EFFECT OF SILICON CARBIDE (SiC) ON MECHANICAL AND PHYSICAL PROPERTIES OF SOLID STATE RECYCLED ALUMINIUM AA6061 BY USING HOT EXTRUSION METHOD

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This thesis especially dedicated to:

My beloved parents;

Kuddus Hamada and Salawiyah Sulleh

With every prayer, hope and sacrifice for my successful;

My siblings;
Dewi Anggriany Kuddus
Nirmala Kuddus
Suraya Kuddus
Norafifah Kuddus
For their patience and love;

My beloved fiance;
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For the endless support, and encourage me;

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ABSTRACT

In solid state recycling processes, there are two methods in recycling aluminium which are conventional and direct conversion methods. Direct conversion method is a current approach that excludes the metal chips re-melting process compared to the conventional recycling method. Direct conversion in a hot extrusion process that contributes to the green technology production in reducing energy consumption, operating costs and parts. This research aims to investigate the effect of silicon carbide (SiC) on mechanical and properties of recycled aluminium AA6061 produced by hot extrusion method. This study employed full factorial 2^3 design experiments that should satisfy the two operating temperature (T) of 450°C and 550°C, with two preheating time (t) of 1 hour and 3 hour reinforced with two volume fraction of silicon carbide (SiC) of 5 wt.% and 15 wt.%. Response Surface Methodology (RSM) utilized the factor towards the response which is Ultimate Tensile Strength (UTS), Elongation to Failure (ETF) and Microhardness (MH). The best parameter setting for the extrusion was found to be at T=550°C, t=1 hour and SiC=5 wt.%. This parameter resulted in UTS=18022 MPa, ETF=18.07%, MH=71.52Hv, and Density=2.73 g/cm^3. Based on RSM, with desirability of 87.67%, the optimum parameter T=550°C, t=2 hour and SiC=5 wt.% were suggested an optimized composite performance. The mechanical properties were analyzed by tensile and microhardness testing. While that, the physical property analysis was focusing on density and microstructure analysis. In conclusion, hot extrusion process was proven as an alternative method in direct recycling of aluminium chips.

ABSTRAK

Terdapat dua kaedah dalam kitar semula aluminium iaitu kaedah penukaran konvensional dan secara terus. Kaedah penukaran terus adalah pendekatan semasa yang mengecualikan proses pencairan logam melalui kaedah konvensional. Penukaran secara terus melalui proses penyemperitan panas menyumbang kepada sistem teknologi hijau dalam mengurangkan penggunaan tenaga, kos operasi dan bahagian. Kajian ini bertujuan untuk mengkaji kesan silikon karbida (SiC) pada mekanikal dan sifat aluminium AA6061 yang dikitar semula melalui kaedah penyemperitan panas. Kajian ini menggunakan eksperimen reka bentuk faktorial penuh 2^3 menggunakan dua suhu operasi (T) 450°C dan 550°C dengan dua masa pemanasan (t) selama 1 jam dan 3 jam diperkuatkan dengan dua komposisi silikon karbida (SiC) daripada 5% dan 15%. Kaedah Gerakbalas Permukaan (RSM) menilai faktor-faktor yang berkaitan dengan tindak balas Kekuatan tegangan muktamad (UTS), Pemanjangan kearah kegagalan (ETF) dan Mikrokekerasan (MH). Tetapan parameter terbaik untuk penyemperitan adalah pada T=550°C, t=1jam dan SiC 5%. Keputusan parameter ini untuk UTS=18022 MPa, ETF=18.07%, MH=71.52Hv, dan Ketumpatan=2.73 g/cm^3. Berdasarkan RSM, dengan keinginan 87.67%, parameter maksimum T=550°C, t=2 jam dan SiC=5%. Telah dicadangkan untuk menghasilkan prestasi komposit yang optimal. Sifat mekanikal yang dianalisis oleh ujian tegangan dan mikrokekerasan. Manakala, analisis sifat fizikal akan memberi tumpuan kepada keseimbangan ketumpatan dan analisis mikrostruktur. Kesimpulannya, proses penyemperitan panas terbukti sebagai kaedah alternatif dalam kitar semula langsung cip aluminium.

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LIST OF ABBREVIATION

AA6061	-	Aluminium alloy 6061
Adj. R2	-	Adjusted R2
ASTM	-	American Society for Testing Materials
CCD	-	Central Composite Design
ETF	-	Elongation to Failure
F	-	Force
Hv	-	Hardness Vickers
MH	-	Microhardness
MMC	-	Metal Matrix Composite
Pred. R2	-	Predicted R2
P-value	-	Proportion of time of probability
R2	-	Coefficient of determination
RSM	-	Response Surface Methodology
SiC	-	Silicon Carbide
Std. Dev	-	Square root of the residual mean square
T	-	Temperature
t	-	Preheating time
UTHM	-	Universiti Tun Hussein Onn Malaysia
UTS	-	Ultimate Tensile Strength

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(i) M. I. A. Kadir, M. S. Mustapa, A. S. Mahdi, **S. Kuddus**, and M. A. Samsi (2017). Evaluation of hardness strength and microstructures of recycled Al chip and powder AA6061 fabricated by cold compaction method., (January). https://doi.org/10.1088/1757-899X/165/1/012012

(ii) **Kuddus, S.,** Mustapa, M. S., Ibrahim, M. R., Shamsudin, S., Irfan, M., Kadir, A., & Lajis, M. A. (2017). Microstructures and Tensile Characteristics on Direct Recycled Aluminium Chips AA6061 / Al Powder by Hot Pressing Method, 909, 9–14. http://doi.org/10.4028/www.scientific.net/MSF.909.9

(iii) **S Kuddus**, M S Mustapa, M R Ibrahim, S Shamsudin, M A Lajis, A Wagiman. (2018). Physical Characteristics of Solid State Recycled Aluminum Chip AA6061 Reinforced with Silicon Carbide (SiC) byusing Hot Extrusion Technique. https://www.researchgate.net/publication/331434720_Physical_Characteristics_of_Solid_State_Recycled_Aluminum_Chip_AA6061_Reinforced_with_Silicon_Carbide_SiC_by_using_Hot_Extrusion_Technique

CHAPTER 1

INTRODUCTION

1.1 Introduction

Aluminium is the most heavily used nonferrous metal in the world that it can be seen easily in packaging, soft drink cans, food plates, foils, sidings, gutters, and automotive parts. Aluminium is a perfectly recyclable material as it is a 100% material that is endlessly recyclable compared to other common recyclable materials that clutter up our landfills such as glass, paper, metals, cardboard and plastics. Air pollution is associated with synthetic materials and other harmful impurities that diffuse and become part of the air. These materials are mostly industrial wastes, vehicle exhaust fumes, action logging, and solid particles and gases that escape into the air. There are many adverse effects that would befall mankind if control measures are not taken immediately to address the contamination. The government also takes the initiative to raise public awareness about recycling by introducing the 3R (Reuse, Reduce, Recycle) campaign to provide garbage bins of various colours, so that litter could be easily separated by categories such as plastic, glass and paper. Figure 1.1 shows the evolution of different manufacturing concepts and their contributions to stakeholder values, and the proposed closed-loop system involving 6Rs.

Metals have always been the most recycled material in the world. The recycling of waste metallic material and use of scrap is important for economic production of steelworks (Torkar *et al*., 2010). In fact, the making of steel requires recycled steel in the production of the raw material. Recycling metals saves energy and helps prevent the depletion of natural resources. An entire industry has grown up around recycling metal. This is because everything that contains metal is intrinsically valuable. In the subsequent decades, the transportation and construction sectors have always been the principal benefactors of aluminium products. Even at present, the bulk usage is in manufacturing doors and windows, followed by passenger vehicles. The short history of aluminium, in comparison to other metals, has seen extensive development and growth, revolutionizing the way we live. As new purposes are discovered in space exploration and here at home, recycled aluminium will continue to be an important part of the future.

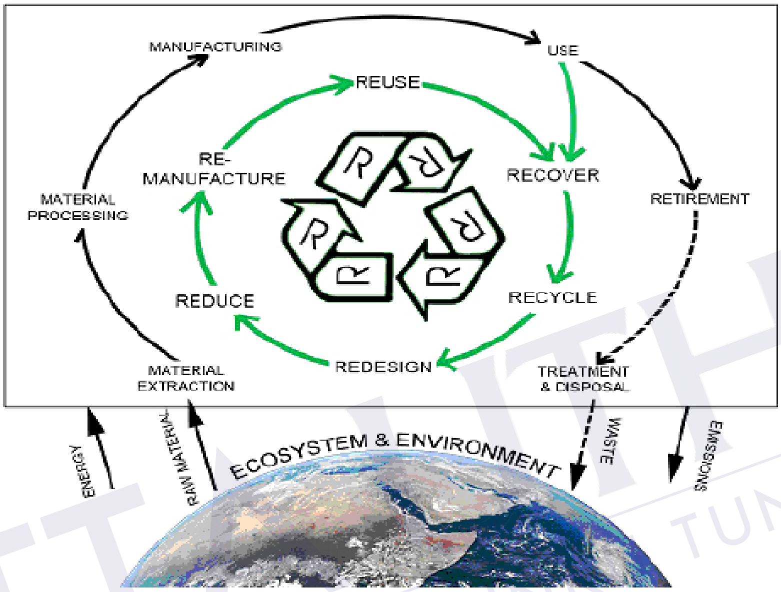

Figure 1.1: Close loop product life cycle system in 6R approach (Jayal *et al.*, 2010)

1.2 Research background

Aluminium alloy is a lighter alloy used as structural metal, combining many advantages such as high specific stiffness, high specific strength, good dimensional stability, machinability, and offers excellent corrosion resistance with good strength and low density. Due to increasing demand, solid waste problem is one of the most popular issues that has received extensive public extension despite the increasing amount of aluminium utilized today coming from recycled metals such as in automotive components. Based on the data from the International Aluminium Institute, the current global aluminium old scrap market primarily consists of scraps from automotive and packaging. These factors will make recycling more competitive, and over time, the relative importance of secondary aluminium production to society will grow. Aluminium recycling is one of the processes by which scrap aluminium can be reused in products after its initial production. However, there are losses at every stage of conventional aluminium recycling process, such as losses caused by metal oxidation during melting, some losses through 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. Ultimately, not more than 54% of the metal is recovered (Gronostajski *et al*., 2000).

1.3 Problem statement

Conventional recycling techniques generate dangerous residues that require elimination. This process usually requires high cost and vaporization techniques (Liu & Müller, 2012). Aluminium loss can easily reach 45%-50% and at the end, the aluminium loss is very high, making this traditional recovery procedure highly inefficient (Duflou *et al*., 2015). For that reason, aluminium is needed to have alternative recovery instead of conventional aluminium recycling as the demand increases and to prevent the shortage of the primary sources of aluminium that cause expensive cost of operation. At the same time, pollution to the environment can be reduced when the nature of recycling is adapted. Hot extrusion is proven have better properties by previous studies compared to other different techniques of recycling. The conventional aluminium recycling carried out with a melting phase at the same time requires pre-processing of the scraps to remove impurities. There are loses at every stage of recycling process due to metal oxidation, slag mixing, and scraps resulting from casting (Cui & Roven, 2010). Consequently, this study introduces a new approach of solid state direct recycling of aluminium using hot extrusion technique which leads to simpler steps and gives benefits of low energy consumption and operating cost due to the process implied above the recrystallization temperature (Chiba *et al*., 2011).

On the other hand, the hardness and compression properties of the recycled materials are slightly lower than powder metallurgical-produced material. This is where reinforcing material plays an important role to bear a major portion of stress in the metal matrix composites due to its stiffer properties (Boopathin *et al*., 2013). To obtain better properties of the extruded products, new investigations are undertaken, with the main aim of determining the effect of small additions of strengthening particles into the aluminium chips on the properties of the final compaction products. Ceramic reinforcement such as alumina and silicon carbide (SiC) particles is widely used as reinforcement for aluminium alloy (Adamiak *et al*., 2004; Torralba *et al*., 2003). For a while, silicon carbide particulates are the most favoured reinforcements for aluminium alloy composites because of the enhanced achievable properties such as hardness and compression (Canakci & Varol, 2014) whereby, the hardness of the AA7075 composites increase with increasing amount of SiC content.

To overcome this problem, various studies are conducted to find the solution. Identifying the optimum method and parameter in direct conversion recycling prevents the melting phase and manages to reduce pollution. However, the related work conducted which focuses on aluminium chip particles mixed with SiC reinforcement was less reported. Therefore, this study proposes to investigate the effect of mechanical and physical properties with different compositions of reinforced particles, operating temperature and preheating time. Additionally, response surface methodology analysis is employed in order to create the optimization parameter.

1.4 Objectives of study

This research aims to seek the effect of hot extrusion parameters in solid state of recycled aluminium AA6061, which focuses on the objective as follows:

i. To investigate effect of Silicon Carbide (SiC) on the mechanical and physical properties of recycled aluminium chips.
ii. To determine the optimization of hot extrusion parameters effect over the mechanical properties response by employing the Response Surface Methodology (RSM).

1.5 Scope of study

To achieve the objectives of this research, there are scopes of works that should be considered:

i. Selection of the material in this study
    a. Aluminium alloy AA6061

   b. Silicon Carbide as reinforced particles

ii. Preparation of specimens AA6061-SiC composite at different percentage of reinforcement (5, 15) wt.%.

iii. Conducting the solid state recycled through hot extrusion process with the designated parameter:

   a. Preheating temperature of 450 ºC and 550ºC.
   b. Preheating duration of 1 and 3 hours.

iv. Developing the optimization on the effects of reinforced particles, operating temperature and preheating time over the mechanical properties responses by employing the Response Surface Methodology (RSM) approach:

   a. Software : Minitab 18
   b. 3 factors and 2 levels

v. Investigating and evaluating the responses on mechanical and physical properties as below:

   a. Tensile analysis of ultimate tensile strength (UTS) and elongation to failure (ETF).
   b. Microstructure analysis focusing on grain size, grain boundary and void using optical microstructure (OM).
   c. Subsurface layer changes consisting of microhardness (Hv) using Vickers microhardness tester.
   d. Density of the specimen by using density balance machine.
   e. Fracture surface morphology using Scanning Electron Microscopy (SEM).

1.6 Significant of study

This research aim to explore the solid state recycled through new approach of direct recycling process by optimization parameter in hot extrusion method. The metal matrix composite (MMC) in this study will shows the improvement of strength and microstructure which is aluminium alloy as matrix material will be mixed with silicon carbide (SiC). The performance of mechanical and physical properties will be focus in this study. On the other hand, this study expected to review the possibility of recycling metal waste using direct conversion over than conventional process.

CHAPTER 2

LITERATURE REVIEW

2.1 Aluminium alloy

In 1807, the English chemist Humphrey Davy, believed that the mineral alumina (Al_2O_3) had metallic base that was extracted to metal. He proceeded to name the metal as alumium and later changing its name to aluminium. In 1825, the Danish physicist/chemist, Hans Orsted, finally succeeded in separating the metal and noted it as "resemble tin". In 1845, the German physicist, Friedrich Wohler, was the first to determine the specific gravity, ductility, and various other properties of aluminium (Groover, 2011).

The modern electrolytic process for producing aluminium was based on the concurrent but independent work of Charles Hall in the United States and Paul Heroult in France in around 1886. In 1888, Hall and a group of businessmen started the Pittsburgh Reduction Co. The first ingot of aluminium was produced by the electrolytic smelting process that same year. Because the demands for aluminium widened, the need for large amounts of electricity for the production process led the company to relocate in Niagara Falls in 1895, where hydroelectric power was becoming available at a very low cost. In 1907, the company changed its name to the Aluminium Company of America (Alcoa). It was the sole producer of aluminium in the United States until World War II (Groover, 2011).

Aluminium and magnesium are light metals, and regularly used in engineering applications. Both elements are generous on Earth, aluminium on land, and magnesium in the sea, and are easily extracted from their natural shapes. Table 2.1 shows the occurrence of elements on Earth where aluminium is the most common metal in the Earth's crust that provides almost an endless raw material source. Reared with oxygen and silicon, aluminium is the third common element and has a content amount up to 8% in the continental crust, and 6.8% in the entire Earth's crust (Schmitz, 2014).

Table 2.1: Occurrence of elements on earth (Schmitz, 2014)

Element	Occurrence in %	
	Total earth	Earth crust
Others	<1	<1
Aluminium	1.1	8.0
Ca	1.1	2.4
Na	<1	2.1
K	<1	2.3
S	1.9	<1
Ni	2.4	<1
Mg	13.0	4.0
Si	15.0	28.0
O	30.0	46.0
Fe	35.0	6.0

Table 2.2 shows the characteristic of aluminium in comparison to copper and steel. Aluminium is a white silvery shining metal of high electrical conductivity and has good ductility. In terms of chemical reaction, it has high reactive base metal with high affection to hydrogen in the liquid phase and strong tendency to form aluminium oxide compounds. Due to the opaque oxide skin that seals the metal against air, it has good resistance on the surface from chemical attack.

i. Low specific gravity

   It has density of 2.7 g/cm^3, one third of the specific gravity of steel, and its ratio is also better than heavy metals. The advantage is when the low weight application is needed such as during construction, airplanes, vehicles and frequent movement component. The reduction of mass forces during acceleration and movement in transportable equipment results in lower energy requirements. It requires less cost for operation and maintenance because it has good resistance of corrosion.

ii. Good strength

   Aluminium has different strength characteristic of alloy and suitable for a variety of designs in applications.

iii. Good resistance corrosion

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