EFFECT OF PARTIAL REMELTING ON MICROSTRUCTURE AND MECHANICAL PROPERTIES OF THIXOFORMED ALUMINIUM ALLOYS

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

by

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I hereby, declared this report entitled "Effect of partial remelting on microstructure and mechanical properties of thixoformed magnesium alloys" is the result of my own research except as cited in reference.

Signature : ……………………………………….

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APPROVAL

This report is submitted to the Faculty of Manufacturing Engineering of Universiti Teknikal Malaysia Melaka as a partial fulfilment of the requirement for Degree of Manufacturing Engineering (Hons). The member of the supervisory committee is as follow:

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(Profesor Madya Ir. Ts. Dr. Mohd Shukor Bin Salleh)

ABSTRAK

Keputusan penyiasatan eksperimen yang dilakukan dengan aloi aluminium LM 21/A308 dibentangkan. Struktur mikro bahan semasa pencairan separa dalam keadaan separa pepejal disiasat daripada proses berbeza yang dialami oleh bahan dan sifatnya dibandingkan. Pembolehubah yang dikaji ialah proses tuangan kacau, proses pembentukan thixo dan pembentukan thixo dengan proses rawatan haba. Bersama-sama dengan analisis mikrostruktur Scanning Electron Microscope (SEM) dan ujian mekanikal telah dilakukan termasuk ujian tegangan dan ujian kekerasan (Vickers). Berdasarkan dapatan eksperimen, didapati bahawa pencairan semula separa juga boleh mengaburkan struktur. Mikroskop Elektron Pengimbasan membenarkan pencirian mikrostruktur untuk menentukan proses tuangan menghasilkan struktur mikro bukan dendritik dengan kelajuan kacau 500 rpm, mikrostruktur pembentukan thixo adalah hampir sferoid dan pembentukan thixo T6 dirawat haba adalah globul sepenuhnya manakala ujian tegangan membolehkan spesimen pembentukan thixo T6 dirawat haba mempunyai nilai Kekuatan Tegangan Muktamad (MPa), Kekuatan Hasil (MPa) dan Pemanjangan hingga Patah (%) yang tertinggi masing-masing sebanyak 258.77 MPa, 134.36 MPa dan 8.93%. Ujian kekerasan menunjukkan bahawa spesimen yang dirawat haba T6 meningkatkan sifat morfologi dengan 128.4 HV disebabkan oleh penghalusan dan pengglobalisasian juzuk mikro struktur dengan struktur bukan dendritik. Kesan positif struktur mikro struktur mengaburkan kesan keliangan negatif terhadap peningkatan harta benda. Adalah dicadangkan bahawa bahan tetulang akan dilepaskan dalam matriks untuk meningkatkan kekerasan, dan kemuluran dengan peratusan tetulang kepada berat yang lebih tinggi. Selain itu, dengan meningkatkan masa kacauan dan kelajuan kacauan juga mampu menambah baik kekuatan bahan.

ABSTRACT

The results of experimental investigations performed with LM 21/A308 aluminium alloy are presented. The microstructure of the material during partial remelting in the semi-solid state is investigated from different processes experienced by the material and the properties are compared. The variables examined were stirred casting process, thixo-forming process and thixo-forming with heat treatment process. Along with microstructural analysis Scanning Electron Microscope (SEM) and the mechanical tests were performed including tensile test and hardness test (Vickers). Based on the experimental findings, it was obtained that partial re-melting can also obscure the structure. Scanning Electron Microscope allows microstructure characterization to determine as-cast process produced a non-dendritic microstructure with 500 rpm stirring speed, thixoformed near- spheroidal microstructure and thixoformed T6 heat treated was fully globule while tensile test allows thixoformed T6 heat treated specimen to have the highest value of Ultimate Tensile Strength (MPa), Yield Strength (MPa) and Elongation to Fracture (%) of 258.77 MPa, 134.36 MPa and 8.93% respectively. The hardness test showed that T6 heat treated specimen improved the morphological properties with 128.4 HV due to the refinement and globularization of structural micro-constituents with non-dendritic structures. The positive effect of structural microstructure obscures the negative porosity effect on property enhancement. It is suggested that reinforcement materials are to be discharged in the matrix to improve the hardness, and ductility with higher reinforcement to weight percentage. In addition, by increasing the stirring time and stirring speed is also able to improve the strength of the material.

DEDICATION

This research is dedicated from me to my family who constantly supported my work and effort to finish this report with amazing results. Specially made for my Ibu, Abby; my Ayah, Azlan; specifically my Syaifullah.

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LIST OF ABBREVIATIONS

S.S.M.P	-	Semi-solid Metal Processing
EBSD	-	Electron Backscatter Diffraction
VW	-	Volkswagen
HCP	-	Hexagonal Close-packed
3C	-	Computer, Communication, Consumer
ASTM	-	American Society for Testing Materials
SAE	-	Society of Automotive Engineers
RE	-	Rare Earth
Li	-	Lithium
Al	-	Aluminium
Si	-	Silica
Ca	-	Calcium
Mn	-	Manganese
Cu	-	Copper
Zn	-	Zinc
Sr	-	Strontium
Y	-	Yttrium
Zr	-	Zirconium
Ag	-	Argon
A	-	Aluminium
E	-	Rare Earth
H	-	Thorium

K	-	Potassium
M	-	Manganese
Q	-	Silver
S	-	Silicon
T	-	Tin
Z	-	Zinc
BTU	-	British Thermal Unit
AZ31	-	Aluminium Zinc-based Alloy with 3 and 1 percentile
AS41	-	Aluminium Silicon-based with 4 and 1 percentile
M.I.T	-	Massachusetts Institute of Technology
C.S	-	Cooling Slope
ITT	-	International Telephone and Telegraph
MHD	-	Magnetohydrodynamic
Ti-B	-	Boron Titanium
NRC	-	New Rheocasting
DTM	-	Direct Thermal Method
SCR	-	Shearing-Cooling Roll
SIMA	-	Stress-Induced and Melt-Activated
SEM	-	Scanning Electron Microscope
EDS	-	Energy Disperse Spectroscopy
OM	-	Optical Microscope
XRD	-	X-ray Diffractometer
H2O	-	Water
HNO3	-	Hydrogen Nitrate
CrO3	-	Chromium Trioxide
D	-	Diameter

N	-	Total Grain Numbers
F	-	Factor
HV	-	Hardness Vickers
T6	-	Treatment 6

LIST OF SYMBOLS

^0C	-	Degree Celsius
^0F	-	Degree Fahrenheit
%	-	Percentage
GPa	-	Giga Pascal
K^{-1}	-	Kelvin power^{-1}
V	-	Voltage
g/cm^3	-	gram per centimetre cube
lb/in^3	-	pound per inch cube
Mpa	-	Mega Pascal
ksi	-	Kilopound per square inch
µm/m°C	-	micrometre per metre degree Celsius
W/mK	-	Watt per milli Kelvin
nm	-	nanometre
μm	-	micrometre
wt.%	-	weight percentage
mm	-	micrometre
kW	-	kilowatt
g	-	gram

CHAPTER 1.0
INTRODUCTION

1.1 Background of Study

Semi-solid metal processing (S.S.M.P.) is the processing of alloys at temperatures between solidus and liquidus. When thixotropic behaviour was discovered in the early years of 1970 Spencer was supervised by Flemings. They relied on the thixotropic behaviour of metallic alloys at the time (Spencer et al., 1972). They discovered that implementing shear to alloys as they were solidifying lowered stress. As an outcome, the tension was significantly lower at a temperature just below liquidus than when the alloy was chilled to the same temperature without shearing. (Fan, 2002). The creation of globular microstructures in solid phases is related to the distinctive features of these alloys, surrounded by the homogenously distributed liquid fractions (Riek et al., 1975). Metallic alloy suspensions' qualities were promptly put to use in industries (Mehrabian and Flemings, 1972). The technology consisted of two main operational activities: preparing the globular microstructure and forming a semi-solid slurry. The thixotropic structure was referred to as "rheo-forming" or "thixoforming," depending on how it was produced from the liquid phase directly or from the solid state.

1.2 Problem Statement

Today's industries, after oxygen and silicon, aluminium is the most prevalent mineral on Earth, making it the most widely available metal naturally found on the globe and the second-most consumed metal in the world, just behind iron. Even if the aluminium content is as high as 99 percent, it is primarily employed as an alloy. (Flagel, 2020). However, there are some limitations when using aluminium alloys to perform in semi-solid manufacturing process (S.S.M.P). This is due to the high sensitivity of temperature which impacts the formation of the nucleation and growth of the alloy and reduces bonding between grain structure during solidification, which decreases formability efficiency during the secondary forming process (Zhu et al., 2004). Through partial remelting of semi-solid metal processing, the desired condition of aluminium alloy slurry can be achieved. The partial remelting process, however, has a state of phase that needs to be analysed. Similar to the cooling slope casting process, there is also a morphological situation to achieve the semi-solid slurry mechanism. In addition, less research are allocated for LM21/ A308 aluminium alloy in semi-solid metal processing.

1.3 Objectives

1) To produce aluminium alloy for thixoforming using partial remelting.

2) To investigate the microstructural evolution of aluminium alloy after partial remelting.

3) To determine the mechanical properties of thixoformed aluminium alloy.

1.4 Scope of Project

This study showed microstructure evolution and properties of LM21 aluminium alloy when it underwent the stir casting process before thixoforming and then treated with T6 heat treatment after thixoforming. The outcome measurement of aluminium alloy will be identified by the morphological analysis of which of the process will give non-dendritic structure by scanning electron microscopy while the hardness and tensile tests are for the mechanical properties.

1.5 Significant / Important of Study

There are some potential advantages that can be obtained after the partial re-melting process for industry. The application of structural components for common engineering reasons, LM21 is suited for many of the applications that LM4 can be utilised for. It's typically employed in applications where a large proof stress and rigidity are necessary without the use of heat treatment. Its casting qualities enable it to be employed for the creation of slender forms as well as pressure-tight castings. LM21 can be used for both sand and permanent mould castings. It's utilised in diesel engine crankcases, clutch cases, gear boxes, tool handles, domestic fittings, electrical equipment, and office equipment, among other things. With the addition of this study, limitations of aluminium alloy use can be decreased.

1.6 Organization of the Report

The first chapter gives the overall introduction of my project. Based on the background of the study, the problem statement, objectives, scope of the project, significance of the study, organization of the report and summary of the project.

The second chapter gives the review of Aluminium and Aluminium Alloy, Machinability of Aluminium, Semi Solid Metal Processing (SSMP), Stir Casting, Thixoforming Process and T6 Heat Treatment.

The third chapter gives the flow of methodology used for the whole project starting with the experimental design, preparation of material used, processing, microstructural analysis and mechanical testing.

The fourth chapter discusses the results of the experiment from the microstructural analysis and the mechanical properties analysis.

The last chapter concludes the whole project based on the findings gathered.

1.7 Summary

The aim of this study is to provide the fundamentals of semi-solid metal processing for aluminium alloys. This research focuses on how the microstructure of aluminium alloy varies with different processes to make the semi-solid slurry. Analysis from the process that affects the condition of the microstructure and mechanical properties will be obtained.

CHAPTER 2.0
LITERATURE REVIEW

This chapter discusses literature of aluminium alloy and its properties along with the different processes that will be underwent according to the previous chapter that is under semi-solid metal process. The literature review part is divided into three parts which are Aluminium and Aluminium Alloy, Machinability Aluminium Alloys and Semi-solid Metal Processing.

2.1 Aluminium and Aluminium Alloy

2.1.1 Aluminium

Aluminium is a ductile, malleable, corrosion-resistant metal with a high electrical conductivity. It's commonly used for foil and conductor cables, but it needs to be alloyed with other elements to achieve the greater strengths required for other uses. Aluminium is one of the lightest engineering metals, with a strength-to-weight ratio that is higher than steel.

Aluminium is being used in an ever-increasing variety of applications by combining its beneficial features such as strength, lightweight, corrosion resistance, recyclability, and machinability. This collection of items includes anything from building components to tiny packaging foils. Below in the Table 2.1 is shown the properties of aluminium.

Table 2. 1: Properties of Aluminium (AZOM Materials)

No.	Property	Value / Characteristics
1	Atomic Number	13
2	Atomic Weight (g/mol)	26.98

3	Valency	3
4	Crystal Structure	FCC
5	Melting Point (°C)	660.2
6	Boiling Point (°C)	2480
7	Mean Specific Heat (0-100°C) (cal/g.°C)	0.219
8	Thermal Conductivity (0-100°C) (cal/cms. °C)	0.57
9	Co-Efficient of Linear Expansion (0-100°C) ($x10^{-6}$/°C)	23.5
10	Electrical Resistivity at 20°C (Ω.cm)	2.69
11	Density (g/cm^3)	2.6898
12	Modulus of Elasticity (GPa)	68.3
13	Poissons Ratio	0.34

2.1.2 Aluminium Alloys

Aluminum alloys have a unique combination of low density, formability, excellent thermal and electrical conductivity, high strength-to-weight ratio and corrosion resistance Aluminium alloys are a very relevant material in modern industries due to their characteristics and low production costs. They were used in a variety of industries, such as the automotive, aeronautics, maritime, and electronic industries, as well as food packaging and cans, culinary utensils, construction, and chemical equipment (Wallerstein et al., 2021).

2.1.3 ASTM / SAE Alloy Designation

Aluminium alloys are given a designation according to the ASTM/SAE system which is universally accepted. According to this order, the first two letters point LM to the principles alloying elements, then the next two numbers 21 specify nominal percentage of these alloying elements in the equivalent order and the next capital letter indicates chronological sequence of development. Table 2.2 below shows alloying elements.