MICROSTRUCTURE EVOLUTION AND MECHANICAL PROPERTIES OF RHEOCAST Al-5Si-3Cu ALLOY

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MICROSTRUCTURE EVOLUTION AND MECHANICAL PROPERTIES OF RHEOCAST Al-5Si-3Cu ALLOY

This report is submitted in accordance with requirement of the University Teknikal Malaysia Melaka (UTeM) for Bachelor Degree of Manufacturing Engineering (Manufacturing Process) (Hons.)

by

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APPROVAL

This report is submitted to the Faculty of Manufacturing Engineering of UTeM as a partial fulfillment of the requirements for the degree of Bachelor of Manufacturing Engineering (Manufacturing Process) (Hons.). The member of the supervisory is as follow:

.....

(Dr. Mohd Shukor bin Salleh)

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ABSTRAK

Dalam kajian, kaedah tuangan cerun rheocasting digunakan untuk menghasilkan bahan mentah bukan dendrit Al-5Si-3Cu. Evolusi mikrostruktur daripada aloi Al-5Si-3Cu telah dikaji. Selain itu, kekerasan, kekuatan tegangan dan ketahanan tuangan cerun penyejukan dan tuangan konvensional juga telah dikaji. Semua ujikaji eksperimen telah dilakukan dengan menggunakan aloi Al-5Si-3Cu yang sama. Beberapa sampel kemudian telah menjalani rawatan haba T6 dengan rawatan larutan pada suhu 520°C selama 8 jam, lindap kejutan di dalam air, diikuti oleh proses penuaan pada suhu 154°C selama 4 jam. Semua sampel telah dicirikan dengan menggunakan mikroskopi optik (OM), mikroskop imbasan electron (SEM), ujian kekerasan, ujian tegangan dan ujian kehausan. X-ray pembelauan (XRD) telah digunakan untuk mengkaji fasa yang hadir dalam aloi. Keputusan ujikaji telah menunjukkan kaedah tuangan cerun rheocasting Al-5Si-3Cu mempamerkan ciri mickrostruktur berbentuk sfera disebabkan semua struktur dendrit telah berubah kepada bentuk globul dan bentuk roset. Nilai kekerasan Vicker menunjukkan sampel melalui teknik cerun penyejukan rheocasting lebih keras berbanding tuangan konvensional. Di samping itu, ia telah diperhatikan bahawa untuk kekuatan tegangan muktamad, kekuatan alah dan pemanjangan rheocasting cerun penyejukan mempunyai nilai yang lebih tinggi berbanding dengan pemutus konvensional. Selain itu, tingkah laku memakai penyejukan cerun menunjukkan peningkatan berbanding pemutus konvensional iaitu 218.341MPA untuk UTS, 151.446MPa for YS dan 8.76% pemanjangan. Selain itu, tingkah laku memakai penyejukan cerun menunjukkan peningkatan berbanding pemutus konvensional. Rheocasting cerun penyejukan yang menjalani T6 rawatan haba menunjukkan hasil yang positif dari segi pengagihan mikrostruktur bangsa yang sama, peningkatan dalam kekerasan, sifat tegangan dan memakai tingkah laku berbanding dengan sampel bukan haba dirawat

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ABSTRACT

In this study, cooling slope (CS) rheocasting was employed to produce a non-dendritic feedstock of Al-5Si-3Cu. The microstructural evolution of the non-dendritic Al-5Si-3Cu alloys were studied. Besides, the hardness, tensile strength and wear behaviour of cooling slope casting and conventional casting samples were investigated. All the experimental works were carried out by using same Al-5Si-3Cu alloy. Some of the rheocast samples were then treated with a T6 heat treatment that is solution treatment at 520°C for 8 hours, quenching in water, and then followed by aging at 154°C for 4 hours. All of the samples were then characterised by optical microscopy (OM), scanning electron microscope (SEM), hardness tests, tensile test as well as wear tests. X-ray diffraction (XRD) was used to investigate the phases presents in the alloys. The results showed that the CS rheocast Al-5Si-3Cu alloy exhibits the spherical microstructural feature due to all dendritic structures were transform into α-Al globule and rosette. The Vicker's hardness value revealed that cooling slope rheocasting sample achieved the higher hardness than conventional casting. In addition, it was observed that for ultimate tensile strength (UTS), yield strength (YS) and elongation of the cooling slope rheocasting has the higher value compared to conventional casting which is 218.341MPa for UTS, 151.446MPa for YS and 8.76% elongation. Moreover, the wear behaviour of cooling slope show an improvement as compared to conventional casting. The cooling slope rheocasting that underwent T6 heat treatment showed the positive results in terms of homogenous microstructure distribution, improvement in hardness, tensile properties and wear behaviour as compared to non-heat treated sample

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DEDICATION

I would like to dedicate this project to my beloved parents, Ishak Bin Ismail and Norihan Binti Ab. Malek to whom I'm deeply indebted and grateful for their continuous support throughout my social and academic life.

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

CS	-	Cooling Slope
UTM	-	Universal Testing Machine
SEM	-	Scanning Electron Microscope
CNC	-	Computer Numerical Control
SSM	-	Semisolid Metal
OM	-	Optical Microscopy
FKP	-	Fakulti Kejuruteraan Pembuatan
FTK	-	Fakulti Teknologi Kejuruteraan
EDM	-	Electrical Discharge Machining
XRD	-	X-ray diffraction
EDX	-	Energy dispersive X-ray

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LIST OF SYMBOLS

ºC	-	Degree Celsius
mm	-	Millimetre
º	-	Degree
kV	-	Kilovolt
N	-	Newton
s	-	Second
m/s	-	Metre per second
µm	-	Micrometre
HV	-	Vickers pyramid number
MPa	-	Megapascals

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CHAPTER 1
INTRODUCTION

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

1.1 Background of Study

Over the past four decades, Semi Solid Metal (SSM) Processing has been carried out in the metal casting industry. SSM processing is a technology used with aluminium that provides several advantages compared with conventional techniques, such as high products quality, high production rate and improve the mechanical properties. There are two SSM processing routes which are thixoforming and rheocasting. Thixoforming involves the preparation of feedstock material, reheat uniformly to a semi solid state and forming near net-shaped products. Rheocasting involves mechanical stirring to create non-dendritic semi solid slurry and straightly injected into the die. In recent years, rheocasting process becomes popular because this process gives more benefits compared to conventional casting process including low cost and increase casting precision and qualities.

According to Nafisi *et al*. (2006), the viscosity of SSM depends on the metallurgical and process parameters such as chemical composition, particle size, solid fraction, shape and distribution, pouring temperature and mold characteristics. The rheocasting process is proficient in producing semi solid metal with homogenous and globular microstructure. The formation of globular structure during rheocasting process is important to understand.

Aluminium alloys are one of the well-known materials used in automotive manufacturing, especially aluminium-silicon (Al-Si) alloys because of the good castability, low density and high strength to weight ratio. According to Mazzolani (1995), aluminium alloys require very small quantities of additional elements including magnesium, silicon, zinc,

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copper and manganese. Silicon helps to increase ductility and strength and decrease the melting point while copper helps to reduces corrosion resistance, weldability and ductility. Morphology of silicon particle such as shape, size, and distribution are most influential factor on the mechanical properties of Al-Si-Cu alloy.

Three categories of technique have been developed to transform the microstructures which are liquid method route, solid state route and combination methods. Among the SSMP processing technique, cooling slope (CS) casting, which is liquid method route, is one of the simplest technique to obtain globular microstructure from the dendritic microstructure. The CS technique includes the pouring of melt over an inclined cooling plate has a number of advantages such as cost effectiveness, simplicity and requires a very low amount of equipment. Solid nuclei are produced due to the contact between the melt and slope plate and cause rapid heat transferring. After applying shear stress and melt flow, those nuclei are separated from the surface and dispersed into the melt. When the nuclei reheated to the semi-solid temperature range, the ingots obtained exhibit a non-dendritic and globular structure. In previous study, Khosravi (2014), have stated that the pouring temperature, length of cooling plate, angle of the slope, partial re-melting temperature and isothermal holding time are the main processing parameters that affect the final microstructure of the solidified slurry during CS process.

Thus, this present study aims to produce globular microstructure in Al-5Si-3Cu alloy by using cooling slope casting method and to evaluate the strength of the specimen after cooling slope process. It also attempts to investigate the influence of the rheocast process on wear properties of the aluminium alloys.

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1.2 Problem Statement

Salleh *et al*. (2014) in their study state that the dendritic structure in the conventional casting samples may generate a microporosity in a samples by creating a solid skeleton within the melt during solidification. The development of microporosity decrease the mechanical properties of the alloy. Besides, Fan (2002) in her study mentioned that magnetohydrodynamic (MHD) stirring is one of the most popular methods to prepare the billets. The disadvantages of the MHD stirring are the non-uniformity of the microstructure produced in the cross section of cast billets and high production cost. In addition, Kumar and Dhindaw (2014) also reported that MHD process has the limitation of non-uniform structures. This statement also supported by Taghavi and Ghassemi (2009) in their study.

They state that MHD have some problem including the restriction in size and morphology of primary solid phases. The microstructures produced in the radial direction of produced ingots also non-uniform. Therefore, in this research, rheocasting technique is used to produce an aluminium samples as it may reduce the microporosity and increase the mechanical properties.

1.3 Research Objectives

This study is conducted to achieve the following objectives:

1. To produce globular microstructure in Al-5Si-3Cu alloy by using cooling slope casting method.
2. To evaluate the strength of the specimen after cooling slope process.
3. To investigate the wear properties of the aluminium alloy.

1.4 Scope

The aim of this present project is to produce a globular microstructure in the Al-5Si-3Cu alloy by using cooling slope process. The microstructural evolution is done by optical microscopy. Besides, this study focusing on the mechanical properties and wear behavior of rheocast Al-5Si-3Cu. The mechanical properties are achieved through tensile testing and hardness testing. The wear behavior is investigating by using the wear testing. Al-Si based alloys which is Al-5Si-3Cu alloy is used as the material of cast specimen in this project. The result from microstructural and is used to examined whether the rheocasting process affect the uniformity of the microstructure.

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1.5 Chapter Overview

In chapter one, it provides the background of the study, problem statements, research objectives, scope and chapter overview. The main objectives of this project is to study the microstructure and mechanical properties of rheocast Al-5Si-3Cu which focusing on the tensile and hardness of the cast specimen. This project also attempts to investigate the effect of the rheocasting process on microstructure and mechanical properties of Al-5Si-3Cu alloy. The scopes of this project focusing on the microstructural evolution and mechanical properties of the specimen. In chapter two, the literature review is providing as the support in terms of discussion by previous study. Chapter two was performed by online search by journal and significant resources. In chapter three, the methods of how this project is conduct are discussed. Chapter four shows the data and results gained through the conducted experiment. Last but not least, chapter five concludes the findings of this study and recommendations for future improvement.

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CHAPTER 2
LITERATURE REVIEW

This chapter provides the literature review on semisolid processing of aluminium alloy and cooling slope casting which have been defined and done by various researcher years ago. The review for semisolid metal processing, aluminium alloy, cooling slope, heat treatments and mechanical properties are presented in this chapter.

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2.1 Semisolid Metal Processing (SSM)

Semi solid metal processing (SSM) is a new metal forming techniques that was proprietary by Spencer throughout his PhD studies below the supervision of professor Flemings at the Massachussetts Institute of Technology within the early 1970s. Based on the previous study by Fan (2002), SSM processing are differ from the conventional metal forming because SSM processing involving the semi solid slurries, in which non-dendritic solid particles area unit distributed in a very liquid matrix. SSM slurries show particular rheological attributes, in which the steady state behavior is pseudo plastic and the transient state behavior is thixotropic.

2.1.1 Semisolid metal processing of aluminium alloy

Todays, all forming processes can be completed by using SSM processing technique easily. There are two main categories of processing technique which are rheo-routes and thixo-routes. These processing techniques are classed based on the status of the outset material. The preparation of SSM slurry in rheo-routes from a liquid state with spheroidal microstructure and injected directly into a die without an intermediate stage. In thixo-routes, the molten metal

is solidified initially when the material in the form of billets because it can form non-dendritic structure when it is heated into the semi-solid state. Then, it is injected into the die for product forming. Thixocasting is performed in closed die while thixoforging is performed in open die (Mohamed *et al.,* 2014). Figure 2.1 show the schematic illustration of rheoforming and thixoforming**.**

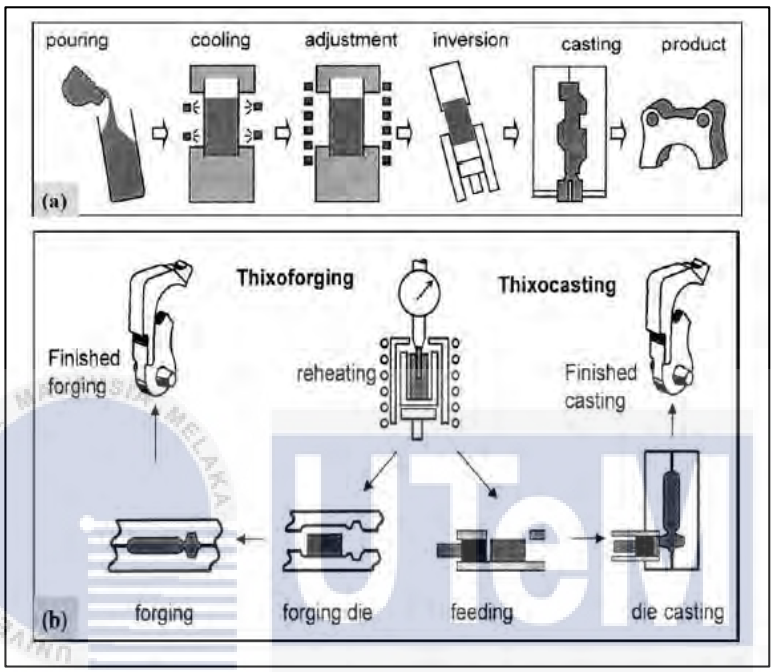

Figure 2.1**:** Schematic illustration of (a) Rheoforming (b) Thixoforming (Fan, 2002)

A globular microstructure with right amount of liquid fraction is needed to ensure SSM processing to be successful (Mohamed *et al.,* 2014). The near-globular particles will move easily past one another when shear force is applied, cause in decreasing in viscosity and make the material behave like a liquid. The presence of non-dendritic morphology in which involves the formation of fine near spheroidal particles through forced convection cause by stirring was proposed by several mechanisms (Fan., 2002).

2.1.2 Rheological behavior of semi-solid slurries

In previous study by Dey *et al*. (2006), rheological behavior is an essential aspect for the forecast of flow into die cavities amid forming process. The flow behavior between liquidus and solidus range is known as rheological behavior. It depends on the temperature and shear rate. SSM slurries are categories into liquid-like slurries and solid-like slurries.