Faculty of Manufacturing Engineering

MECHANICAL PROPERTIES OF RECYCLING CHIP ALUMINIUM 7075 THROUGH POWDER METALLURGY TECHNIQUE

Fariza Fuziana Binti Yacob

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FARIZA FUZIANA BINTI YACOB

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DECLARATION

I declare that this thesis entitle "Mechanical Properties of Recycling Chip Aluminium 7075 through Powder Metallurgy Technique" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature	:	…………………………....
Name	:	Fariza Fuziana Binti Yacob
Date	:	31st July 2015

APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Master of Science in Manufacturing Engineering .

Signature	:	…………………………..
Name	:	Profesor Madya Dr. Mohd Warikh Bin Abd Rashid
Date	:	31st July 2015

DEDICATION

To my beloved parents who always support me:

Yacob Bin Ahmad

Rosinah Binti Abdullah

And

To my Beloved Husband,

Mohd Khairul Azhar Bin Mohamad Latif

To my Supervisor*,*

Prof. Madya Dr Mohd Warikh Bin Abd Rashid

To my Families and my Friends

Especially Fevilia, Khairul, Sharafina, Nadiah, Mazlin, Anisah and others

Thanks for their love and care.

ABSTRACT

This research has been carried out based on the recycling of 7075 aluminium alloy via powder metallurgy technique. Methods chose in recycling waste material is being concerned as one of the major issues. Recycled materials were obtained from 7075 aluminium alloy machining chips via powder metallurgy technique. Both ball milling time and sintering temperature have a positive effect on the mechanical properties. The main point in this research is to produce recycled 7075 aluminium alloy by using powder metallurgy technique. This is because by using conventional method, a lot of heat will be involved throughout the process and can pollute the environment. This powder metallurgy technique is propose in a way that this process can assist in saving the environment where minimal heat is used throughout the process. By using this technique, the environmental factor can be reduced other than saving energy and cost. In this research, recycled 7075 aluminium alloy with addition of alumina and graphite was produced. Physical and mechanical properties of the sample with and without addition of alumina and graphite are tested. Each property is then compared to determine which sample has better properties. All samples undergoes the same process which started with ball milling at 100, 150 and 200 rpm, pressed at pressure of 40 tonnes and sintered at three different temperatures which are 550, 600 and 650 °C. After sintering, the sample undergoes physical and mechanical testing. The microstructure of specimens were observed using Scanning Electron Microscopy (SEM) to study the surface morphology, while tensile test were measured by using a Universal Testing Machine (UTM). Besides, particle size distribution was measured using Particle Size Analyzer (PSA) for each speed of powder produced and green density was measured using electronic densimeter before and after the sintering process. Microhardness analysis was made using Vickers Hardness to measure the hardness of the samples after being sintered. Sample A8 (200 rpm ball milling, 650 °C sintering temperature, graphite reinforcement) point out as the highest sintered density of recycled 7075 aluminium alloy (2.681 g/cm^3) with less porosity. The microhardness value with 71 Hv, 25.082 MPa tensile strength and 3.45 % elongation to failure were recorded as the maximum value obtained in the research by the same A8 sample. It is found that porosity, density, tensile strength and microhardness correlates to each other.

ABSTRAK

Kajian ini telah dijalankan berdasarkan kitar semula 7075 aloi aluminium melalui teknik metalurgi serbuk. Kaedah dipilih dalam kitar semula bahan buangan dititik berat sebagai salah satu isu utama. Bahan kitar semula telah diperolehi daripada pemesinan cip aloi aluminium 7075 melalui teknik metalurgi serbuk. Kedua-dua masa penghancuran dan suhu pensinteran memberikan kesan positif ke atas sifat-sifat mekanikal. Tujuan utama dalam kajian ini adalah untuk menghasilkan aloi aluminium 7075 secara kitar semula dengan menggunakan teknik metalurgi serbuk. Ini kerana dengan menggunakan kaedah konvensional, banyak haba akan terlibat sepanjang proses itu yang boleh mencemarkan alam sekitar. Teknik metalurgi serbuk menggunakan cara dimana proses ini boleh membantu dalam menyelamatkan alam sekitar secara meminimumkan haba yang digunakan sepanjang proses. Dengan menggunakan teknik ini, faktor alam sekitar dapat dikurangkan selain daripada menjimatkan tenaga dan kos. Dalam kajian ini, kitar semula 7075 aloi aluminium dengan penambahan alumina dan grafit telah dihasilkan. Sifat-sifat fizikal dan mekanikal sampel dengan penambahan dan tanpa penambahan alumina dan grafit diuji. Setiap sifat kemudiannya dibandingkan untuk menentukan sampel yang mempunyai ciri-ciri yang lebih baik. Semua sampel melalui proses yang sama yang bermula dengan bebola penghancuran pada 100, 150 dan 200 rpm, ditekan pada tekanan 40 tan dan disinter pada tiga suhu yang berbeza iaitu 550, 600 dan 650 ^{o}C. Selepas pensinteran, sampel menjalani ujian fizikal dan mekanikal. Mikrostruktur spesimen diperhatikan menggunakan Mikroskopi Imbasan Elektron (SEM) untuk mengkaji morfologi permukaan, manakala ujian tegangan telah diukur dengan menggunakan Mesin Ujian Universal (UTM). Selain itu, taburan saiz zarah diukur menggunakan Penganalisa Saiz Zarah (PSA) bagi setiap kelajuan serbuk yang dihasilkan dan ketumpatan diukur menggunakan densimeter elektronik sebelum dan selepas proses pensinteran. Analisis mikro-kekerasan dibuat menggunakan Kekerasan Vickers untuk mengukur kekerasan sampel selepas di bakar. Sampel A8 (dengan 200 rpm bebola penghancuran, 650 ^{o}C suhu pensinteran, tetulang grafit) menunjukkan kepadatan tersinter tertinggi selepas 7075 aloi aluminium dikitar semula (2.681 g/cm^3) dengan kurang keliangan. Nilai kekerasan dengan 71.0 Hv, 25.082 MPa kekuatan tegangan dan 3.45 % kegagalan pemanjangan direkodkan sebagai nilai maksimum yang diperoleh dalam kajian dengan sampel yang sama iaitu A8. Hal ini menunjukkan bahawa keliangan, ketumpatan, kekuatan tegangan dan kekerasan mempunyai hubung kait antara satu sama lain.

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LIST OF ABBREVIATIONS

%	-	Percent
AA	-	Aluminium Association
Al	-	Aluminium
Al_2O_3	-	Alumina
AlN	-	Aluminium nitride
ANSI	-	American National Standard Institute
ASM	-	American Society for Metals
ASTM	-	American Society for Testing and Materials
B_4C	-	Boron carbide
$C_{18}H_{36}O_2$	-	Stearic acid
CIP	-	Cold Isostatic Pressing
g	-	Gram
g/cm^3	-	Gram per cubic centimeter
HB	-	Brinell hardness
Hv	-	Vickers hardness
kcal/kg	-	Kilocalorie per kilogram
kg/dm^3	-	Kilogram per cubic decimeter
m/min	-	Meter per minute
min	-	Minute
mm	-	Milimeter

mm/tooth	-	Milimeter per tooth
MPa	-	Mega Pascal
MPa	-	Mega Pascal
^{o}C	-	Degree celcius
PM	-	Powder metallurgy
PSA	-	Particle Size Analyzer
rpm	-	Revolution per minute
SEM	-	Scanning Electron Microscopy
Si_3N_4	-	Silicon nitride
SiC	-	Silicon carbide
TiB_2	-	Titanium diboride
TiC	-	Titanium carbide
TiO_2	-	Titanium dioxide
UTHM	-	Universiti Tun Hussein Onn
UTS	-	Ultimate tensile strength
W/(mK)	-	Watt per meter Calvin
µm	-	Micrometer

LIST OF PUBLICATIONS

1) **Fuziana, Y. F.,** Warikh, A. R. M., Lajis, M. A., Azam, M. A., and Muhammad, N. S., (2014). Recycling aluminium (Al 6061) chip through powder metallurgy route. Materials Research Innovations, 18(S6), S6-354. 1st International Conference on The Science and Engineering of Materials (ICoSEM 2013), 13-14 Nov. 2013. University of Malaya.

2) Rashid, M.W.A., **Yacob, F. F**., Lajis, M. A., Abid, M.A.A.M., Mohamed, E., and Ito, T., (2014). A Review: The Potential of Powder Metallurgy in Recycling Aluminum Chips (Al 6061 & Al 7075). International Design and System Division Conference, 17-19 Sept. 2014. Tokushima University, Japan.

CHAPTER 1

INTRODUCTION

Nowadays, one of the great challenges of the world is conserving energy to reduce the usage of primary natural resources by developing and improving lightweight materials (Hassan and Gupta, 2005; Warikh et al., 2012). The increasing global demand of aluminium is because of its excellent corrosion resistance with good strength and low density compared with steel (Frery and Frery, 2004; Ng et al., 2012). Aluminium is the most abundant metallic element and it is the third constituent of the earth's crust. However, a large quantity of aluminium machined chips will be produced with the increasing of its application. So, to encourage the contribution of aluminium to the industry, it is necessary to develop good recycling process. The public concern of global warming has led to the production of secondary aluminium to substitute the current used of primary aluminium (Amini et al., 2009; Frery and Frery, 2004). The main advantages of aluminium recycling are low in production cost, do not harm the environment and saving primary aluminium resources and thus satisfy the modern industrial societies aim (Logozar et al., 2006; Zhou et al., 2006). Recently, direct conversion method of aluminium chip recycling has been introduced without the melting process to overcome the disadvantages of conventional method.

1.1 Background of Study

Nowadays, methods chose in recycling waste material is being concerned as one of the major issues. The cost of material processing produced by conventional methods is much higher compared to recycled materials (Sherafat et al., 2009). Thus, recycling has become a well-known method used in material production, mainly in developed countries (Chmura and Gronotajski, 2006). In recent years, a technology in manufacturing materials has been developed with desired properties, including manufactured product from waste material (Chmura and Gronotajski, 2000; Gronotajski and Matuszak, 1999; Gronotajski et al., 2001).

The production process of primary aluminium requires complicated processes starting with bauxite mining, purification of alumina by a Bayer process that consumes a lot of energy. This deficiency has encourage the development of secondary aluminium resources due to climate change concern and environmental benefit including energy saving, reduction of solid waste disposal and reduction of greenhouse gasses emissions (Frery and Frery, 2004). Thus, its economic and environmental benefits have made the secondary aluminium resource turn out to be even more popular issue in aluminium production area. Most reported work of aluminium recycling used pure aluminium without the specific series.

During manufacturing of products, many different types and sizes of chips are produced after the machining process (Puga et al., 2009). However, conventional recycling will cause metal lost due to oxidation and also increase the labour and energy cost (Gronotajski et al., 2001; Gronotajski et al., 2002). However, only 5% of energy required in producing the aluminium from ore needed to recycle it (Gronotajski and Matuszak, 1999; Verran and Kurzawa, 2008). Therefore, secondary aluminium has been approved in many countries. The efficiency of the two methods can be evaluated by comparing the total cost involved and percentage of metal losses during the recycling processes.

By using the conventional aluminium recycling method, several melting techniques were conducted to study the recyclability of aluminium chips and the effects of chips preparation in the aluminium dross production and recovery rate (Puga et al., 2009). Besides, the pressure of cold press also affects the melting process. Research had been conducted using both conventional and direct conversion methods to recycle different types of aluminium chips. For example, aluminium turning chips were melted at 800 ^oC with protective salt flux under nitrogen atmosphere. The authors also stated that the complicated part was to separate the selected aluminium chips into different types and sizes (Amini et al., 2009; Xiao and Reuter, 2002). Other than that, aluminium chips were milled into powder, cold compacted and followed by extrusion at the temperature range of 500–550 ^oC (Gronotajski and Matuszak, 1999). Other researchers also added the sintering process before the final extrusion (Samuel, 2003). Tekkaya et al. (2009) directly hot extruded the 6061 aluminium chips into blocks. Using the direct conversion recycling process, Sherafat et al. (2009) mixed the 7075 aluminium chips with aluminium powder to study the effects of amount of aluminium powder and extrusion temperature on the mechanical properties of materials produced.

It has been found that the direct conversion of aluminium and its alloy chips into final products is highly potential in aluminium recycling process to produce materials with lower porosity and relative density with up to 95 %, and produce slightly lower tensile and hardness of recycled aluminium compared to those metallurgically produced aluminium (Gronotajski and Matuszak, 1999; Gronotajski et al., 1998). The main aim of the investigations was to determine the effect of particle size distribution of the aluminium powder produced from the chips, ball milling speed and different sintering temperature on the properties of the final samples.

1.2 Problem Statement

An alternative process has been elaborated to avoid the troubles deriving from the conventional recycling process, where the chips are cut or milled and converted directly by powder metallurgy process into final products. Conventional aluminium recycling process starts with collection of used aluminium products, followed by the treatment and sorting process for reprocessing. Then, the cleaned product will go through remelting process to produce molten aluminium. The molten aluminium is then made into large blocks called ingot before further processing into finished products. The remelting process is the main disadvantage of conventional aluminium recycling process that can cause carbon dioxide emission, produce new scrap and hazardous waste, high energy consumption and operating cost and also causing 46 % material loss.

Recycling of aluminium and its alloys by the direct convertion method is relatively simple, consumed only a small amount of energy and does not have any harmful effects on the environment and produce 95 % of material recovery. The correct size and shape of chips is essential for good compaction during the preliminary pressing operation. It has been found that direct conversion of aluminium and its alloy chips into final products results in materials characterised by low porosity and a relative density, exceeding 95 %, the hardness and tensile properties of the recycled materials, however, being slightly lower than those of metallurgically-produced material. To obtain better properties of the extruded products, new investigations were undertaken, the main aim of the investigations being to determine the effect of small additions of strengthening particles into the aluminium chips on the properties of the final products.

At the point when metal products are manufactured, significant measures of waste as chips and disposes of are produced. This waste and scrap is return to melting, whereby a portion of the metal is recouped and reutilized in production processes. Throughout recycling of waste material, a huge amount of metal is lost as a consequence of oxidation during remelting process and costs of labour and energy as well as the expenditures on environmental protection increases the general cost of the process (Gronostajski et al., 2001). So, by eliminating the remelting process, the entire problem caused by remelting process can be avoided.

A few researchers found that the hardness and tensile properties of the recycled materials are slightly lower than those of metallurgically produced materials, which is due to residual porosity and imperfect bonding between the chips after hot extrusion process (Gronostajski et al., 1998). Therefore, in order to obtain better mechanical properties of the products, the effect of aluminium powders as a binder in recycling Aluminium 7075 was investigated (Sherafat et al., 2009).

Powder Metallurgy is thought to be the most common production technique for metal matrix composites (Rahimian et al., 2009). Authors also compared that powder metallurgy technique have lower processing temperature and this is the reason why melting of aluminium is axed from the recycling of aluminium chips. Besides that, powder metallurgy has proven that it can be cost effective. Therefore, in this research, powder metallurgy will be used as the method to recycle aluminium alloy 7075.

1.3 Objectives of study

a) To produce recycled 7075 aluminium alloy by using powder metallurgy technique.

b) To analyze the recycled 7075 aluminium alloy performance in terms of physical and mechanical properties.

1.4 Scope of study

The scope of this thesis are conducted using Al7075 billet and converted into chips using high speed end milling machine (Sodick-MC430L) with the following parameters and conditions:

a) Tool: 10.0 mm diameter uncoated solid carbide
b) Dry cutting operation without coolant
c) Spindle speed: 35 000 rpm
d) High cutting speed: 1100 m/min
e) Depth of cut, DOC: 0.5 mm
f) Feed, f: 0.02 mm/tooth

The aluminium chips were then converted into powder by ball milling process using planetary ball milling machine (Insmart Twin Bowl Mini Ball Mill) at three different ball milling speed which are 100, 150 and 200 rpm. During the ball milling process, the aluminium powder was mixed with 4 % alumina, Al_2O_3 (0.5 µm, 99 % purity) and compared with sample with a mixture of 1 % of graphite. Then, powder metallurgy method was continued by compaction process with constant pressure of 40 tonne into the standard tensile specimens (6 mm x 100 mm x 5 mm) based on ASTM E8 and were sintered in tube furnace in argon environment, at three different temperatures which are 550, 600 and 650 ^{o}C.

The microstructure of specimens were observed using Zeiss EVO-50 ESEM Scanning Electron Microscope machine to study the surface morphology. Tensile test were measured by using a Universal Testing Machine (Shimadzu AG-1 100KN, Japan). Particle size distribution was measured using Particle Size Analyzer (Malvern Mastersizer 2000) for each speed of powder produced. Green density was measured using Electronic

Densimeter (Alfa Mirage MD-300S) before and after the sintering process. Microhardness analysis was made using Vickers Hardness (HM-200 Series Micro Vickers Hardness Tester) to measure the hardness of the samples after being sintered and was calculated with average repeated test for the results.

1.5 Significance of Study

This research uses a direct technique for recycling aluminium chips by powder metallurgy process instead of conventional method which it will carry out without melting phase. This technique is characterized by fewer steps and gives benefit on low energy consumption and operating cost. It reveals the performance of recycled aluminium chips on their mechanical properties and microstructure by comparing them with the original aluminium-base composite. It is expected to review the possibility of this recycled aluminium chips as a secondary resources as an alternative to overcome the shortage of primary resources. This will be an initiative to machining practitioners and industry as a way to support our government on Green Technology and waste management. It will help to reduce the land use for mining and provides very low air pollution emission. This effort can be describe as sustainable manufacturing which is to create the manufactured products using the process that minimize negative environmental impact, conserve energy and natural resources, safe for communities and economically.

1.6 Structure of Thesis

This project was organized into five chapters:

- Chapter 1 is the introduction of the report. This chapter contains the background, problem statement, objectives and scope of the thesis. It provides an overview of the thesis, summarization of chapters and brief explanation of overall thesis.