FINITE ELEMENT MICROMECHANICAL MODELING OF ALUMINIUM MAGNESIUM ALLOY DURING PLASTIC DEFORMATION

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SUPERVISOR DECLARATION

"I hereby declare that I have read this thesis and in my opinion this report is sufficient in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering (Structure & Material)"

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DECLARATION

"I hereby declare that the work in this report is my own except for summaries and quotations which have been duly acknowledged."

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ABSTRACT

Work-hardening wrought Al-Mg alloys are also known commercially as the 5000 series aluminium-based alloys are currently being used as automotive body in white (BIW) material. Magnesium is the principle alloying element and is added for solid-solution strengthening. Since mechanical properties of aluminium magnesium alloy is affected by its microstructure, so it is important to know the behavior of each phase under plastic condition. This project is focused on the micromechanical modeling of aluminium magnesium alloy during plastic deformation using finite element analysis. Grain size of aluminium matrix and the size of intermetallic particles were determined by metallographic examination and SEM microscope. Geometric model was then built to represent the microstructure and Finite Element Method will be applied to conduct numerical analysis. The method used for this study is by using Ansys software. To perform the simulation of the micromechanical modeling, the boundary condition and the constraints have been determined before run the simulation. Result shows that aluminium magnesium alloy 5083 has a higher strength and far better than the pure aluminium. This is because the existence of intermetallic particles as a strengthening element improves the properties of the aluminium. On the other hand, the existence of the intermetallic particles also leads to disadvantage to the alloy structure. The results show that the contact between the intermetallic particle and the aluminium matrix is the area where stress concentration happened that possibly lead to fracture.

ABSTRAK

Kerja-pengerasan tempa aloi Al-Mg juga dikenali secara komersial sebagai siri 5000 aloi berasaskan aluminium sering digunakan sebagai bahan BIW automotif. Magnesium merupakan unsur mengaloi prinsip dan ditambah untuk menguatkan larutan pepejal. Sejak sifat mekanikal aloi aluminium magnesium dipengaruhi oleh mikrostruktur, jadi ia adalah penting untuk mengetahui tingkah laku setiap fasa dalam keadaan plastik. Projek ini memberi tumpuan kepada model mikromekanikal aluminium aloi magnesium semasa ubah bentuk plastik menggunakan analisis unsur terhingga. Saiz sebutir matriks aluminium dan saiz zarah intermetalik ditentukan oleh pemeriksaan metalografi dan SEM mikroskop. Model geometri kemudiannya dibina untuk mewakili mikrostruktur dan Kaedah Unsur Terhingga akan digunakan untuk menjalankan analisis berangka. Kaedah yang digunakan untuk kajian ini adalah dengan menggunakan perisian ANSYS. Untuk melaksanakan simulasi model micromechanical, keadaan sempadan dan kekangan telah ditentukan sebelum menjalankan simulasi. Keputusan menunjukkan bahawa aluminium aloi magnesium 5083 mempunyai kekuatan yang lebih tinggi dan jauh lebih baik daripada aluminium tulen. Ini adalah kerana kewujudan zarah intermetallic sebagai elemen pengukuhan meningkatkan sifat-sifat aluminium. Sebaliknya, kewujudan zarah intermetallic juga membawa kepada kelemahan struktur aloi. Keputusan menunjukkan bahawa hubungan antara zarah intermetallic dan aluminium matriks adalah kawasan di mana penumpuan tegasan yang berlaku yang mungkin membawa kepada keretakan.

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LIST OF ABBREVIATION

AA5083	Aluminium Alloy 5083
PSM	Projek Sarjana Muda
SEM	Scanning Electron Microscope
UTeM	Universiti Teknikal Malaysia Melaka
F	Force Vector
K	Stiffness Matrix
U	Unknown Vector (e.g. displacement, x)

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CHAPTER 1

INTRODUCTION

This chapter will cover on the problem statement, objective of the project and project scope. Furthermore, the information of the project will be stated clearly to enhance the understanding as a method to achieve the project goal. In this research, this project will be focusing on the micromechanical modeling of aluminium magnesium alloy during plastic deformation using finite element analysis.

1.0 Background

Work-hardening wrought Al-Mg alloys which are known commercially as the 5xxx series Aluminium alloys are an important group of commercial Al alloys with good combination of strength and formability and therefore they have various applications. Magnesium added for Al solid solution strengthening in amount ranging from 0.5 to 6 wt% [1]. As Mg has a high solubillity in solid solutions, therefore it provides the most effective enhancement of strength. Commercial Al-Mg alloys also contain elements such as Mn, Fe, Si or Cr and Ti. These elements form the second phase particles due to a limited solubility in solid solutions [2]. Thus, in micro scale, Al-Mg alloy is built from different phases with different properties.

In this study, the microstructure of Al-Mg alloy 5083 are identified and modeled in order to understand the respond of the microstructure to external load.

1.1 Problem Statement

There is very limited understanding of the fundamental mechanisms of plastic deformation in aluminium magnesium alloy which include the interaction between aluminium matrix and intermetallic particles during the plastic deformation. Since mechanical properties of this aluminium magnesium alloy is affected by its microstructure, so it is important to know the behavior of each phase under plastic condition. Finite Element Method can be used to simulate the microstructure changes of aluminium magnesium alloy during plastic deformation.

1.2 Objectives

1. To study the microstructure and mechanical properties of aluminium magnesium alloy during plastic deformation.
2. To build micromechanical model geometry based on metallography examination.
3. To simulate plastic deformation by using finite element method.

1.3 Scope

The scope of the project mainly focused on:

1. Three dimensional CAD model of the microstructure will be built after SEM examination.
2. CAD model and finite element analysis will be done using the available software.
3. Utilization of Finite Element Analysis (ANSYS) to simulate the effect of external load to the plastic deformation.

CHAPTER 2

LITERATURE REVIEW

2.0 Introduction

This chapter will cover the literature reviewed for this study. The chapter will cover the basic knowledge on Aluminium Alloy and Finite Element Theory. This literature review shows the studies for mechanical properties, and process included that will help and give some information for this study.

2.1 Aluminium Alloy

Aluminium is the third most abundant metallic element on the earth and always occurs in combination with other elements such as oxygen and silicon. However, aluminium is extremely useful in engineering field as it poses a combination of critical properties especially for transportation application. Although pure aluminium has low strength, it can be alloyed to strength up to 690 Mpa [3].

Among the many alloying elements added to aluminium, the most widely used are copper,silicon, magnesium, zinc and manganese. These are used in various combinations, and in many cases they are used together with other additions to produce classes of age hardening, casting and work hardening alloys [4].

Al-Mg alloys are an important group of commercial Al alloys with good combination of strength and formability and therefore they have various applications in transport, packaging and general engineering industries. They belong to the group of non-heat treatable Al alloys which derive their strength mainly from solution strengthening and work hardening during deformation. Cold deformation is particularly effective in strengthening since restoration processes are thermally activated [5].

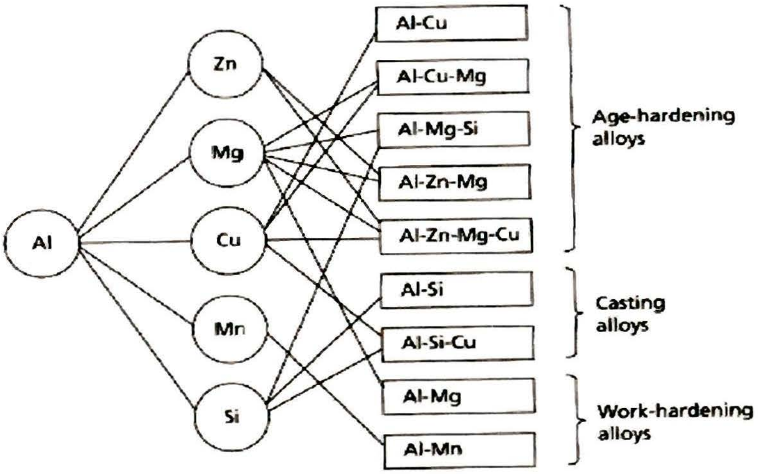

Figure 2.1 Major aluminium alloy system [4]

2.1.1 Wrought Aluminium Alloy

Usually ingot shapes such as sheet and extrusion ingots are produced through semi continuously cast by the direct-chill method. For the sheet ingots, about the 1/2 inch of metal is removed from the ingot surface. Where the surface is contact with the hot-rolling mill rolls. This operation called scalping. Effect from this operation we can get the smooth surface for the fabricated sheet or plate [4].

Then the ingots are preheated or homogenized at a high temperature for about 10 to 24 hours to allow atomic diffusion. In that case, it will make the composition of the ingots become uniform [4]. During the preheated process, one of the important thing to do is the preheating must be done at a temperature below the melting point of the constituent with the lowest melting temperature.

Then, the ingots must go to hot rolled by using a four-high reversing hot-rolling mill after through the reheating process.

2.1.2 Wrought Aluminium Alloy 5XXX Series

Magnesium additions to aluminium provide among the highest strength non-heat-treatable alloys. These alloys also are exceptionally tough, absorbing lots of energy during fracture, and so can be used in critical application where superior toughness is vital. Alloys of the 5xxx series are readily welded by commercial procedures.

Generally, the 5xxx alloys also have an excellent resistance to atmospheric and seawater corrosion to the point that they may be used in severe marine environment. However, alloys with more than 3% Mg are not recommended for service in which significant exposure to high temperature may be encountered because some sensitization to SCC may develop. For these types of application, alloys such as 5052, 5454 and 5754 containing less magnesium are recommended [6].

Alloy grades that have been used thoroughly as automotive BIW material are listed in Table 2.1. The alloys are nominally supplied to the BIW press shop in an annealed temper, designated as -o temper. The 0 temper is by means of annealed and recrystallized, which it is tempered with the lowest strength and highest ductility [3]. The microstructure are characterized by a recrystallized grain structure as shown in Figure 2.2 and populated by iron (Fe) rich and magnesium (Mg) rich intermetallic particles and dispersoids as shown in Figure 2.3. The chemical element composition contained in commonly used 5xxx series aluminium alloys is shown in Table 2.1. Table 2.2 illustrates that the solubility of the main alloying element is relatively limited mainly if considering that iron and silicon are coming from the processing and are not (depending on the alloy) properly alloying elements. The classifying of the alloying elements in accordance to their solubility into three classes can be determined, which are:

i. High solubility solutes (>10% at %): Zn: Ag: Mg: Li.
ii. Intermediate solubility solutes (>1 and <10 at %) Ga: Ge: Cu: Si.
iii. Low solubility solutes (<1 at %) all others

Table 2.1 Composition of commonly used 5xxx series alloys used for automotive BIW components in weight percent with Al as remainder [3]

Alloy	Mg	Si	Cu	Fe	Mn	Zn	Cr	Ti
5251	1.7-2.4	0.40	0.15	0.50	0.10-0.50	0.15	0.15	0.15
5052	2.2-2.8	0.25	0.10	0.40	0.10	0.10	0.15-0.35	-
5754	2.6-3.6	0.40	0.10	0.40	0.50	0.20	0.30	0.15
5182	4.0-5.0	0.20	0.15	0.35	0.20-0.50	0.25	0.10	0.10
5083	4.0-4.9	0.40	0.10	0.40	0.40-1.00	0.25	0.05-0.25	0.15

Table 2.2 Solubility (wt %, temperature °C) of the main elements of Aluminium[3]

Alloying element	Maximum solid state solubility	Solubility at lower temperature	Atomic radius difference (%)	Lattice structure
Si	1.65 (250°)	0.05 (250°)	-6.3	Cubic; A4
Fe	0.052 (655°)	0.001 (400°)	-11.2	BCC/FCC
Cu	5.65 (548°)	0.2 (200°)	-11.2	FCC
Mn	1.82 (659°)	0.36 (500°)	-8.4	Cubic; A12
Mg	14.9 (451°)	2.95 (150°)	+11.9	CPH
Zn	82.8 (382°)	4.4 (100°)	-4.2	CPH

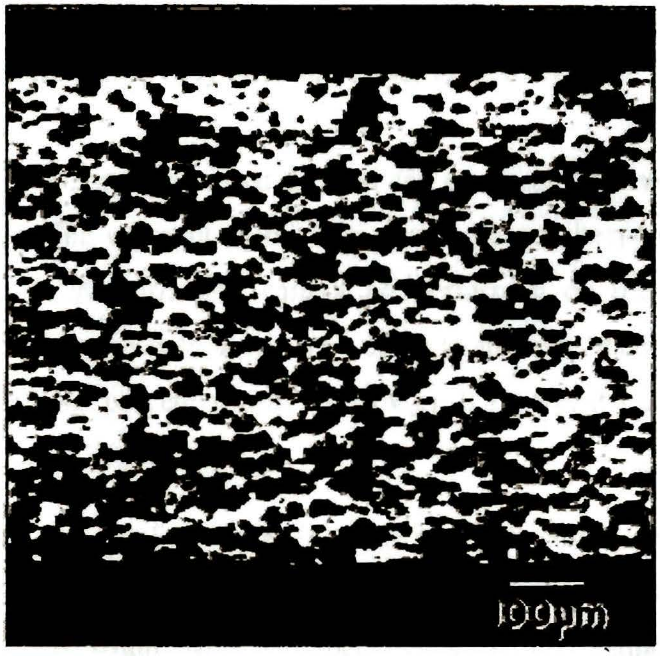

Figure 2.2 Recrystallized grain structure of an annealed Al-Mg sheet [3]

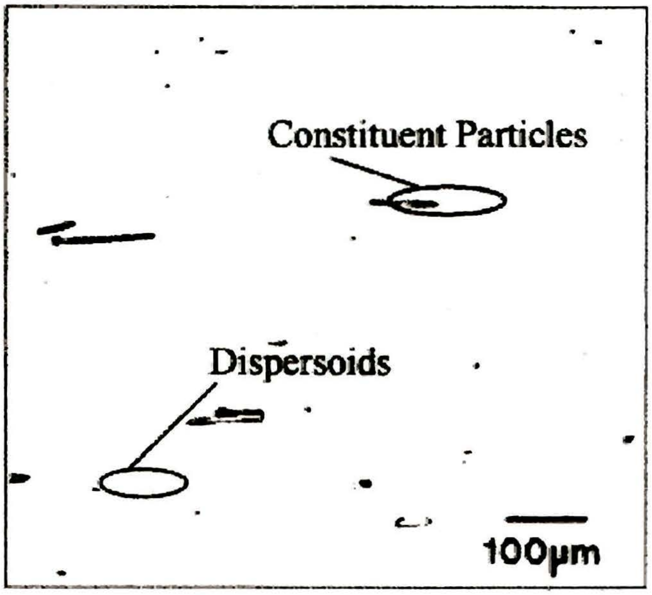

Figure 2.3 Constituent particles and dispersoids structure [3]

2.1.3 Wrought Aluminium Alloy AA5083 series characteristics

In this study, the specimen that is used for this project is wrought aluminium alloy AA5083 series. The wrought aluminium alloys are non-heat-treatable aluminium alloys as precipitation strengthening cannot be performed on them. Moreover, this aluminium alloy can only be cold worked in order to increase their strength. AA5083 alloy contains about *4.45* percent magnesium (Mg), 0.7 percent manganese (Mn) and *0.15* percent chromium (Cr) [3].

The AA5083 alloy is full-hardened temper, -H38 temper and is solution heat treated and naturally aged to a substantially stable condition-T4. H38 temper is by means of the alloy was strain hardened, then heated at low temperature to increase ductility and stabilized its mechanical properties meanwhile T4 is meant by the alloy was solution heat treated and naturally aged to a substantially stable condition. Typical chemical composition for aluminium alloy 5083 is shown in Table 2.3 and a typical mechanical property for aluminium alloy 5083 is shown in Table 2.4. Table 2.5 shows the typical physical properties for aluminium alloy 5083.