Faculty of Engineering

# ANALYSIS OF FRACTURE BEHAVIOUR FOR ALUMINIUM 6061 BY USING FINITE ELEMENT ANALYSIS

**Dunstan Dungat Anak Tedong**

**Bachelor of Engineering with Honours**
**(Mechanical and Manufacturing Engineering)**
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________________________________________ _______________

Assoc. Prof. Dr Syed Tarmizi Bin Syed Shazali Date

Project Supervisor

# ANALYSIS OF FRACTURE BEHAVIOUR FOR ALUMINIUM 6061 BY USING FINITE ELEMENT ANALYSIS

DUNSTAN DUNGAT ANAK TEDONG

A dissertation submitted in partial fulfilment

of the requirement for the degree of

Bachelor of Engineering with Honours

(Mechanical and Manufacturing Engineering)

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Dedicated to my beloved parents who always bestow me sustainable motivations and encouragements

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# ABSTRACT

In this report, the study on the fracture behaviour of aluminium alloy 6061 by using experimental testing and finite element analysis simulation was investigated. The experiments were carried out by using thin aluminium sheet with the thickness of 1.5 mm. The aluminium sheet were cut into dog-bone specimen according to ASTM E8/E8M and notch was applied on certain sample. This experimental study was focused on the tensile properties and fracture behaviour of dog-bone without notch, V-notch, and U-notch specimen. The Vickers hardness test and tensile test were applied to evaluate the hardness measurements and tensile strength for aluminium alloy 6061 respectively as well as the microstructure analysis for the fracture behaviour. The results showed the dog-bone without notch exhibited higher tensile strength and maximum force compared to V-notch and U-notch specimen. Microstructure analysis on the fracture surface for each specimen was observed by using scanning electron microscope revealed that all three types of specimens were fractured in ductile mode. The difference was the dimple formation in fractured surface of dog-bone without notch could be easily recognized compared to fractured surface of V-notch and U-notch specimen in higher magnification. Both notched specimen exhibits the similar fractured surface image. The finite element analysis simulation is done by using ANSYS Workbench 16.0 for each type of specimen in which non-linear simulation was applied. The comparison between experimental values and simulation showed that for dog-bone without notch the value obtained were almost the same. However, there were a large difference between experimental and simulation value for V-notch and U-notch specimen.

# ABSTRAK

Dalam laporan ini, kajian mengenai tingkah laku patah aloi aluminium 6061 dengan menggunakan ujian eksperimen dan simulasi analisis unsur terhingga diselidiki. Eksperimen dilakukan dengan menggunakan lembaran aluminium nipis dengan ketebalan 1.5 mm. Lembaran aluminium dipotong menjadi spesimen tulang anjing mengikut ASTM E8 / E8M dan takaran telah digunakan pada sampel tertentu. Kajian eksperimen ini memberi tumpuan kepada sifat-sifat tegangan dan kelakuan patah tulang anjing tanpa takik, spesimen takik V, dan spesimen takik U. Ujian kekerasan Vickers dan ujian tegangan digunakan untuk menilai pengukuran kekerasan dan kekuatan tegangan untuk aloi aluminium 6061 serta analisis mikrostruktur dilaksanakan untuk memerhati tingkah laku patah. Hasilnya menunjukkan tulang anjing tanpa takik telah mempamerkan kekuatan tegangan yang lebih tinggi dan daya maksimum berbanding spesimen takik V dan takik U. Analisis mikrostruktur pada permukaan patah untuk setiap spesimen diperhatikan dengan menggunakan mikroskop pengimbasan elektron dan mendedahkan bahawa ketiga-tiga jenis spesimen tersebut patah dalam mod mulur. Perbezaannya ialah pembentukan suram di permukaan tulang patah tanpa keretakan dapat dilihat dengan mudah berbanding dengan permukaan retak spesimen takik V dan takik U dalam perbesaran yang lebih tinggi. Kedua-dua spesimen bertakik mempamerkan permukaan yang pecah yang sama. Simulasi analisis unsur terhingga dilakukan dengan menggunakan perisian ANSYS Workbench 16.0 untuk setiap jenis spesimen di mana simulasi bukan linear telah diaplikasikan. Perbandingan antara nilai eksperimen dan simulasi menunjukkan bahawa untuk spesimen tulang anjing tanpa takik memperolehi nilai yang hampir sama. Walau bagaimanapun, terdapat perbezaan besar antara nilai eksperimen dan simulasi untuk spesimen takik V dan takik U.

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| | | |
|---|---|---|
| ° | – | Degree |
| °C | – | Degree Celsius |
| δ | – | Elongation |
| Γ | – | Fracture energy |
| $\mu m$ | – | Micron |
| $\varepsilon$ | – | Strain |
| $\varepsilon_{True}$ | – | True strain |
| $l_i$ | – | Length after elongation |
| $l_0$ | – | Length initial |
| $\sigma$ | – | Stress |
| $\sigma_{True}$ | – | True stress |
| $\sigma_{ut}$ | – | Ultimate tensile strength |
| $\sigma_{uc}$ | – | Ultimate compression strength |
| $A_0$ | – | Original area before loading |
| E | – | Young’s modulus |
| F | – | Force |
| g | – | Gram |
| kg | – | Kilogram |
| $kJ/m^2$ | – | Kilo Joule per meter square |
| kN | – | Kilo Newton |
| m | – | Meter |
| mm | – | Millimeter |
| m/s | – | Meter per second |
| mm/min | – | Millimeter per minute |
| GPa | – | Giga Pascal |
| MPa | – | Mega Pascal |

# LIST OF ABBREVIATIONS

| | | |
|---|---|---|
| Al | – | Aluminium |
| AA | – | Aluminium Alloy |
| CTOD | – | Crack Tip Opening Displacement |
| EWF | – | Essential Work of Fracture |
| FEA | – | Finite Element Analysis |
| FEM | – | Finite Element Method |
| HCP | – | Hexagonal Close-Packed |
| HV | – | Hardness Vickers |
| HB | – | Hardness Brinell |
| SEM | – | Scanning Electron Microscope |
| SENT | – | Single Edge Notched Tension |
| SIF | – | Stress Intensity Factor |
| TS | – | Tensile Strength |
| VCCT | – | Virtual Crack Closure Technique |
| XFEM | – | Extended Finite Element Method |

# CHAPTER 1

# INTRODUCTION

## 1.1 Introduction of Aluminium

Aluminium alloys (AA) are used in a wide range of engineering applications and majority application is in the construction sector, as it offer high strength-to-weight ratios and good durability (Su, Young, & Gardner, 2014). It also being used in a broad spectrum of load-bearing applications which are light-weight structures, light rail, bridge decks, marine crafts, and off-shore platforms (Summers et al., 2015). Aluminium alloy can be put into different shape, size, and thickness. Figure 1.1 shows a thin aluminium alloy sheet.

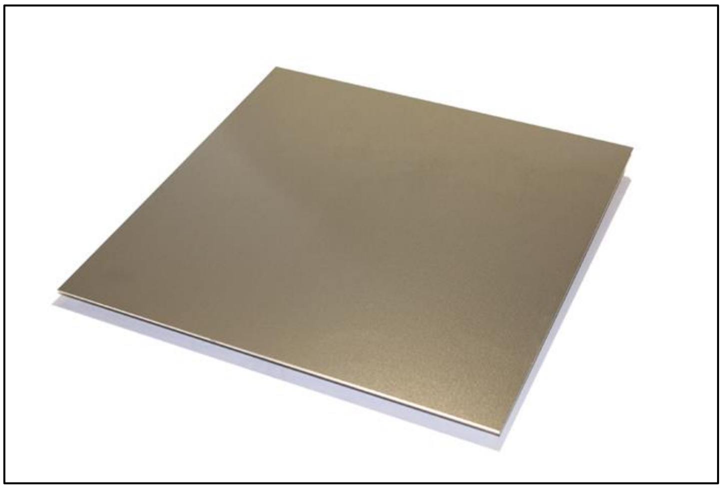

**Figure 1.1**: Thin sheet aluminium alloy (Extracted from: https://5.imimg.com/data5/PL/SN/MY-29850369/aluminium-sheet-6061-500x500.jpg)

According to Santos, Machado, Sales, Barrozo, & Ezugwu (2016) aluminium is the third most abundant metal in the earth's crust and in its natural form is combined with oxygen and other elements. Generally, aluminium is a white metal produced by electrical process from the oxide (alumina), which is prepared from bauxite. Bauxite is a clayey mineral extracted from the earth. Aluminium is a lightweight metal having specific gravity 2.7 and melting point of 660°C. The metal would be weak and soft for most purposes in its pure state hence it does not have a high tensile strength. It becomes hard and rigid when mixed with other elements such as manganese, silicon, copper and magnesium to form aluminium alloys which can increases the strength properties and produce an alloy with properties tailored to any specific applications. Therefore, it can be used in the process of forming, casting, forging and die casting.

In cold environment, aluminium is well suited as the tensile strength increases with decreasing temperature while retaining its toughness. It is also a good conductor of electricity which is an important property and is widely used for overhead cables. The high resistance to corrosion and its non-toxicity makes it a useful metal for cooking utensils under ordinary conditions. It is extensively used in aircraft and automobile components where saving of weight is an advantage.

## 1.2 Introduction to Finite Element Analysis

It has been more than century, approximately back to early 1900s finite element analysis (FEA) is a general numerical method that is applied to solve a variety of engineering problems and the underlying theory. General purpose computer software is employed by major companies including Boeing, Ford, General Electric, Intel, IBM, Apple, and others to complete daily engineering analysis tasks in an efficient way. According to Pidaparti (2017) the prediction of material that subjected to loads can be made by using numerical method, which is finite element analysis. There is a few software that are used in FEA modelling and simulation such as ANSYS, ABAQUS, and DEFORM. ANSYS software is used for three-dimensional (3D) finite element analysis (FEA) by applying plain strain assumptions (Matur, Krishnan, Dinesh, & Engineering, 2014). According to Niu and Su (2016) a commercial FEA software which is ABAQUS with user-defined element subroutine is used to calculate the stress intensity factors (SIF) based on the VCCT. DEFORM 3D is a FEA software is used to perform the tensile test simulation by applying the Cockcroft and Latham criterion (D. C. Chen, You, & Gao, 2014).

## 1.3 Background of Project

This project is regarding the analysis of fracture behaviour of Aluminium 6061, also known as AA6061. There are two methods which are experimental and by using finite element analysis (FEA). The experiment such as tensile test, hardness test, microstructure analysis had to be done on the Aluminium 6061 specimen. Two types of crack model or notch, which are V-notch and U-notch will be created on the aluminium alloy. The simulation of the crack model is also analysed by using finite element analysis method in which to predict the fracture behaviour and maximum stress that acting on Aluminium 6061.

## 1.4 Problem Statement

Aluminium 6061 applies in structural components, aircraft, and cooking utensils hence, they are relatively strong and have good corrosion resistance. Application in structural components is being focused such as beam, scaffolding, handrails, drive shafts, automotive frame sections, and bicycle frames. Aluminium 6061 tend to be crack-sensitive, thus research on the fracture behaviour is important. Fracture can occur during the manufacturing process of the aluminium when it is put into shape of sheet, plate, rod, and structural beam. Lack of research on the behaviour during crack propagation in thin aluminium sheet (Shaikh, Khan, & Ahmed, 2017). The tensile behaviour is one of the main concern for the reliability of structural components to reduce failure. This is due to the load and stresses that experienced by the structural components. Hence, the mechanical properties are being determined during experimental testing which is tensile test to analyse the fracture behaviour of thin aluminium sheet with notched specimen.

Structural components designed by engineers need an efficient instrument to predict the load-carrying capacity of notched or cracked components. Therefore, FEA simulation is used as a modus operandi in predicting the fracture behaviour of aluminium. Experimental solution is verified by using the model using finite element method (FEM) formulation (Farahani, Tavares, Belinha, & Moreira, 2017). Relying only on the computational method is inadequate hence the experiments such as tension and compression test had to be conducted.

## 1.5 Aim and Objectives

The main of this research is to analyse the fracture behaviour of Aluminium 6061 by using finite element analysis. To achieve the aim of study, several objectives are taken which are:

I. **To investigate the mechanical properties of Aluminium 6061 using experimental testing.**

   Literature review is done on the research regarding the mechanical properties. Experimental testing such as tensile test is used to investigate the fracture behaviour and to obtain the mechanical properties of Aluminium 6061.

II. **To analyse and simulate the fracture behaviour of Aluminium 6061 by using finite element analysis (FEA).**

   FEA simulation is done after the experimental testing by using ANSYS software. The parameters and boundary conditions are obtained from the experimental testing.

III. **To compare the fracture behaviour of experimental testing with finite element analysis (FEA) simulation.**

   The comparison between experimental data with FEA simulation result. Discussion regarding the differences of results are also referred to the result obtain by other researchers in the literature review.

## 1.6 Methodology

Methodology consist of several processes or steps that must be taken throughout the study. In this research, a proper methodology is planned to accomplish the aim and objectives. The sequence of the processes or steps for this study is shown in Figure 1.2. The methodology starts off with literature review, preparation of questionnaires, study visit, material selection, experimental testing, FEA simulation, and analysis of data collected.

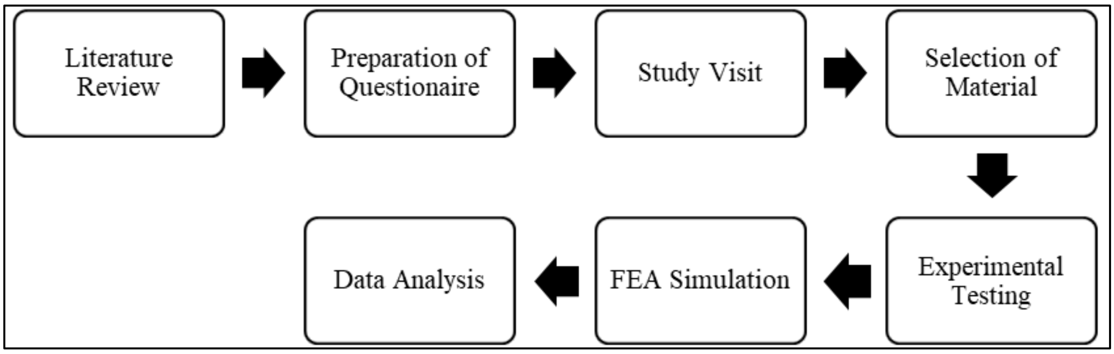


**Figure 1.2**: Sequence of methodology

i. Literature review

The first step is literature review where literature review consists of studies of fracture behaviour and the testing method used for aluminium. Moreover, information of various research such as heat treatment also been done. The other similar research also helps for better understanding of FEA.

ii. Preparation of questionnaire

Questionnaire is developed to collect information on the problems of aluminium and the problems regarding fracture behaviour thin metal sheet.

iii. Study visits

Several visits to the industries in which aluminium is available are conducted to increase understanding on the problem.

iv. Selection of material

There are various types of aluminium available in the market with its own purposes. Material that is used in structural component is chosen which is Aluminium 6061.

v. Experimental testing

There are two types of specimen which are dog-bone without notch, V-notch, and U-notch specimen is prepared. All the specimens are tested by using tensile testing machine is conducted in the laboratory.

vi. FEA simulation

SolidWorks and ANSYS software is used for modelling and simulation of the test specimen under tensile loading.

vii. Data analysis

Experimental and numerical results is compared, and stress-strain curve is tabulated and analysed.

## 1.7 Expected Outcome

From this research, better understanding about the fracture behaviour for Aluminium 6061 can be achieved and comparison of outcomes from current research. The prediction of fracture is useful for structural components application as it is also concerning about the safety of Aluminium 6061 products.

## 1.8 Summary

Aluminium is widely utilised in the application of structural component due to its physical properties such as high strength-to-weight ratios and good durability. Aluminium can chemically combine to form aluminium alloy that can increases the mechanical properties and applied to any specific applications. Hence, fracture behaviour of Aluminium 6061 is analysed experimentally during tensile loading and together with the FEA simulation.