



**THE EFFECT OF COOLING SLOPE CASTING ON MICROSTRUCTURE AND
MECHANICAL PROPERTIES OF A319 ALLOY AFTER PROCESSED BY
EQUAL CHANNEL ANGULAR PRESSING**

This report is submitted in accordance with requirement of the University Teknikal
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by

NOR SHWAZNI BINTI ISHAK

B051310315

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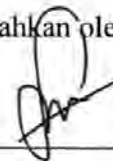
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Alamat Tetap:
F 468 BATU 2 JLN JENIANG
08300 GURUN
KEDAH

Tarikh: 16/6/2017




Cop Rasmi: **DR. MOHD SHUKOR BIN SALLEH**
Senior Lecturer
Faculty of Manufacturing Engineering
Universiti Teknikal Malaysia Melaka
Hang Tuah Jaya
76100 Durian Tunggal, Melaka

Tarikh: 16/6/2017

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I hereby, declared this report entitled “The Effect of Cooling Slope Casting on Microstructure and Mechanical Properties of A319 Alloy after Processed by Equal Channel Angular Pressing” is the results of my own research as cited in references.

Signature : 

Author's Name : NOR SHWAZNI BINTI ISHAK

Date : 16 / 6 / 2017

APPROVAL

This report is submitted to the Faculty of Manufacturing Engineering of Universiti Teknikal Malaysia Melaka as a partial fulfillment of the requirements for the degree of Bachelor of Manufacturing Engineering (Manufacturing Process) (Hons.).

The members of supervisory committee are as follow:



(Dr. Mohd Shukor bin Salleh)

DR. MOHD SHUKOR BIN SALLEH
Senior Lecturer
Faculty of Manufacturing Engineering
Universiti Teknikal Malaysia Melaka
Hang Tuah Jaya
76100 Durian Tunggal, Melaka

ABSTRAK

Dalam projek ini, feedstock daripada aloi A319 dihasilkan dengan menggunakan kaedah tuangan cerun penyejukan. Bahan suapan yang dihasilkan kemudiannya digunakan untuk saluran sama sudut menekan (ECAP) menggunakan laluan A pada suhu bilik. Mikrostruktur dan sifat mekanik aloi A319 sebelum dan selepas diproses oleh ECAP telah disiasat. Sebahagian daripada sampel ECAP telah menjalani T6 rawatan haba untuk menilai kesan jadual rawatan haba ke atas globularization aloi. Sampel aloi A319 telah dipanaskan pada 520 °C selama 8 jam dan kemudian lindap kejutan dalam air dan proses penuaan pada 154 °C selama 4 jam untuk meningkatkan sifat-sifat aloi A319. Kesemua sampel telah dianalisis dengan mikroskop optik (OM) dan mikroskop elektron pengimbas (SEM), ujian kekerasan serta ujian tegangan dan patah. Hasil kajian menunjukkan mikrostruktur selepas diproses oleh ECAP mempamerkan struktur lebih halus selepas 1 pass. Tambahan pula, struktur ECAPed aloi A319 mempunyai tindak balas yang sangat baik untuk pemulihan dan mekanisme penghabluran semula ditapis mikrostruktur berbanding sampel cerun penyejukan. The α -Al globules kurang daripada 80 μm dan faktor bentuk adalah lebih daripada 0.60. Selain itu, sampel ECAP yang menjalani T6 rawatan haba mendedahkan hasil positif dari segi pengagihan fasa homogen dan peningkatan sifat-sifat mekanikal berbanding dengan sampel bukan rawatan haba. Nilai kekerasan Vicker ini menunjukkan bahawa sampel ECAPed menunjukkan kekerasan yang diperolehi lebih tinggi 108.0 HV kepada 114.5 HV selepas rawatan haba. Di samping itu, kekuatan tegangan sampel ECAPed menyediakan 191.483 MPa sehingga 220 MPa dan kemuluran yang tinggi oleh sifat patah. Oleh itu, berdasarkan keputusan yang diperolehi mendedahkan bahawa taburan mikrostruktur dan sifat mekanik aloi bertambah baik ke tahap tertentu kerana saiz grain yang sangat halus disampaikan oleh proses ECAPed.

ABSTRACT

In this project, a feedstock of A319 alloy is produced by using cooling slope casting method. The feedstock then used for equal channel angular pressing (ECAP) using route A at room temperature. The microstructure and mechanical properties of A319 alloy before and after processed by ECAP are investigated. Some of the ECAP samples have undergone T6 heat treatment in order to evaluate the effect of heat treatment schedule on globularization of the alloy. The samples of A319 alloy was heated at 520 °C for 8 hours and then quenching in water and afterwards aging at 154 °C for 4 hours to enhance the properties of A319 alloy. All of the samples were then analyzed by optical microscope (OM) and scanning electron microscopy (SEM), hardness tests as well as tensile and fracture tests. The results revealed that the microstructure after processed by ECAP exhibits more refined structure after 1 pass. Furthermore, the structure of ECAPed A319 alloy had an excellent response to recovery and recrystallization mechanism refined the microstructure as compared to the cooling slope sample. The α -Al globules were less than 80 μm and the shape factor is more than 0.60. Moreover, the ECAP samples that underwent T6 heat treatment revealed the positive results in terms of homogenous distribution of phases and enhancement of mechanical properties as compared with non-heat treated sample. The Vicker's hardness value indicated that ECAPed sample promoted the higher hardness 108.0 HV to 114.5 HV after T6 heat treatment. In addition, it was observed that for ultimate tensile strength of ECAPed sample provide higher strength 191.483 MPa up to 220 MPa and high ductility of fracture behavior after T6 heat treatment. Therefore, the results revealed that the microstructural distribution and mechanical properties of the alloy were improved to a particular extent due to the highly refined grains imparted by ECAPed process.

DEDICATION

I am dedicating this work to my beloved parents, Ishak bin Ahmed and Rubiah bt. Yusoff, who always inspire and support me with their dua and boundless love to endeavour in achieving a success in everything I do.

To my supervisor, Dr. Mohd Shukor bin Salleh, family and all my friends, without whom none of my success would be possible.

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LIST OF ABBREVIATIONS

ASTM	-	American society for testing and materials
CS	-	Cooling Slope
EDM	-	Electrical Discharge Machine
EDX	-	Energy-dispersive X-ray spectroscopy
ECAP	-	Equal Channel Angular Pressing
GS	-	Grain Size
MIT	-	Massachusetts Institute of Technology
MHD	-	Magnetohydrodynamic Stirring
OM	-	Optical Microscopy
FKP	-	Fakulti Kejuruteraan Pembuatan
RT	-	Room Temperature
RAP	-	Recrystallisation and Partial Melting
SEM	-	Scanning Electron Microscope
SF	-	Shape Factor
SIMA	-	Strain Induced Melt Activated
SEED	-	Swirled Enthalpy Equilibrium Device
SSM	-	Semisolid Metal
TEM	-	Transmission Electron Microscopy
UTS	-	Ultimate tensile strength
UTM	-	Universal Testing Machine

LIST OF SYMBOLS

°	-	Degree
°C/min	-	Degree celsius per minute
% EL	-	Percent elongation
mm	-	Milimeter
mm/min.	-	Millimetre per minute
mm/s	-	Millimeter pre second
MPa	-	Mega Pascal
kg	-	Kilograms
kN	-	Kilo newton
S	-	Second
µm	-	Micro meter
wt. %	-	Weight percent

CHAPTER 1

INTRODUCTION

This chapter discusses the background of the study. In addition, this chapter also presents the problem statement, research objective, scope of study and the chapter overview.

1.1 Background of study

The automotive industry in producing the product with good physical and mechanical properties based on alloy becomes the highest demanded. Cooling slope casting is one of the techniques that have been used in recent years in casting industry. Before the CS casting is introduced, the technique such as thixoforming has been used to produce feedstock material for production purpose According to Kumar *et al.* (2014), the thixoforming process involved a huge cost of producing specialized ingots and restricted of size to identify the non-dendritic or globular microstructure in feedstock. In other hand, high cost involved in preparing the feedstock by using thixoforming process. All these process are related with the semi-solid metal process by Kapranos *et al.* (2003).

Semi-solid metal process (SSMP) is a process of producing the product based on automotive manufacturing. Not only that, this forming process was invented at Massachusetts Institute of Technology (MIT) by Spencer in early 1970s. During last 4 decades, there a lot of materials have been tested using this semi-solid metal

process. SSMP is a significance aspect involved in the art of aeronautics which heavier compare to aircraft and marine component for near net shape of manufacturing.

The cooling slope casting (CS) is a most popular method used in producing the suitable feedstock based on alloys. The CS used simple equipment to setup the process with low cost. In addition, Mohammed *et al.* (2013) found that the cooling slope technique is the simplest non agitation process which can be used to produce feedstock with a near-globular solid fraction in a liquid matrix. Moreover, in this method the molten alloy is poured through a cooling slope plate and subsequent solidification in a mould. The CS is a continuous casting process that works by applying a low superheat to the metal at a constant temperature near to or just above the liquidus temperature. The molten metal is then poured into cooling slope and the solidified sample is collected from the mould. Legoretta *et al.* (2008) stated that in CS process the parameters involved such as mould material, mould temperature, cooling slope length, cooling slope angle, superheat and pouring temperature which directly affect the final microstructure of the solidified slurry

Besides that, there are several advantages and disadvantages of the CS process. The advantages of this process are most simple method to produce feedstock with cost effective because CS process used advanced semisolid process based on the technology without any special tool and equipment required. Not only that, the process provides a globular or spheroidal microstructure and non-dendritic microstructure with less segregation and porosity occur in the feedstock.

Furthermore, the limitation of the CS process gave a largest challenge in considering the suitable process parameters such as pouring temperature, cooling slope and cooling slope length to prevent the formation of pores and oxide know as casting defects.

Instead of CS casting method used in producing a feedstock, the first development of Equal Channel Angular Pressing was introduced by V.M. Segal at an institute in Minsk with his co-workers in 1977. The ECAP is also known as an Equal Channel Angular Extrusion (ECAE) that show the most suitable Severe Plastic Deformation (SPD) process which is a practical technique to produce the materials with good mechanical properties such as strength, high ductility by grain refining and the production of billets size with no changes. The ECAP became wide range of application used to accumulate deformation of in materials without any reduction in workpiece section by Parshikov *et al.* (2013).

In addition, the advantages of the ECAP is the orientation of the billet is altered or changed after each pressed. According to Thi and Ly (2007) a lot of systems of alloy have been well created using ECAP technique based on metals and alloys application. Martínez *et al.* (2005) found that the alloy A319 is generally consists of two main solidification stages with a hypoeutectic Al-Si alloy and the formation of aluminium rich (Al) dendrites through development of two phases (Al)-Si eutectic.

Therefore, the current study aims to investigate the microstructure and mechanical properties of A319 alloy. In order to make the research success, the A319 alloy are formed using CS combine with ECAP to produce the feedstock to analyze the microstructure and mechanical properties of A319 alloy.

1.2 Problem Statement

In the previous project by Werenskiold (2004), the process of ECAP has been applied to a commercial 6xxx series aluminium alloy. Moreover, Máthis *et al.* (2005) in studying AZ91 Mg alloy behavior processed by ECAP found that the crystal grain size was inhomogeneous for 4 passes of billets processed by ECAP and to get a homogenous microstructure the billets must pass at least 8 passes of ECAP process. It was observed that, the reduction of the grain size and the higher of the dislocation density effects in the increase of the tensile strength less than 100 °C. Yet, the homogenous distribution also achieved after 8 passes. Most of the researchers stated that microstructure produce after ECAP processed provide more refine microstructure compared to CS casting.

It was observed that the information regarding on the microstructure and mechanical properties of A319 alloy is still in shortage. The parameters of aluminium alloy used for ECAP process not an exactly for A319 alloy but for others aluminium alloys or closer to A319 alloy by Proni *et al.* (2016). Based on the problem faced, the feedstock produce by CS casting will go through the ECAP process to identify a better microstructure of A319 alloy. The higher the number of passes contributes a more refine microstructure of A319 alloy and mechanical properties.

1.3 Project Objectives

The objective of this project are focusing on:

- 1) To produce A319 feedstock via cooling slope casting process.
- 2) To investigate the microstructure of A319 alloy after ECAP process.
- 3) To investigate the mechanical properties of A319 alloy after Equal Channel Angular Pressing (ECAP).

1.4 Project Scope

In this project, the microstructure and mechanical properties of A319 alloy will be analyzed using the Cooling Slope technique and Equal Chanel Angular Pressing. After the feedstock is produced, it will go through the testing processes which the samples will go through the hardness testing, tensile testing and fracture testing. In this study, the A319 alloy is chosen as samples in order to investigate the properties in A319 alloy. On top of that, the microstructural of the A319 alloy testing is done by the Optical Microscopy (OM) and Scanning Electron Microscopy (SEM) Therefore, the results from microstructural behavior is applied to analyze the globalization of primary crystal of A319 alloy after process of cooling slope casting and ECAP as a comparisons.

1.5 Chapter overview

In chapter one, it consists the background of the study, problem statement, project objectives, scope and chapter overview. The major objectives of this project are to produce the feedstock for ECAP process by CS technique and to investigate the microstructure and mechanical properties of A319 alloy after the specimen have go through the ECAP process. The scope and limitations of the research basically focus on the microstructure and mechanical properties on cast specimen using CS process. In chapter two, the literature review is provided by previous study by online research by journals and other reliable resources regarding on the CS process in order to support the discussion and the methodology of project. Chapter three discusses the technique applied to conduct this research. Chapter four shows the data and results attained from the experiment conducted. Last but not least, chapter five completes the findings of study and it provides suggestions and recommendation for future research and improvement.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter provides the literature review on semisolid processing of aluminium alloy specifically and cooling slope casting that had been conducted in manufacturing industry. Additionally, reviews on cooling slope casting process on other aluminium alloys are presented. Generally, this chapter begins with review on semisolid metal processing of aluminium alloy. Besides, the preference of the A319 alloy as a primary material used in this study also supported in this chapter.

2.2 Semi Solid Processing

Semisolid processing (SSM) is known as a thixoforming process. Based on Mohamed *et al.* (2013), SSM processing is a technology used for metal forming that was invented by Spencer with supervises by Prof. Flemings at Massachusetts Institute of Technology (MIT) in 1970s. In addition, SSM processing provides a unique ability to form near net shape product by Kumar *et al.* (2014). The SSM processing is the key element of globular microstructure compared to dendritic microstructure that can minimize the segregation and porosity in the casting process with thixotropic behavior of semi-solid slurry.

According to Haga and Kapranos (2002) there are some advantages of SSM processing compared to conventional casting routes. The advantages of this