium alloy were cold pressed at different temperature. A floating cylindrical die with a diameter of 24 mm was used. The designation of product that Ref used melted ingot as reference specimen, *CP9M* used cold pressed at 900 MPa and melted in molten *AA 336* aluminium alloy at 750°C. Meanwhile, for *CP9S* used cold presses at 900 MPa and melted into *KCl*, *NaCl* and *KF* flux at 750°C.

Maoling *et al.*, (2008) used a cold pressed and were loaded into a 40 mm diameter cylindrical container. The pressure and the holding time were 300-310 MPa and 3-5 s, respectively. Following the cold-press process, the container with the formed billet was heated at 673 K for 20 min.

Fogagnolo *et al.*, (2003) which is aluminium alloy chips were cold pressed at different pressures to determine the compressibility curve. A floating cylindrical die with 25 mm of diameter was used. The samples, previously cold pressed at 650 MPa, were submitted to hot pressing at 500°C in a cylindrical mould with graffito as lubricant. Two times and two pressures were used to obtain the hot pressed samples, according to Table.2.5.

Table 2.5: Parameter used for the hot pressing (Fogagnolo *et al.*, 2003)

Pressing pressure (MPa)	Pressing time (min)
400	5
700	5
400	50
700	50

The mixture were pre-compacted by cold molding in a device with a device with a floating die under a constant pressure change in the range of 210-400MPa. In some cases, pre-sintering was employed to set in motion the diffusion transport of matter between the aluminium alloy particles and the hardening phases. Because of the relatively small number of contact bridges between the particles and the highly intensive oxidation of their surfaces, the extended of diffusion transport during pre-sintering was very limited (Gronostajski *et al.*, 2000, 1999).

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PTTA UTHM
PERPUSTAKAAN TUNKU TUN AMINAH