UNIVERSITI TEKNIKAL MALAYSIA MELAKA

STUDY THE MATERIAL PERFORMANCE OF ALUMINUM - ZINC AND GALVANIZED IRON FOR ROOFING

This report submitted in accordance with requirement of the Universiti Teknikal Malaysia Melaka (UTeM) for the Bachelor's Degree in Manufacturing Engineering Technology (Process and Technology) with Honours

By

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APPROVAL

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

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ABSTRAK

Bumbung merupakan satu komponen yang bertindak sebagai tempat perlindungan bagi sebuah rumah. Terdapat banyak jenis bumbung seperti bumbung jubin, bumbung jerami, bumbung gentian kaca dan bumbung logam. Bagi projek kali ini, kajian tentang sifat-sifat mekanikal Aluminium-Zink, kepingan bumbung logam Alu-Zn dan Galvanized Iron, kepingan bumbung logam GI bagi sistem bumbung. Spesimen untuk ujian tegangan disediakan mengikut ASTM E8 dengan dimensi 165mm × 19mm × 0.3mm dalam bentuk tulang anjing. Untuk ujian keletihan pula ukuran mengikut ASTM E467 dengan dimensi 117mm × 26mm × 0.3mm dalam bentuk tulang anjing. Untuk ujian tegangan, nilai purata menunjukkan Alu-Zn adalah lebih tinggi berbanding dengan spesimen GI dengan nilai 347.46 MPa atau 53.81%. Keadaan ini berlaku kerana fasa Martensite berlaku pada spesimen Alu-Zn, pada suhu 600°C. Sementara itu spesimen GI muncul dalam fasa Bainite apabila disejukkan pada suhu bilik daripada suhu sebelumnya 450°C. Bagi ujian keletihan pula, pada kitaran 5 adalah had kitaran untuk spesimen Alu-Zn dengan daya yang dikenakan sebanyak 14.187 MPa. Pada peringkat ini, perubahan fasa berlaku daripada elastik kepada perubahan bentuk plastik. Sebaliknya, spesimen GI juga menunjukkan pada kitaran 5 adalah had kitaran untuk perubahan fasa dengan daya yang dikenakan sebanyak 6.959 MPa. Mengenai perubahan fasa, faktor yang mempengaruhi setalah daya yang berbeza dikenakan adalah 50.98% kepada spesimen Alu-Zn berbanding spesimen GI dalam ujian keletihan adalah ikatan yang terbentuk antara atom bagi kedua-dua spesimen berikut. Spesimen Alu-Zn terdiri daripada ikatan kovalen dan ikatan logam, manakala spesimen GI terdiri daripada ikatan kovalen sahaja. Oleh itu, kajian ini telah mengenalpasti dengan jelas bahawa sifat mekanikal bagi spesimen Alu-Zn dan spesimen GI. Kajian ini juga telah mengenal pasti bahawa Alu-Zn mempunyai kekuatan tegangan yang lebih tinggi dengan nilai 347.46

MPa. Ujian keletihan pula telah menunjukkan bahawa pada kitaran 5 adalah had kitaran dengan daya yang dikenakan adalah 14.187 mpa.

ABSTRACT

Roofing is a part which is act as shelter for a house. There are many type of roofing such as tile roof, thatched roof, fiberglass roof and metal roof. For this project, to study about mechanical properties of Aluminum-Zinc, Alu-Zn sheet metal roof and Galvanized Iron, GI sheet metal for roofing system. Specimen for tensile testing prepared according to ASTM E8 with dimension of 165 mm × 19 mm × 0.3 mm in dog bone shape. For fatigue testing were prepared according to ASTM E467 with dimension of 117 mm × 26 mm × 0.3 mm in dog bone shape. For the tensile testing, mean value show that Alu-Zn specimen is higher compare to GI specimen by 347.46 MPa or 53.81%. This condition appear due to Martensite phase occur in Alu-zn specimen, from 600 °C. Meanwhile appear in GI specimen is Bainite phase when quench at room temperature from 450 °C. Fatigue testing showed cycle count of 5 cycles is the limit for Alu-Zn specimen with force applied is 14.187 MPa. At this stage, phase changes occur from elastic to plastic deformation. On the other hand, GI specimen also showed cycle count of 5 cycles is the limit with force applied is 6.959 MPa. On the top phase changes, factor that influence different force applied by 50.98% to Alu-Zn specimen and GI specimen in fatigue testing is bonding. Alu-Zn specimen consists of covalent and metallic bond, whereas GI specimen consists of covalent bond only. Hence, this project provides a clear mechanical property of Alu-Zn and GI specimen. This study has identified that Alu-Zn show higher tensile strength by 347.46 MPa. Fatigue testing show cycle limit at 5 cycles with force applied is 14.187 MPa.

DEDICATION

I want to thanks to my family, lecturer and friends that give me extra spirit to continue develop this project.

ACKNOWLEDGEMENT

All praise is due to Allah who has given me this opportunity to accomplish this project upon my final year project entitled STUDY THE MATERIAL PERFORMANCE OF ALUMINUM - ZINC AND GALVANIZED IRON FOR ROOFING. I would like to express my sincere appreciation and gratitude to my supervisor Madam. Nooririnah Binti Omar and all staff especially panel for encouragement, guidance, critics, motivation and supported. Without their support and interest, this Final Year Project Report would not have been same as presented here.

This project has guide a profitable training experience including support and guideline until I finish the 14 week period. I learned more from this Final Year Project about the way to work. It gives me a real working skill in finishing project. Besides improving and learning deeper about testing that I used. Whatever I learnt from my supervisor, I accepted as a valuable experience for my life.

Finally, I would like to thank my lovely family that always give me full support and all my friends for helping me in what so ever related task into completing this project. I will remember and keep all the knowledge and memories between us.
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LIST OF ABBREVIATIONS, SYMBOLS AND NOMENCLATURE

FEA	-	Finite Element Analysis
Alu-Zn	-	Aluminum Zinc
GI	-	Galvanized Iron
ASTM	-	America Society for Testing and Material
MPa	-	Mega Pascal
σ	-	Stress
P	-	Force
A	-	Area
ε	-	Strain
L_f	-	Final Length
L_o	-	Origin Length
ΔL	-	Change of Length
OYS	-	Offset Yield Strength
EUL	-	Extension under Load
E	-	Slope
Fe	-	Ferum/Iron
Al	-	Aluminum
ZN	-	Zinc
°C	-	Degree of Celcius
FCC	-	Face Centred Cubic
HCP	-	Hexogonal Close Packed
S-N	-	Strain-Number of Cycle to Failure

CHAPTER 1

INTRODUCTION

1.0 Brief History of Roofing

The top of each house is known as the roof. Roof indeed has a wide variety. There are bumpy, and some form of a flat surface. However, these classifications play a different role with the same purpose of protecting households from heat, cold, rain, wind, and other weather effects. The roof reinforcement structure created with the aim of slowing the lifespan of the roofing sheets. In addition to the reinforcement structure, the type of material also affects the strength of the roof. There are many types of materials for the production the roof. Generally, the material of choice for the manufacture of a roof is like clay, metal, leaf thatch and fibre. The material properties have its own advantages. Therefore, a study was carried out on the roof of the structure and the material used for the production of a roof influencing physical strength when a certain load is imposed on the structure.

Roof coverings even function only as a building, failure causes the entire building suffered the same consequences. Thus, the design should be more detailed in order to obtain a structure the roof can bear any burden in a variety of conditions. The storm is not identified correctly, but expectations to apply can be obtained through the events of last were recorded. This information is important for designers to be able provide a secure roof system design used in what circumstances (Zalipah, 2005).

1.1 Problem Statement

Peninsular Malaysia's climate is influenced by the winds of Sumatra. The wind is also known as squall brings heavy rain, accompanied by lightning, thunder, and storms that reach speeds up to 80 km / hour. It was named because of the wind blowing from Sumatra the island of Sumatra to the west coast of Peninsular Malaysia. This phenomenon occurred in April and May, mainly between Port Kelang and Johor (Ku Kassim Ku Yaacob et al, 2007). The failure of the roof structure caused by wind loads reported from time to time. To overcome this problem, a shield of material performance of Alu-Zn and galvanized for roofing in term of mechanical properties will be conducted to give potential solution to the roof problems.

1.2 Objectives

The purpose of this project are:

a) To proof concept of Finite Element Analysis, FEA for Aluminum - Zinc and Galvanized Iron.
b) To investigate the mechanical properties of Aluminum – Zinc metal roof and Galvanized Iron.

1.3 Scope of Project

(a) To conduct mechanical testing such as Tensile Testing and Fatigue Testing on colour pre-painted (Alu-Zn) and Galvanized Iron (GI).
(b) To analysis mechanical properties between pre-painted (Alu-Zn) and Galvanized Iron (GI).

CHAPTER 2

LITERATURE REVIEW

2.0 Introduction

Scientific sources such as journals, newspapers, articles, magazines and the Internet are referred as a reference and generates an understanding in this report. Among the important aspects of the sport in the literature review are types of roof, aluminium roof, roofing galvanize, and the testing.

2.1 Roof Structure

Most of the roofs of houses in Malaysia are a horizontal structure. Roof structures play a role to support the roof load. The structure of roof component should be support the cover roofing system and all load of material that meet during system installation. Wood and steel are the materials used in the installation of roof trusses. Roof frame assembly can be done by installing one by one on top of the house with nails, screws, bolts and nuts. But now, the installation of the roof can be installed directly from the factory. Around the same time Mohd Shukari Midon et al, (1996), for the wall panel, the firstly truss must be installed at industry and shall lifted to site when it needed. Installation of truss can be doing with using nailed plywood gusset plates as shown in the plan or using the punched metal plates. If using the metal plate, the truss will produce in industry that supplied the plate. So, the size of plate that required for every joint is counted by the licenced industry while the size of wood that act as a truss is constant like in sketching.

The process starting with installs the first trusses at one end. When it put at right place, the truss has should be tightened using the nail or screw at wall plate. With use the 50 mm x 100 mm of timber, the end truss then temporarily braced to the ground as shown in figure 2.1.1. This bracing must be strong, although it just temporary because the other trusses must be fastened to it. So, the second truss can be install with put it upside down firstly as shown in figure 2.1.1 and after that, it will lift correctly and the temporary brace with use to hold the position as shown in figure 2.1.2. So, other trusses can be install using same method.

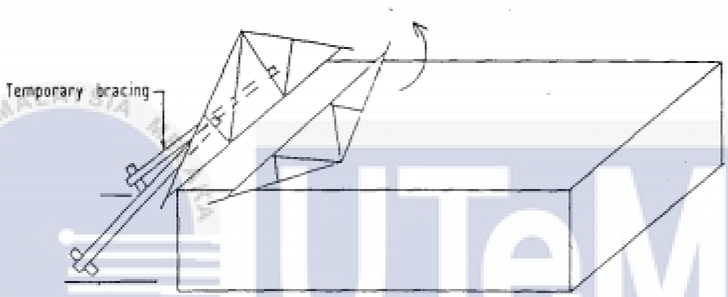

Figure 2.1.1: Erection of first truss
(Mohd Shukari Midon et al, 1996)

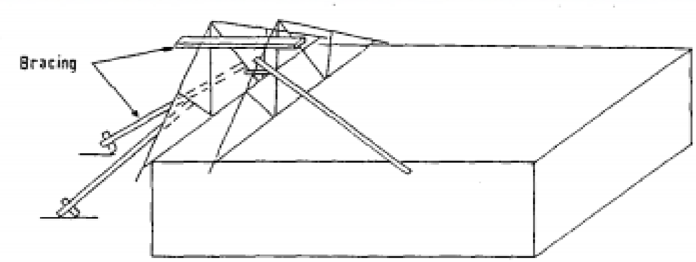

Figure 2.1.2: Erection of second truss
(Mohd Shukari Midon et al, 1996)

2.2 Roofing

The roof of a building is a cover that protects the building from heat and rain. There are various types of the roof where each has its own advantages. However, as strong as any of a roof, if the water does not flow down to the well, the roof is less well physically. Roof covering materials in the production of various types such as, tile roof, thatched roof, fiberglass roof and metal roof.

2.2.1 Tile Roof

In Malaysia, in the past, only rich people can afford to own a tiled roof, because it had to be brought in from abroad. Therefore, a tiled roof is often associated with the wealthy. Roof tiles made of clay tile is still the most popular variant in society. Because it has a very good structure, not easily weathered, safe from fire, and not rusty. However, the tiles also have disadvantages such as the roof colour will fade, mossy and weight. According to Poncogunawan (2015), roof tiles will fade. This is because clay tile created in the combustion process, and without the addition of other materials. So that when exposed to heat and rain can change colour. In addition, clay tiles are arranged will be heavier and require a strong structure.

Figure 2.2.1: Tile roof

2.2.2 Thatched Roof

Thatched roof is a roof of a building made of sago leaves. It is a type of palm tree found in the woods and a lot of Indonesia, Malaysia, and Papua New Guinea. Tree House has many pinnate shaped front 6-8 meters long first straight then slowly bend down. To make the roof of a thatched leaf material is not difficult; just provide some kind of material such as thick bamboo split over 1.5 meters, sago palm leaves and a stem Bamban is cut thin and long like a rope. Once the material is complete, bamboo thatched roof is folded in and then knitted wear ropes made of sticks Bamban (Syahril, 2013).

In Malaysia there is some resorts use thatched roof as a roof in order to maintain the concept of authenticity of Malay. Thatched roof also impact both in terms of beauty and peace atmosphere in the residents living there. This was discussed by Zuhairuse Md Darus et al (2014), developments and design of resort suc as Tanjung Jara and Aryani in Terengganu, The Datai, Bon Ton and Langkawi Lagoon on Langkawi, Pangkor Laut in Perak and Club Med Cherating in Pahang is a symbolic an excellent for traditional Malay vernacular designs concept. for attaining the desired aspiration which transcends the language barrier and traditional architectural synthesis from the design angle and the overall concept, these resorts have successfully embraced the glory of native architecture and elevate the splendour and authenticity especially in the adaptations of local building materials.

Figure 2.2.2: Thatched roof

2.2.3 Fibreglass Roof

Fiberglass roof is used in the installation of the roof in an industrial and warehouse area. The aim is to allow energy refract around the surrounding. This statement can prove by CV.Sekar Sion Company that said fiberglass roof is a roof that serves as a light, translucent, but not easily penetrates to the extreme sunlight. The roof has a strong structure so awe and unbreakable when to use and very useful to minimize the use of electricity. The use of the roof is usually used in residential warehousing, indoor field, and industry. Among the advantages of fiberglass roof is durable in terms of its use, not easily fragile, less expensive when compared with the use of durable quality and can reduce UV rays. <http://www.supplierbahanbangunan.com>

According to Sanjay M et al (2008), a reduction of the heating and cooling loads of more than 50% can be seen when polystyrene or polyurethane insulation layers are used compared to a similar but un-insulated building roof.

Figure 2.2.3: Fiberglass Roof

(Source: <http://www.supplierbahanbangunan.com/atap/atap-fiberglass>23/05/16)

2.2.4 Metal Roof

Metal roofing is made of a mixture of several elements and formed into a corrugated sheet. The roof also called lightweight coated steel roof. The advantage of this roof is leak resistant because it is designed to perfection. The metal roof also has high durability. With its characteristics, the metal roof can be used for decades without suffering serious damage. It is designed by the manufacturer to be easily installed with a relatively short time.

In Malaysia, temperature heat in the average of 22 C - 30 C. The use of a metal roof can contribute to the heat inside the house. According to Berdahl et al (1997) and Miller et al (2004) have studied the effect of roof colour in minimizing surface temperature, and found that high solar reflectance and infrared remittance of roofs surface reduce heat gain and also the UV radiation received by roofs. The utilisation of lighter colour is very highly recommended under Malaysia climate due to their high solar reflectivity, but it is less diffused and not well accepted by the population. Several solutions are possible to minimize the ceiling temperature such as the insulation of roof, attic ventilation, selection of roofing materials more suitable under warm humid conditions, the realisation of high-pitched roof, and may be other suitable and practical techniques.

Figure 2.2.4: Metal Roof

2.3 Galvalume (Alu-Zn)

Galvalume is a combination between aluminium alloy and zinc element. Every metal element has self a property about it which is has potential to increase the lifecycle of metal roofing panel over time. Aluminium-zinc can act for prevent corrosion and increase durability. The advantages of galvalume make it as an excellent choice for metal roofing panel even in exposed conditions. This is because it consists by some of metal coating that protects the steel from rusting. Nowadays, metal roofing panels appear in many different colours and even has a protection paint steel, the metal coating cause the high protection. <http://tricountymetals.com/galvalume-vs-galvanized-roofing-which-is-better/>

Aluminum-Zinc consists of 55% Aluminum, 43.5% Zinc, and 1.5% Silicon. This sheet metal is suitable for low slope roofing on industrial buildings because it had a coating that proven to be an excellent product for long-life building cladding. It still has been widely applied as unpainted sheet with the coating, although directly exposed to the atmosphere. The substrate for pre-printed sheet also is used and this use has also grown significantly. The ASTM A792/A792M is product specification for 55% Al-Zn coated sheet, and the pre-printed sheet version is specified in A755/A755M. (Copyright, 2011 by: Iza)

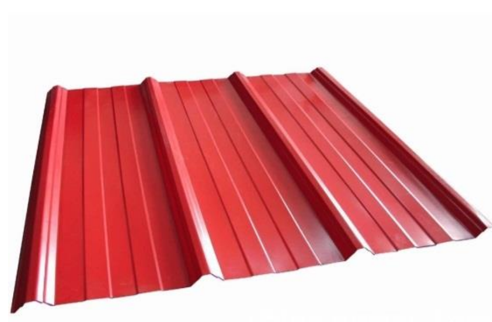

Figure 2.3.1: Types of Alu-Zinc roofing sheets

2.3.1 Specification of Alu-zinc Roof Sheets

Table 2.3.1: Specification of Alu-zinc Roof Sheets

Item	Properties
Chemical composition	55% of Aluminum, 43.5% of Zinc and 1.5% of Silicon
Standard	ASTM A792M / JIS3321
Thickness	0.16 mm – 3.0 mm
Width	600 mm – 1250 mm
Aluminum coating	AZ 185 / AZ150 / AZ100 / AZ50
Surface treatment	Chemical treatment, dry, oil, anti-finger print
Colour series	RMP / SMP / HDP / PVF2

2.3.2 Features of Alu-zinc Roofing Sheet

a) Long-term resistance to corrosion

b) bright surface

c) durable

2.3.3 Application for Aluminum Roofing

a) Warehouse

b) Gymnasium

c) Supermarket

d) Commercial facilities

e) Hospital

2.4 Galvanized

The galvanized iron has a common function with galvalume that protect the metal from corrosion and rusting. Galvanized iron is a process using Zinc element that coated with steel in hot dip process. This process form layers with a layer of zinc forming at the top and a layer of just steel on the bottom layer. Sheet metal of galvanize is durable and scratch resistance but the lifecycle of it decrease when exposed to rain or salt water.

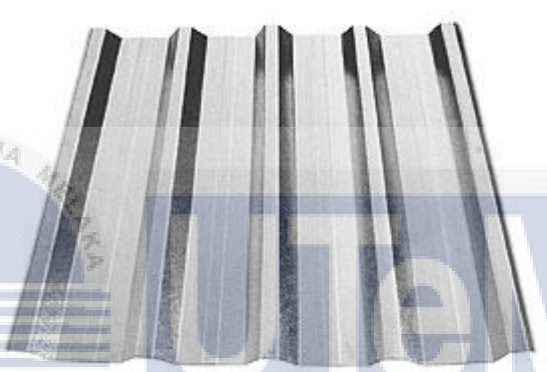

Figure 2.4.1: Galvanized corrugated roofing sheets

According to Satyendra (2013), define the hot dip galvanizing is a principle of the process consists of the immersion of steel strips in molten zinc. Zinc content of minimum of 99.95 % is used to galvanizing high grade for Zinc. The process should be through pre-treatment tanks for degreasing, pickling, and cleansing, the strip passes through the annealing furnace and a pot containing molten zinc. For active the surface with a reducing of gas, and makes it easy to coat zinc on the strip surface, the annealing furnace is used to apply the heat cycle needed to obtain the required mechanical properties. A crystalline surface pattern known as spangles has formed during this process.

2.4.1 Specifications of Galvanized Corrugated Steel Sheet

Table 2.4.1: Specifications of Galvanized Corrugated Steel Sheet

Item	Properties
Chemical composition	99.95% of Zinc and 6.0% of Ferum
Standard	ASTM A526 / JISG 3302 / SGCC / Z50-275
Thickness	0.18 mm – 1.20 mm
Width	20 mm – 1500 mm
Zinc coating	50 – 275 g/mm^2.
Tensile strength	270-500N/mm^2.
Surface finish	Normal spangle, large spangle, small spangle, matte surface.

2.4.2 Application for Galvanized Iron Sheet

(a) Civil engineering structure and building construction

(i) Roofing material

(ii) housing structure member (column, beam)

(b) Automobile

(i) Floor

(ii) various parts

(c) Shipbuilding

(i) Duct

(ii) panel

(d) Electric appliance

(i) Refrigerator

(ii) washing machine

2.4.3 Characteristic of Galvanized Iron Corrugated for Roofing

(a) High corrosion and rust resistance similar.

(b) Excellent waterproof performance.

(c) Durable, anti-corrosion Zinc coating which lasts 20 - 30 years and can withstand bad weather.

(d) Easy to install, no special tools required. Light weight without sacrificing the high strength to weight ratio of steel

(e) Varieties of colours.

2.5 Finite Element Analysis, FEA

Finite element analysis (FEA) is software that becomes popular in recent years. This is reason which is FEA has used in every industry to analysis a part of component before fabricate. FEA is a solution to identify the magnitude of part when applied to the parameter such as a pressure, heat, shear, force, stress and elongation. Using FEA, a complicated stress problem can be solving with numerical solutions and this method is so important in treatments of materials properties. There is a current of study about FEA, that finite element analysis can use for analyse simultaneous all mechanical problem that related in plastic deformation. As a theory, the complicated design for do a simulation is unlimited. Nowadays, development of technology had influence the speed of computer. The simulation of development and analysis software mostly has matured and stable. So, using the finite element analysis will help to get the accurate data and faster. Shao-Yi Hsia et al, (2016)

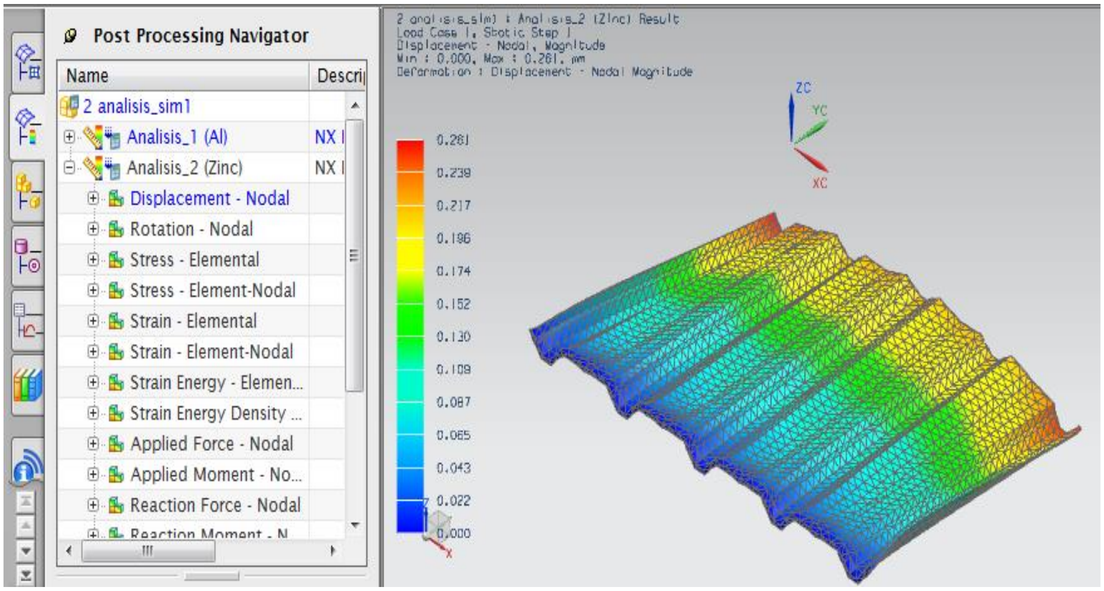

Figure 2.5.1: Finite Element Analysis for GI

2.5.1 FEA Operation

Finite element analysis, FEA is a system that makes grid called a mesh. The design that sketched is programmed to contain the material properties and structure which is acted when the force is applied on it. The parts that applied by force will represent by colour.

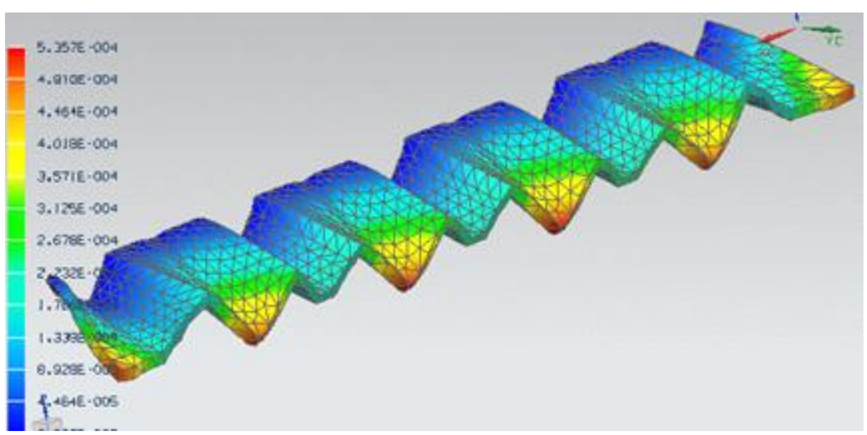

Figure 2.5.2: FEA Operation

From different of colour, the part of component can be identified that area which is weak point and strong point. FEA operations starting with a sketches the object and import it to design simulation. Consider the types of material and type of mechanical testing will be smoothly the operation of FEA. The grid that called a mesh has applied to distribute the magnitude such as force to part design and run the simulation.

CHAPTER 3

METHODOLOGY

3.0 Introduction

This chapter discussed process and methodology that will be conducted in this project included sample selection, mechanical testing such as tensile test, and fatigue testing, procedures and flow chart.

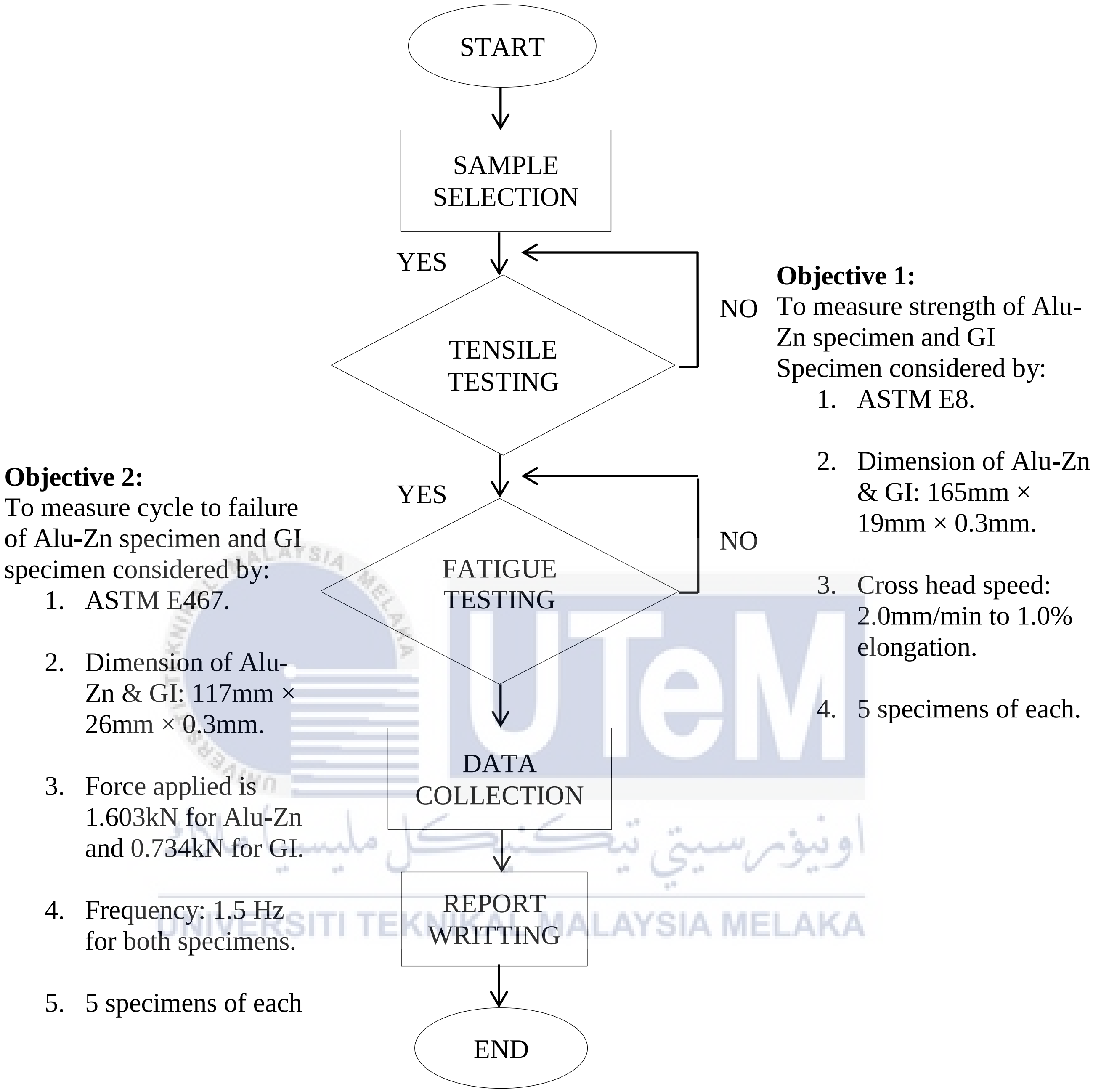

Figure 3.0: Mechanical Testing Flowchart

3.1 Introduction to Tensile Testing

The strength of a material often is the primary concern. The strength of interest may be measured in terms of either the stress necessary to cause appreciable plastic deformation or the maximum stress that the material can withstand. These measures of strength are used, with appropriate caution (in the form of safety factors), in engineering design. Also of interest is the material's ductility, which is a measure of how much it can be deformed before it fractures. Rarely is ductility incorporated directly in design; rather, it is included in material specifications to ensure quality and toughness. Low ductility in a tensile test often is accompanied by low resistance to fracture under other forms of loading. Elastic properties also may be of interest, but special techniques must be used to measure these properties during tensile testing, and more accurate measurements can be made by ultrasonic techniques (W.F, 1992).

3.1.1 Tensile test

The tensile testing is carried out by applying longitudinal or axial load at a specific extension rate to a standard tensile specimen with known dimensions (gauge length and cross sectional area perpendicular to the load direction) till failure. The applied tensile load and extension are recorded during the test for the calculation of stress and strain. A range of universal standards provided by Professional societies such as American Society of Testing and Materials (ASTM), British standard, JIS standard and DIN standard provides testing are selected based on preferential uses. Each standard may contain a variety of test standards suitable for different materials, dimensions and fabrication history. For instance, ASTM E8: is a standard test method for tension testing of metallic materials and ASTM B557 is standard test methods of tension testing wrought and cast aluminium and magnesium alloy products.

A standard specimen is prepared in a square section along the gauge length as shown in figures 3.1.1 b). Both ends of the specimens should have sufficient length and a surface condition such that they are firmly gripped during testing. The initial gauge length *Lo* is standardized (in several countries) and varies with the diameter (*Do*) or the cross-sectional area (*Ao*) of the specimen as listed in table 3.1.1. This is because if the gauge length is too long, the % elongation might be underestimated in this case. There might be some exceptions, for examples, surface hardening or surface coating on the materials. These processes should be employed after specimen machining in order to obtain the tensile properties results which include the actual specimen surface conditions (T.Udomphol, 2006).

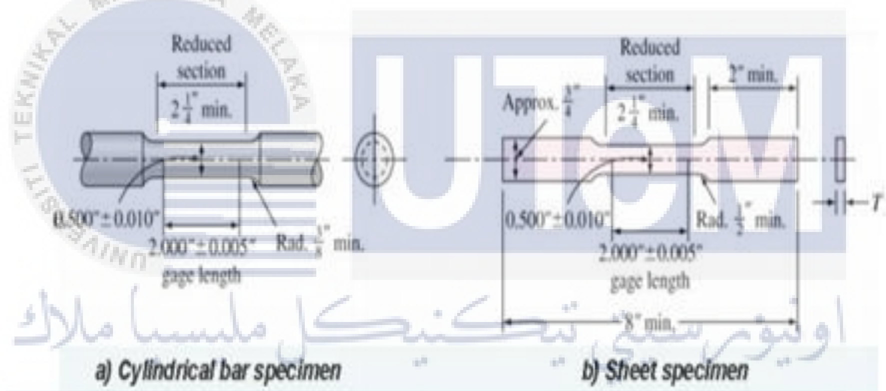

Figure 3.1.1: Standard tensile specimens

Table 3.1.1: Dimensional relationships of tensile specimens used in different countries.

Type Specimen	**United State (ASTM)**	**Great Britain**	**Germany**
Sheet ($L_o/\sqrt{A_o}$)	4.5	5.65	11.3
Rod ($L_o/\sqrt{D_o}$)	4.0	5.0	10.0

The equipment used for tensile testing ranges from simple devices to complicated controlled systems. The so-called universal testing machines are commonly used, which are driven by mechanical screw or hydraulic systems. Figure 3.1.1 a) illustrates a relatively simple screw-driven machine using large two screws to apply the load whereas figure 3.1.1 b) shows a hydraulic testing machine using the pressure of oil in a piston for load supply. These types of machines can be used not only for tension, but also for compression, bending and torsion tests. A more modernized closed-loop servo-hydraulic machine provides variations of load, strain, or testing machine motion (stroke) using a combination of actuator rod and piston. Most of the machines used nowadays are linked to a computer-controlled system in which the load and extension data can be graphically displayed together with the calculations of stress and strain.

General techniques utilized for measuring loads and displacements employs sensors providing electrical signals. Load cells are used for measuring the load applied while strain gauges are used for strain measurement. A Change in a linear dimension is proportional to the change in electrical voltage of the strain gauge attached on to the specimen.

Figure 3.1.2: Hydraulic Tensile Testing Machine

3.1.2 Stress and strain relationship

When a specimen is subjected to an external tensile loading, the metal will undergo elastic and plastic deformation. Initially, the metal will elastically deform giving a linear relationship of load and extension. These two parameters are then used for the calculation of the engineering stress and engineering strain to give a relationship as illustrated in figure 3.1.3 using equations 1 and 2 as follows:

$$\sigma = \frac{P}{A_{\circ}} \qquad \text{.... (1)}$$

$$\varepsilon = \frac{L_f - L_{\circ}}{L_{\circ}} = \Delta L \qquad \text{.... (2)}$$

Where:

- σ is the engineering stress
- ε is the engineering strain
- *P* is the external axial tensile load
- *Ao* is the original cross-sectional area of the specimen
- *Lo* is the original length of the specimen
- *Lf* is the final length of the specimen

The unit of the engineering stress is Pascal (Pa) or N/m2 according to the SI Metric Unit whereas the unit of psi (pound per square inch) can also be used.

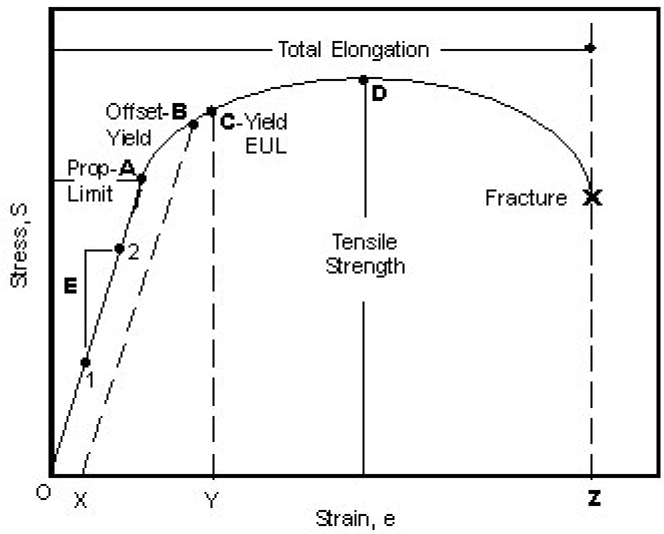

Figure 3.1.3: Stress-strain relationship

Figure 3.1.3 shows the stress-strain diagram with values of stress (load) as ordinate and strain (elongation, compression, deflection, twist etc.) as abscissa. Mechanical properties depend upon the crystal structure, its bonding forces, and the imperfections which exist within the crystal. The shape and magnitude of the curve is dependent on the type of metal being tested. Point A represents the proportional limit of a material. A material loaded in tension beyond point A when unloaded will exhibit permanent deformation. The proportional limit is often difficult to calculate, therefore, two practical measurements, offset yield strength (OYS) and yield by extension under load (EUL) were developed to approximate the proportional limit. The initial portion of the curve below point A represents the elastic region and is approximated by a straight line. The slope (E) of the curve in the elastic region is defined as Young's Modulus of Elasticity and is a measure of material stiffness (Oldfield et al, 2002).

Point B represents the offset yield strength and is found by constructing a line X-B parallel to the curve in the elastic region. Line X-B is offset a strain amount O-X that is typically 0.2% of the gage length. Point C represents the yield strength by extension under load (EUL) and is found by constructing a vertical line Y-C. Line Y-C is offset a strain amount O-Y that is typically 0.5% of gage length. The ultimate tensile strength, or peak stress, is represented by point D. Total elongation, which includes both elastic and plastic deformation, is the amount of uniaxial strain at fracture and is depicted as strain at point Z. Percent Elongation at break is determined by removing the fractured specimen from the grips; fitting the broken ends together and measuring the distance between gage marks. Percent elongation at break reports the amount of plastic deformation only.

Reduction of area, like elongation at break, is a measure of ductility and is expressed in percent. Reduction of area is calculated by measuring the cross sectional area at the fracture point (Az) (Oldfield et al, 2002).

3.1.3 Process Flow

Specimen will be prepared by specimen cleaning to remove impurities such as dust and oil. Specimen is prepared according to ASTM E8. Tensile tests were carried out according to the ASTM E 8M standard, using 05 specimens for each Al alloy, removed longitudinally to the sheet rolling direction. The initial length, (Lo) specimen is taken in advance and recorded. The specimen was positioned in the jaw of the tensile testing machine (manufactured by: INSTRON, series number: 596943632) with minimum load 10KN and maximum load 50KN using the rack and pinion type. Flat Grips for testing flat specimens. The grip retainers were assembled at the top and lower crossheads placed in position and loosely fastened the screws holding the retainers. The pinion shaft handle was turned so that the gears engage the teeth on the wedge grips evenly. The handle was turned until the grips were fully inside the crosshead and the roofing sheets were inserted one after the other between the wedge grips, and the crank handle turned. The extensometer was connected to the specimen. The tensile machine was started to stretch the roofing sheet. At the breaking point the extensometer was removed from the sample and a graph of stress against strain was automatically plotted by the computer.

3.2 Fatigue Test

Fatigue is the progressive, localized, permanent structural change that occurs in materials subjected to fluctuating stresses and strains that may result in cracks or fracture after a sufficient number of fluctuations. Fatigue fractures are caused by the simultaneous action of cyclic stress, tensile stress and plastic strain. If any one of these three is not present, fatigue cracking will not initiate and propagate. The cyclic stress starts the crack; the tensile stress produces crack growth (propagation).

The process of fatigue consists of three stages:

(a) Initial fatigue damage leading to crack nucleation and crack initiation
(b) Progressive cyclic growth of a crack (crack propagation) until the remaining un-cracked cross section of a part becomes too weak to sustain the loads imposed
(c) Final, sudden fracture of the remaining cross section

Fatigue cracking normally results from cyclic stresses that are well below the static yield strength of the material. However, or if the material has an appreciable work-hardening rate, the stresses also may be above the static yield strength (H, 1986).

Figure 3.2.1: Fatigue Machine

3.2.1 Process Flow

Whether simple or complex, all fatigue testing machines consist of the same basic components such as a load train, controllers, and monitors. The load train consists of the load frame, gripping devices, test specimen, and drive (loading) system. Typical load train components in an electrohydraulic axial fatigue machine are shown in figure 3.2.1. The specimen is placed in the flat grip of fatigue test machine (manufactured by: SHIMADZU, series number: I 141005200345). Measure the width of the specimen before the test is done. Fit one end of the specimen to a motor and fit the other end to a bearing hung with a known weight, indicating the stress applied to the specimen. Start the motor to rotate/vibrate the specimen at a constant speed. The revolution counter is used to record the number of cycles to which the specimen fails.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.0 Introduction

In this chapter, the mechanical properties Aluminum-Zinc (Alu-Zn) and Galvanize Iron (GI) will be discussed. The tests that have been carried out are tensile testing and fatigue testing. The following are the results obtained and discussion related to it.

4.1 Tensile Strength Testing

The testing has been conducted using an Instron Universal Testing Machine with extensometer. The cross head speed has 2.0 mm/min up to 1.0 % elongation and the gauge length was 165 mm.

4.1.1 Tensile strength of Aluminum-Zinc (Alu-Zn) and Galvanize Iron (GI)

The figures 4.1(a) and (b) show the two types of specimen that Alu-Zn and GI respectively before testing. Studies on the specimen Alu-Zn and GI using tensile strength is intended to determine the strength of the roof of metal. Durability both specimens are able to prove that usability is very affordable.

Tensile test specimens were performed according to ASTM E8. Specimen is prepared using scissors steel into dog bone shape following dimension on show in figure 4.2

Figure 4.1(a): Specimen of Alu-Zn

Figure 4.1(b): Specimen of GI

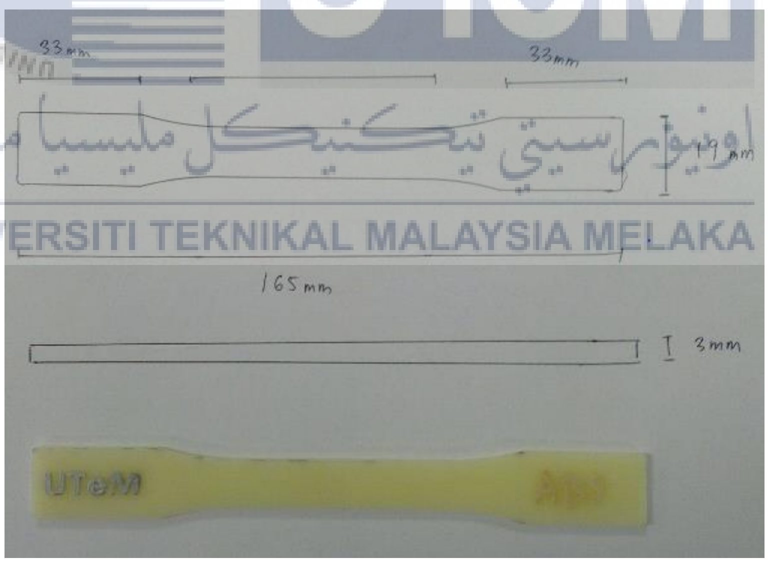

Figure 4.2: Dog Bone Specimen Dimension

There are 5 specimens from Alu-Zn samples and GI samples are prepared to perform the tensile testing. Selection of 5 samples is because to demonstrate more clearly about sustainability of both specimens. The result shown in table 4.1(a) and table 4.1(b) indicates value Ultimate Tensile Strength, UTS and Modulus Young (MPa) for 5 samples from Alu-Zn and GI. Table 4.1(c) show the difference in the ultimate tensile strength for both types of specimen.

Table 4.1(a): Tensile Test for Aluminum Zinc (Alu-Zn) Roofing Specimens

Number of Specimens	**Ultimate Tensile Strength (MPa)**	**Modulus Young's (MPa)**
1	777.82	242240.499
2	712.09	258168.130
3	672.15	675655.769
4	744.68	324138.823
5	718.69	638532.584
Total	3625.43	2,138,735.805
Mean	752.29	427,747.161

Table 4.1(b): Tensile Test for Galvanize Iron (GI) Roofing Specimens

Number of Specimens	**Ultimate Tensile Strength (MPa)**	**Modulus Young's (MPa)**
1	349.96	275493.184
2	367.77	204072.733
3	332.68	224876.117
4	348.29	185236.411
5	338.60	215952.461
Total	1737.30	1,105,630.906
Mean	347.46	221,126.1812

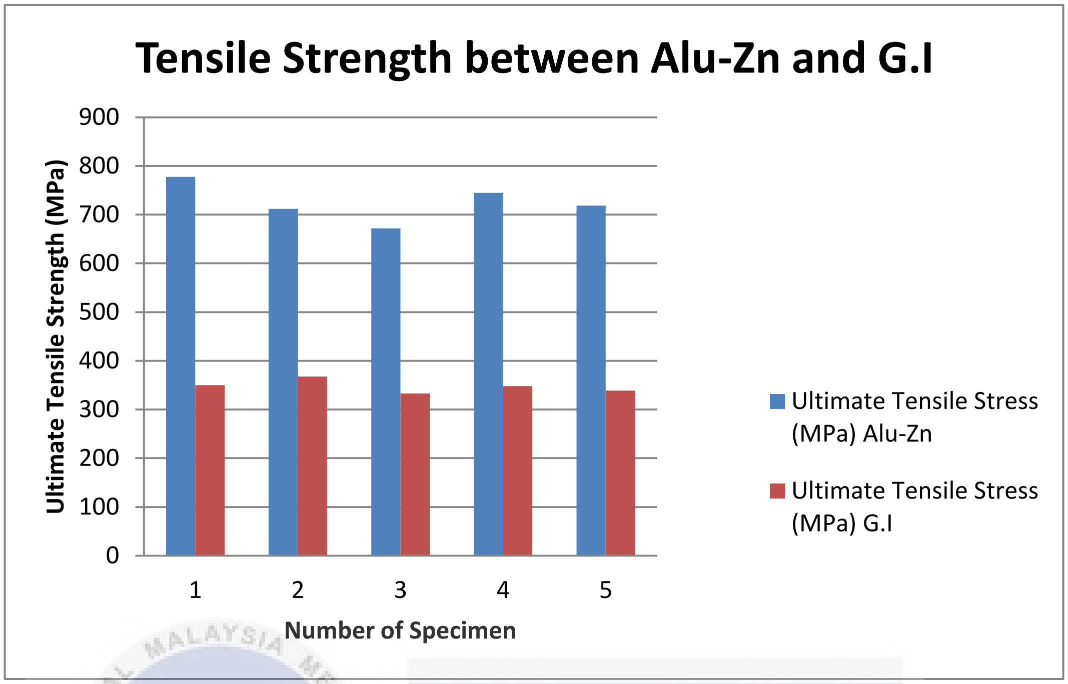

Figure 4.3: Tensile Strength between Alu-Zn and GI

Based on figure 4.4, the graphs clearly show that the mean value of tensile strength for Alu-Zn is higher compared to GI. Mean value of the tensile strength for Alu-Zn specimen is 752.29MPa while the mean value for the GI specimen is 347.46MPa. The difference of mean tensile strength is 53.81% higher for Alu-Zn specimen compared to GI specimen. It can be seen that the Alu-Zn composed of Aluminum 55%, 43.5% of Zinc and 1.5% of Silicon. The material properties that available in Alu-zinc are ductility, toughness and yield strength. For the GI specimens, it composed of Zinc 99.95%. There is also an intermetallic layer that contain about 6% of Iron,Fe. The physical properties of Zinc,Zn such as ductility, toughness and strength is low compared to Aluminum,Al. It can be seen that the percent of zinc which galvanize to iron in hot dip process need 465 °C compare to Alu-Zn need 600 °C. Based on figure 4.5, the eutectic diagram shows type of material that appears when the temperature descrease for the hot dip process. For the Alu-Zn at temperature 600 °C with Zn 43.5%, it still appears in Austenite phase and it quench at room temperature at 27 °C to become Martensite phase. At this phase, Al has rich Face Centered Cubic (FCC) structure. For the GI specimen, phase occur at temperature of 465 °C is 99.95% Zn. When it has been quenching to room temperature at 27 °C, phase has changes from Austenite to Bainite with hexagonal close-packed (HCP) structure. This factor influenced the physical properties of Alu-Zn and GI.

Table 4.1(c): Tensile strength of Aluminum-Zinc (Alu-Zn) Specimen and Galvanize Iron (G.I) Specimen

Number of Specimen	**Ultimate Tensile Strength (MPa)**	
	Alu-Zn	**G.I**
1	777.82	349.96
2	712.09	367.77
3	672.15	332.68
4	744.68	348.29
5	718.69	338.60

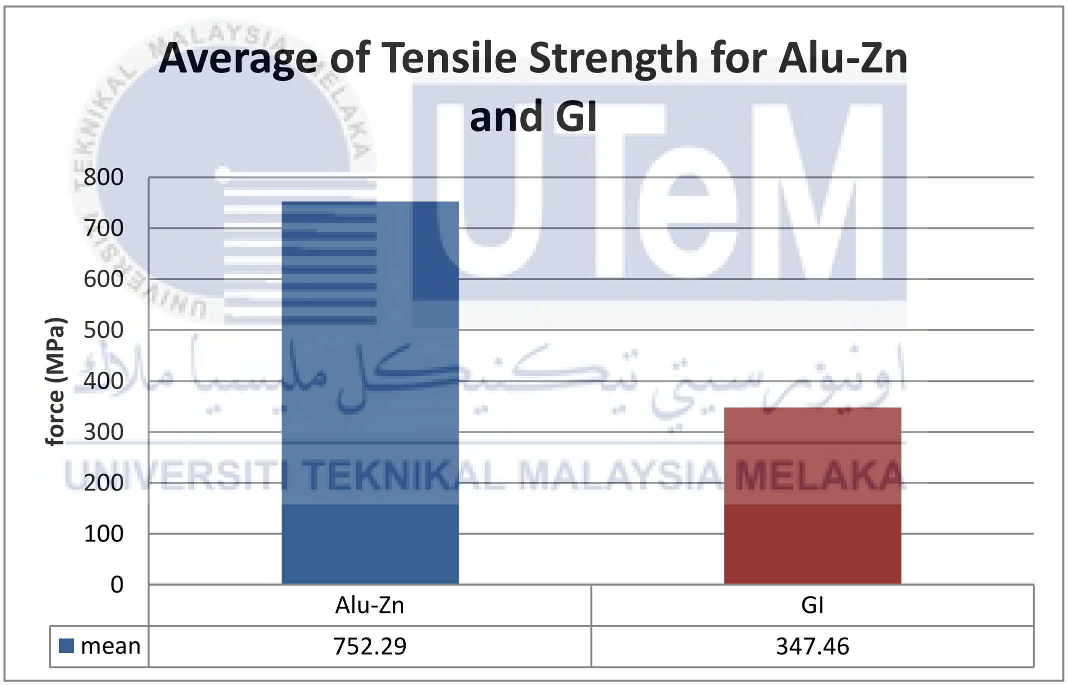

Figure 4.4: Mean for Tensile Strength of Alu-Zn and GI Roofing Specimen

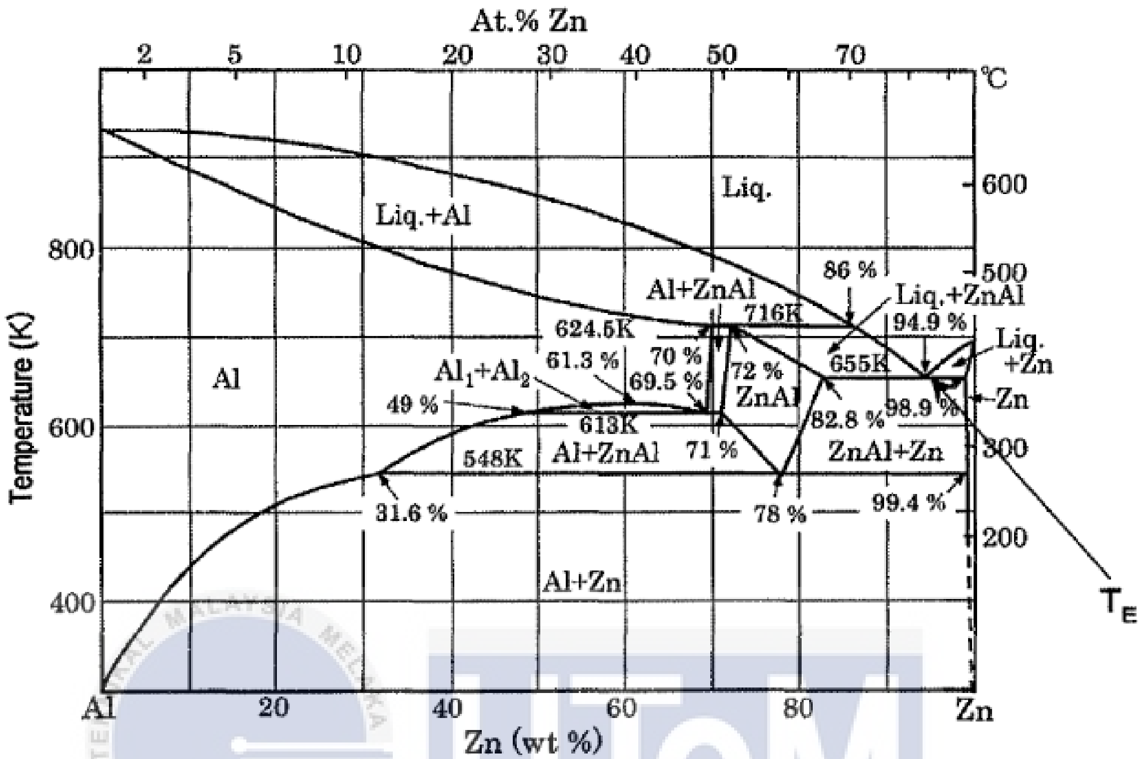

Figure 4.5: Eutectic Diagram

(Source: <https://www.google.com/patents/US8058584>28/112016)

Figure 4.6: Alu-Zn specimens after Tensile Test

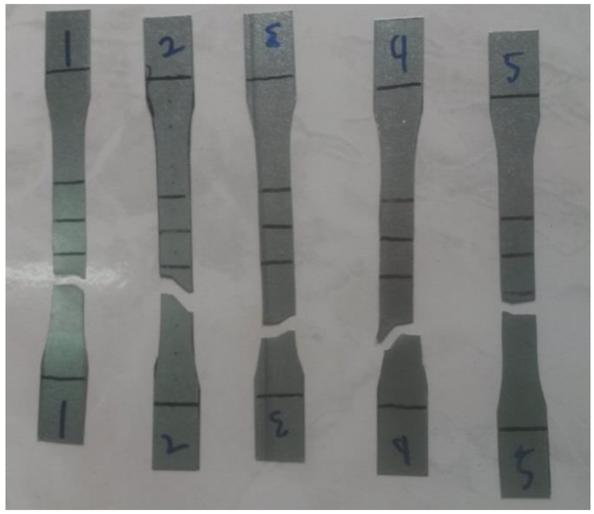

Figure 4.7: GI specimens after Tensile Test

4.2 Fatigue Testing

Fatigue tests were performed on Aluminum-Zinc and Galvanize iron are as crack initiation. The crack initiation test, specimen is subjected to a number of stress cycles with the constant force is applied for fatigue cracks to initiate and to subsequently grow large enough to produce failure.

4.2.1 Fatigue Testing of Aluminum-Zinc (Alu-Zn) and Galvanize Iron (GI)

The figures 4.8(a) and (b) show the two types of specimen that Alu-Zn and GI respectively before fatigue testing. Studies on the specimen Alu-Zn and GI using Shidmazu fatigue machine to determine the stress cycle count of the roof of metal before it rapture. Durability both specimens are able to prove that usability is very affordable.

Fatigue testing specimens were performed according to ASTM E467. Figure 4.9 is show the specimen is prepared using scissors steel into dog bone shape following specification ASTM E467.

Figure 4.8(a): Specimen of Alu-Zn

Figure 4.8(b): Specimen of GI

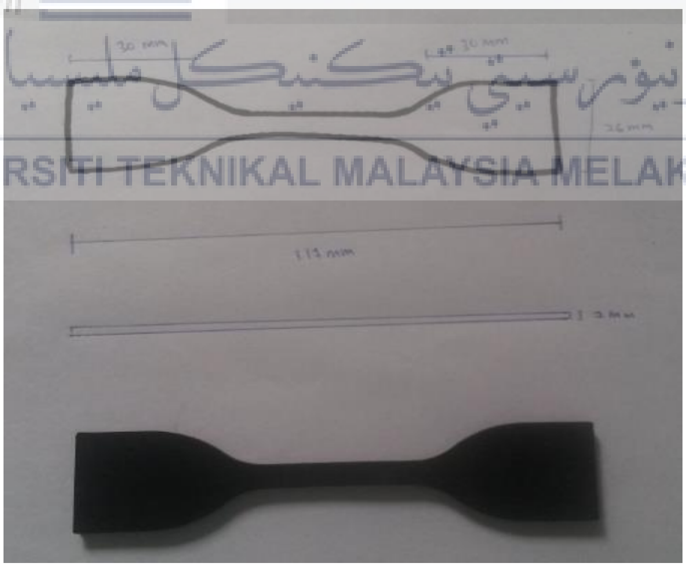

Figure 4.9: Dog Bone Specimen Dimension

There are 5 specimens from Alu-Zn samples and GI samples prepared to perform the fatigue testing. Selection of 5 samples is because to demonstrate more clearly about sustainability of both specimens. The result shown in table 4.2 and table 4.3 indicates the value of stress (MPa) before fracture and cycle count for 5 samples from Alu-Zn and GI. Figure 4.10 and figure 4.11 show the S-N graph probability of failure curve for both types of specimen.

Table 4.2: Fatigue Testing for Aluminum Zinc (Alu-Zn) Roofing Specimens

Cycle to Failure	Mean Stress (MPa)				
	Specimen 1	Specimen 2	Specimen 3	Specimen 4	Specimen 5
1	32.621	35.649	35.316	32.291	32.179
2	5.948	6.586	6.577	6.368	6.181
3	7.439	8.030	7.898	7.591	8.124
4	10.592	11.308	10.564	10.397	11.543
5	13.551	14.784	13.963	13.615	15.022

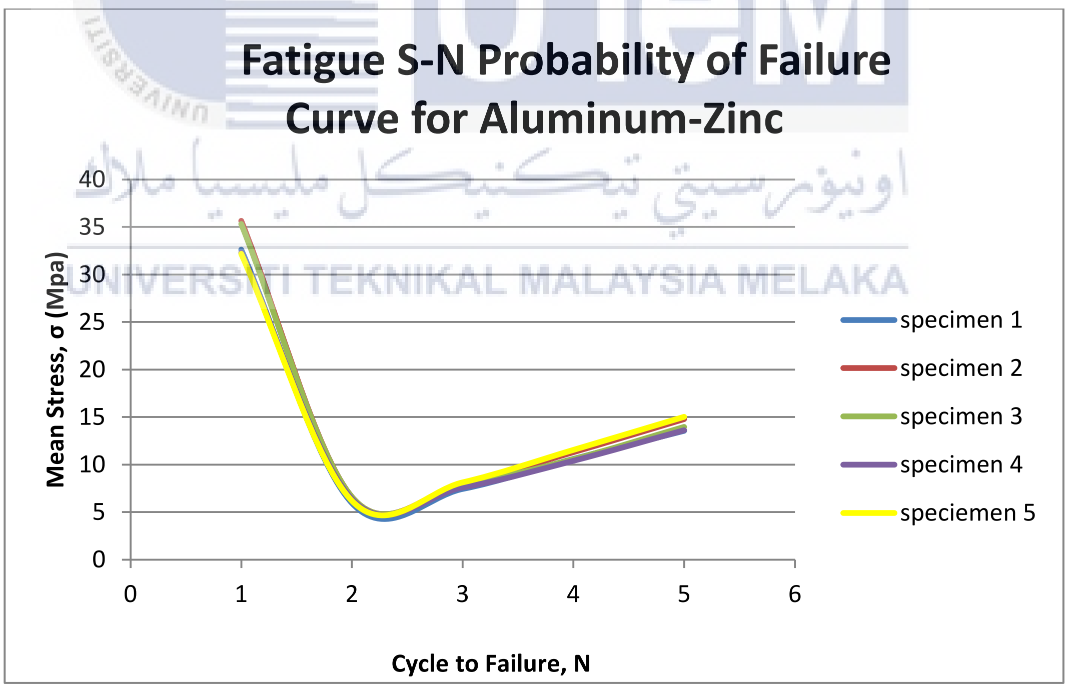

Figure 4.10: Fatigue S-N Probability of Failure Curve for Aluminum-Zinc

Table 4.3: Fatigue Testing for Galvanize Iron (GI) Roofing Specimens

Cycle to Failure	Mean Stress (MPa)				
	Specimen 1	Specimen 2	Specimen 3	Specimen 4	Specimen 5
1	11.669	16.627	13.986	15.496	20.175
2	2.290	2.239	2.546	2.690	2.674
3	4.637	3.233	4.077	4.151	3.124
4	6.398	4.525	5.713	5.927	4.388
5	8.118	5.924	7.334	7.573	5.848

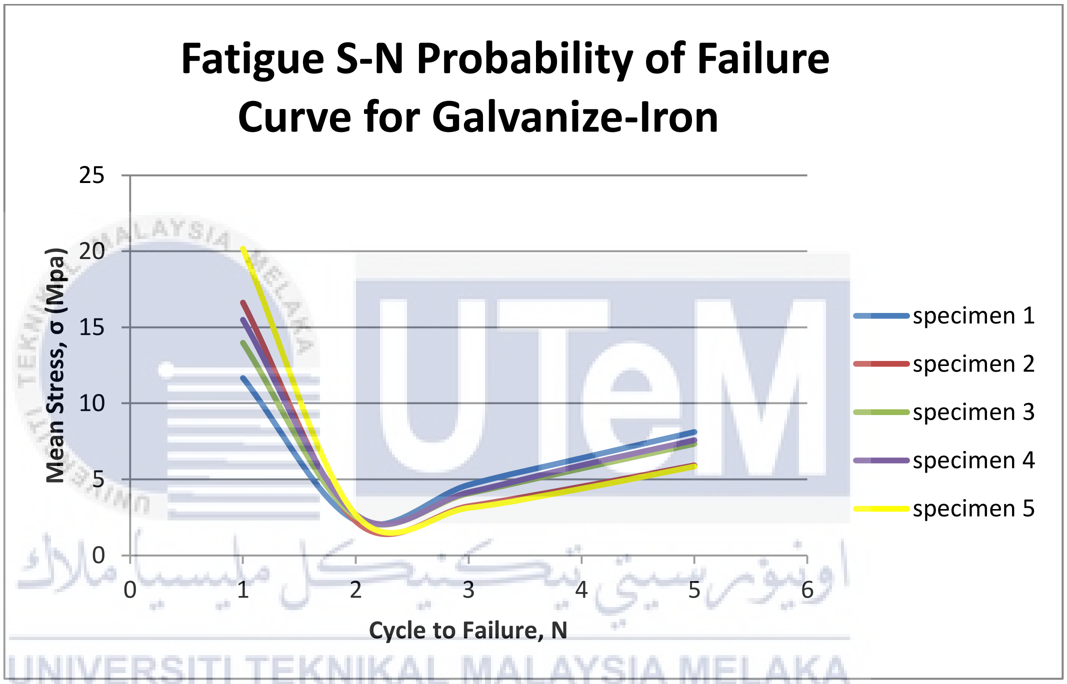

Figure 4.11: Fatigue S-N Probability of Failure Curve for Galvanize-Iron

Figure 4.12 show the comparison of mean stress, (MPa) between Alu-Zn and GI specimen failure. The force that applied to Alu-Zn is about 1.603 kN and GI is 0.734 kN. This force considered from tensile testing before the specimen rapture. For the fatigue frequency, it is consistent at 1.5Hz for this study. It clearly show from S-N curve in figure 4.12, mean stress for cycle 1, Alu-Zn specimen have higher mean stress by 33.611 MPa compare to GI specimen that have only 15.591 MPa. The different mean stress show by 53.61%. The S-N curve in figure 4.12 has shown that at cycle 5, the Alu-Zn specimen needs 14.187 MPa for change from elastic to plastic deformation phase. While for GI specimen is 6.959 MPa for change from elastic to plastic deformation phase. The difference of phase change is 50.98% higher is Alu-Zn specimen compare to GI specimen.

From S-N curve in figure 4.12, cycle limit for Alu-Zn specimen and GI specimen is at 5 cycles to failure. If forced is further applied, specimen will be raptured. Mean stress applied to Alu-Zn specimen is higher compare to GI specimen. This condition due to bonding that exists in Alu-Zn specimen. It consists of covalent bond and metallic bond. Whereas, GI specimen was consist of covalent bond. There are three types of bonding in Primary Bonding. They are metallic bond, ionic bond and covalent bond. Metallic bonding occur when many metal atoms pool their valence electrons in a delocalized electron sea that hold the atoms together. The mobile "Electron Sea" is acting as "glue" bonding the nucleus (positive charge) from repelling each other. For the covalent bond, it forms when elements, usually non-metals, share electrons. Each covalent bond is electron pair mutually attracted by two atomic nuclei. (Aludin Mohd Serah et al, 2015).

This phenomena explain why the Alu-Zn specimen have higher mean stress compare to GI specimen because it consist of two primary bonding; metallic and covalent bonding.

Table 4.4: Comparison of Mean for Fatigue Testing of Alu-Zn and GI for Roofing Specimen

Cycle to Failure	**Mean for each Specimens Stress (MPa)**	
	Alu-Zn Specimen	**GI Specimen**
1	33.611	15.591
2	6.332	2.488
3	7.816	3.844
4	10.881	5.390
5	14.187	6.959

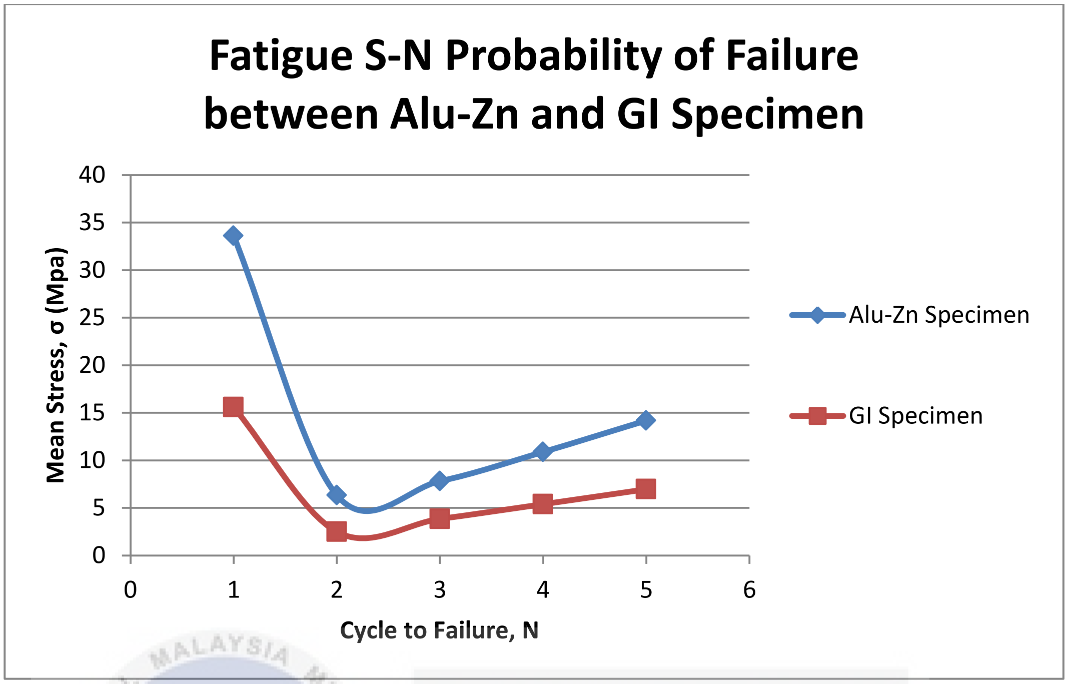

Figure 4.12: Fatigue S-N Probability of Failure between Alu-Zn and GI Specimen

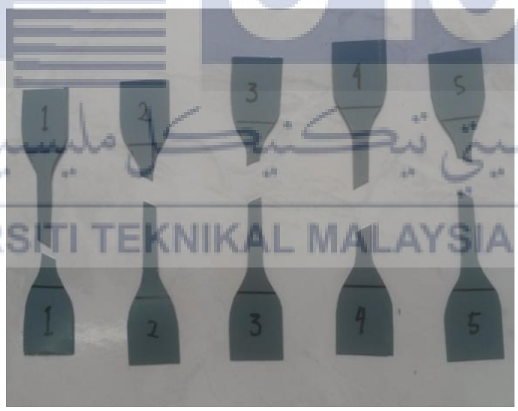

Figure 4.13: Alu-Zn specimens after Tensile Test

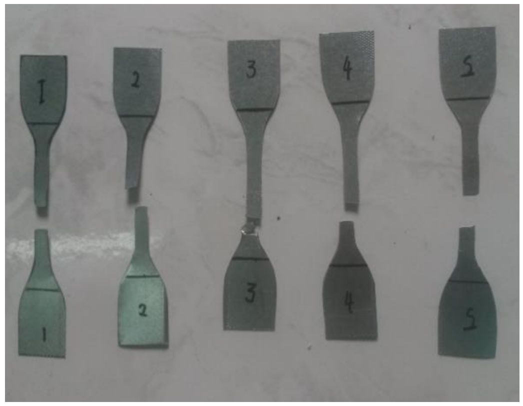

Figure 4.14: GI specimen after Fatigue Testing

CHAPTER 5

CONCLUSION AND FUTURE WORK

5.0 Introduction

In this chapter, the result obtained from the mechanical testing to compare the material properties between Aluminum-Zinc, Alu-Zn and Galvanize Iron, GI. The testing involved are tensile testing and fatigue testing to evaluate the suitable material with excellent mechanical properties for roofing panel.

5.1 Conclusion

Tensile testing have been conducted to Alu-Zn specimen and GI specimen using tensile testing machine (manufactured by: INSTRON, series number: 596943632) with load 10kN. The result has been shown that mean value of tensile strength for Alu-Zn specimen is 752.29 MPa and GI specimen is 347.46 MPa. The difference of mean value for tensile strength is 53.81% higher of Alu-Zn specimen compared to GI specimen. This result proves that Alu-Zn specimen more toughness, ductility and yield strength compared to GI specimen. For microstructure of Alu-Zn specimen at temperature 600 °C with 43.5% Zn, phase present is Austenite. When specimen is quench at room temperature, phase transformation from Austenite to Martensite. At this phase, Al has rich Face Centered Cubic (FCC) structure. On the other hand, for GI specimen, phase present at temperature 465 °C with 99.95% Zn is Austenite. When specimen is quench to room temperature, phase transformation from Austenite to become Bainite with Hexagonal Close-Packed (HCP) structure. This factor influenced the physical properties of Alu-Zn and GI.

Fatigue testing has been conducted by using fatigue test machine (manufactured by: SHIMADZU, series number: I 141005200345). The force that applied to Alu-Zn is about 1.603 kN and GI is 0.734 kN. This force is taken from tensile testing before the specimen rapture. For the fatigue frequency, it constant at of 1.5Hz. It clearly show from S-N curve in figure 4.10, mean stress for cycle 1, Alu-Zn specimen have higher mean stress by 33.611 MPa compare to GI specimen that have only 15.591 MPa. The different mean stress show by 53.61%. This condition due to bonding that exists in Alu-Zn specimen. It consists of covalent bond and metallic bond. Whereas, GI specimen was consist of covalent bond only. This phenomena explain why the Alu-Zn specimen have higher mean stress compare to GI specimen because it consist of two primary bonding; metallic and covalent bonding.

5.2 Future Work

There is probability for significant errors to trust the data from this mechanical testing. The first recommendation should do a metallography testing to analysis microstructure of Alu-Zn specimen and GI specimen. Another testing that study more detail about mechanical properties of Alu-Zn specimen and GI specimen is 3 point test to analysis bending force. On top of that, study of corrosion properties also can be considered.

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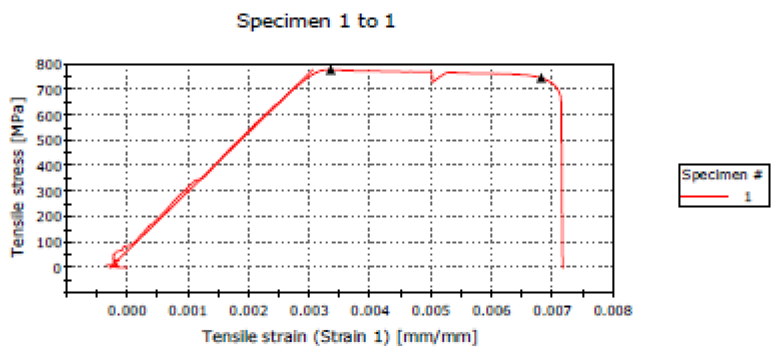
APPENDICES

APPENDIX A

List of Tensile Testing Result for Alu-Zn

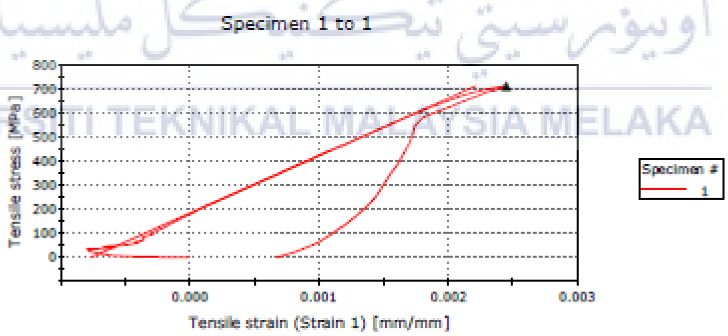
Specimen 1



	Specimen name	Thickness [mm]	Max Load [N]	ultimate tensile stress [MPa]	Data point at Yield (Zero slope)	Modulus (Automatic Young's) [MPa]
1	Tensile Aluzinc	0.30	3033.49	777.82	259	242240.499
Mean		0.30	3033.49	777.82	259	242240.499
StdDev		-----	-----	-----	-----	-----
Max		0.30	3033.49	777.82	259	242240.499
Min		0.30	3033.49	777.82	259	242240.499

	Modulus (Automatic) [MPa]
1	250317.484
Mean	250317.484
StdDev	-----
Max	250317.484
Min	250317.484

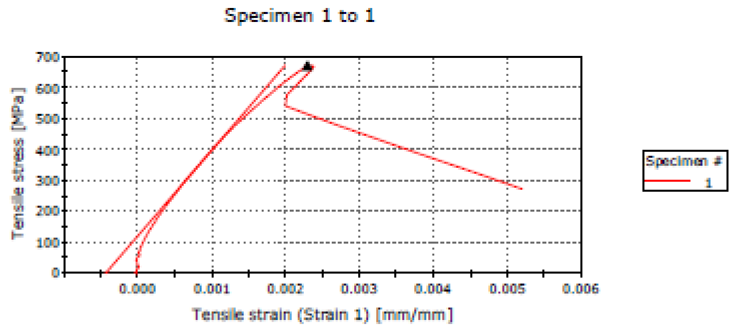
Specimen 2



	Specimen name	Thickness [mm]	Max Load [N]	ultimate tensile stress [MPa]	Data point at Yield (Zero slope)	Modulus (Automatic Young's) [MPa]
1	tensile aluzinc 2	0.30	2777.15	712.09	38	258168.130
Mean		0.30	2777.15	712.09	38	258168.130
StdDev		-----	-----	-----	-----	-----
Max		0.30	2777.15	712.09	38	258168.130
Min		0.30	2777.15	712.09	38	258168.130

	Modulus (Automatic) [MPa]
1	255734.440
Mean	255734.440
StdDev	-----
Max	255734.440
Min	255734.440

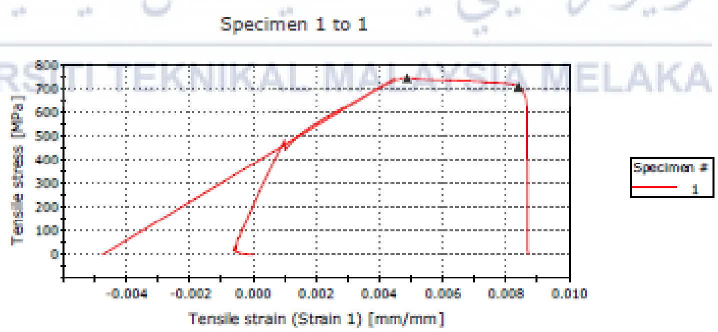
Specimen 3



	Specimen name	Thickness [mm]	Max Load [N]	ultimate tensile stress [MPa]	Data point at Yield (Zero slope)	Modulus (Automatic Young's) [MPa]
1	Tensile Aluzinc 3	0.30	2621.40	672.15	243	675655.769
Mean		0.30	2621.40	672.15	243	675655.769
StdDev		-----	-----	-----	-----	-----
Max		0.30	2621.40	672.15	243	675655.769
Min		0.30	2621.40	672.15	243	675655.769

	Modulus (Automatic) [MPa]
1	459465.640
Mean	459465.640
StdDev	-----
Max	459465.640
Min	459465.640

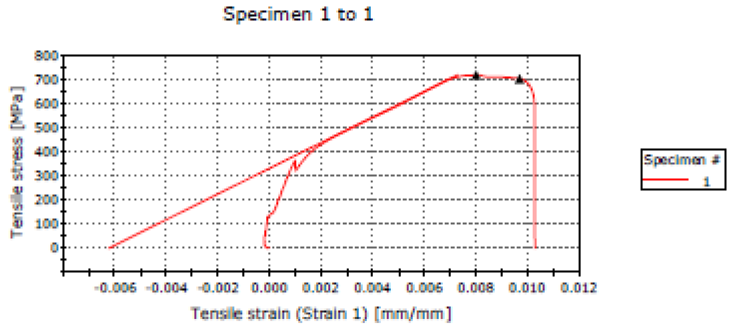
Specimen 4



	Specimen name	Thickness [mm]	Max Load [N]	ultimate tensile stress [MPa]	Data point at Yield (Zero slope)	Modulus (Automatic Young's) [MPa]
1	Tensile Aluzinc 4	0.30	2904.26	744.68	360	324138.823
Mean		0.30	2904.26	744.68	360	324138.823
StdDev		-----	-----	-----	-----	-----
Max		0.30	2904.26	744.68	360	324138.823
Min		0.30	2904.26	744.68	360	324138.823

	Modulus (Automatic) [MPa]
1	304697.214
Mean	304697.214
StdDev	-----
Max	304697.214
Min	304697.214

Specimen 5



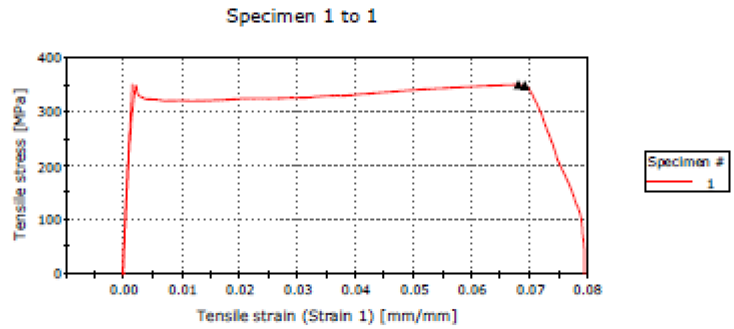
	Specimen name	Thickness [mm]	Max Load [N]	ultimate tensile stress [MPa]	Data point at Yield (Zero slope)	Modulus (Automatic Young's) [MPa]
1	Tensile Aluzinc 5	0.30	2802.89	718.69	371	638532.584
Mean		0.30	2802.89	718.69	371	638532.584
StdDev		-----	-----	-----	-----	-----
Max		0.30	2802.89	718.69	371	638532.584
Min		0.30	2802.89	718.69	371	638532.584

	Modulus (Automatic) [MPa]
1	250599.141
Mean	250599.141
StdDev	-----
Max	250599.141
Min	250599.141

APPENDIX B

List of Tensile Testing Result for GI

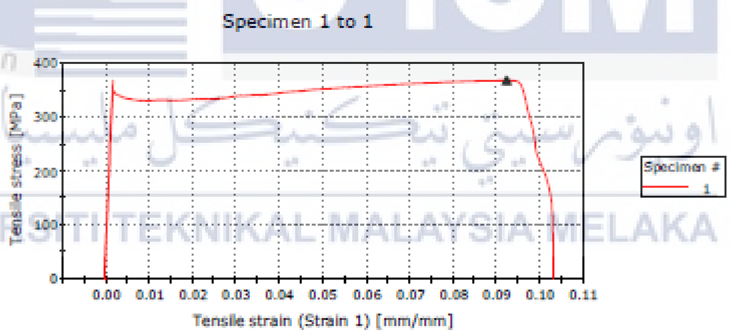
Specimen 1



	Specimen name	Thickness [mm]	Max Load [N]	ultimate tensile stress [MPa]	Data point at Yield (Zero slope)	Modulus (Automatic Young's) [MPa]
1	Tensile GI 1	0.30	1364.85	349.96	144	275493.184
Mean		0.30	1364.85	349.96	144	275493.184
StdDev		-----	-----	-----	-----	-----
Max		0.30	1364.85	349.96	144	275493.184
Min		0.30	1364.85	349.96	144	275493.184

	Modulus (Automatic) [MPa]
1	264370.271
Mean	264370.271
StdDev	-----
Max	264370.271
Min	264370.271

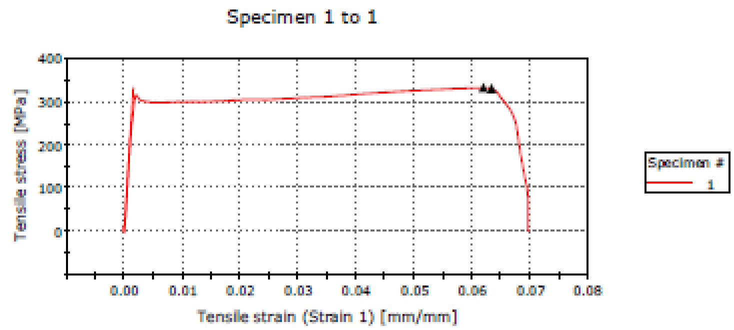
Specimen 2



	Specimen name	Thickness [mm]	Max Load [N]	ultimate tensile stress [MPa]	Data point at Yield (Zero slope)	Modulus (Automatic Young's) [MPa]
1	Tensile GI 2	0.30	1434.28	367.77	126	204072.733
Mean		0.30	1434.28	367.77	126	204072.733
StdDev		-----	-----	-----	-----	-----
Max		0.30	1434.28	367.77	126	204072.733
Min		0.30	1434.28	367.77	126	204072.733

	Modulus (Automatic) [MPa]
1	208176.223
Mean	208176.223
StdDev	-----
Max	208176.223
Min	208176.223

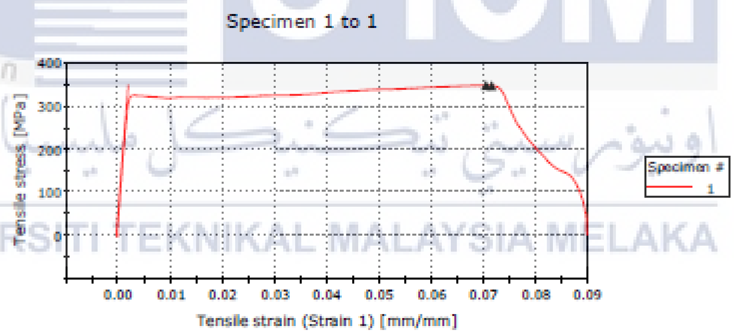
Specimen 3



	Specimen name	Thickness [mm]	Max Load [N]	ultimate tensile stress [MPa]	Data point at Yield (Zero slope)	Modulus (Automatic Young's) [MPa]
1	Tensile GI 3	0.30	1297.43	332.68	119	224876.117
Mean		0.30	1297.43	332.68	119	224876.117
StdDev		-----	-----	-----	-----	-----
Max		0.30	1297.43	332.68	119	224876.117
Min		0.30	1297.43	332.68	119	224876.117

	Modulus (Automatic) [MPa]
1	232449.032
Mean	232449.032
StdDev	-----
Max	232449.032
Min	232449.032

Specimen 4

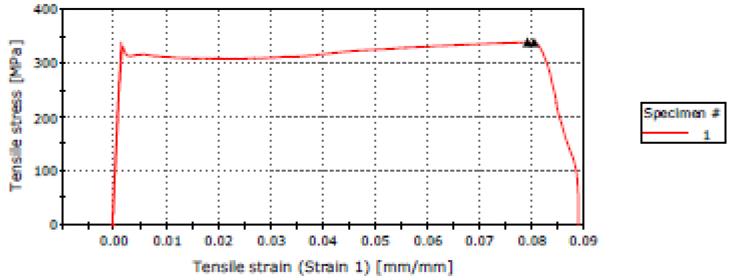


	Specimen name	Thickness [mm]	Max Load [N]	ultimate tensile stress [MPa]	Data point at Yield (Zero slope)	Modulus (Automatic Young's) [MPa]
1	Tensile GI 4	0.30	1358.33	348.29	158	185236.411
Mean		0.30	1358.33	348.29	158	185236.411
StdDev		-----	-----	-----	-----	-----
Max		0.30	1358.33	348.29	158	185236.411
Min		0.30	1358.33	348.29	158	185236.411

	Modulus (Automatic) [MPa]
1	154669.261
Mean	154669.261
StdDev	-----
Max	154669.261
Min	154669.261

Specimen 5

Specimen 1 to 1



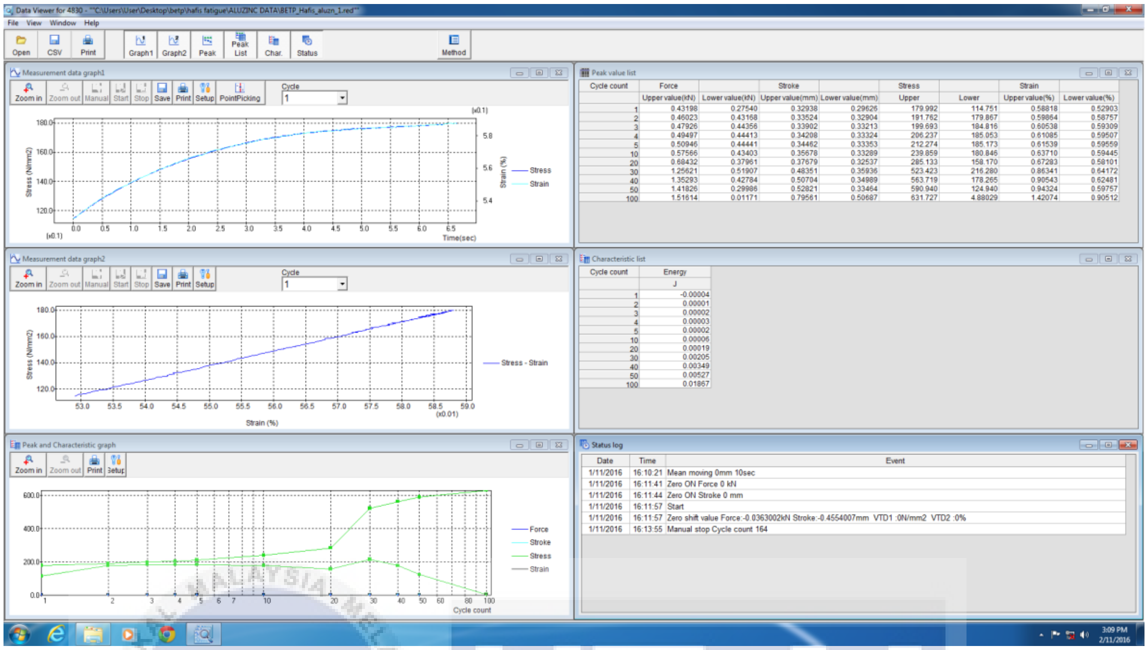
	Specimen name	Thickness [mm]	Max Load [N]	ultimate tensile stress [MPa]	Data point at Yield (Zero slope)	Modulus (Automatic Young's) [MPa]
1	Tensile GI 5	0.30	1320.55	338.60	123	215962.461
Mean		0.30	1320.55	338.60	123	215962.461
StdDev		-----	-----	-----	-----	-----
Max		0.30	1320.55	338.60	123	215962.461
Min		0.30	1320.55	338.60	123	215962.461

	Modulus (Automatic) [MPa]
1	224663.823
Mean	224663.823
StdDev	-----
Max	224663.823
Min	224663.823

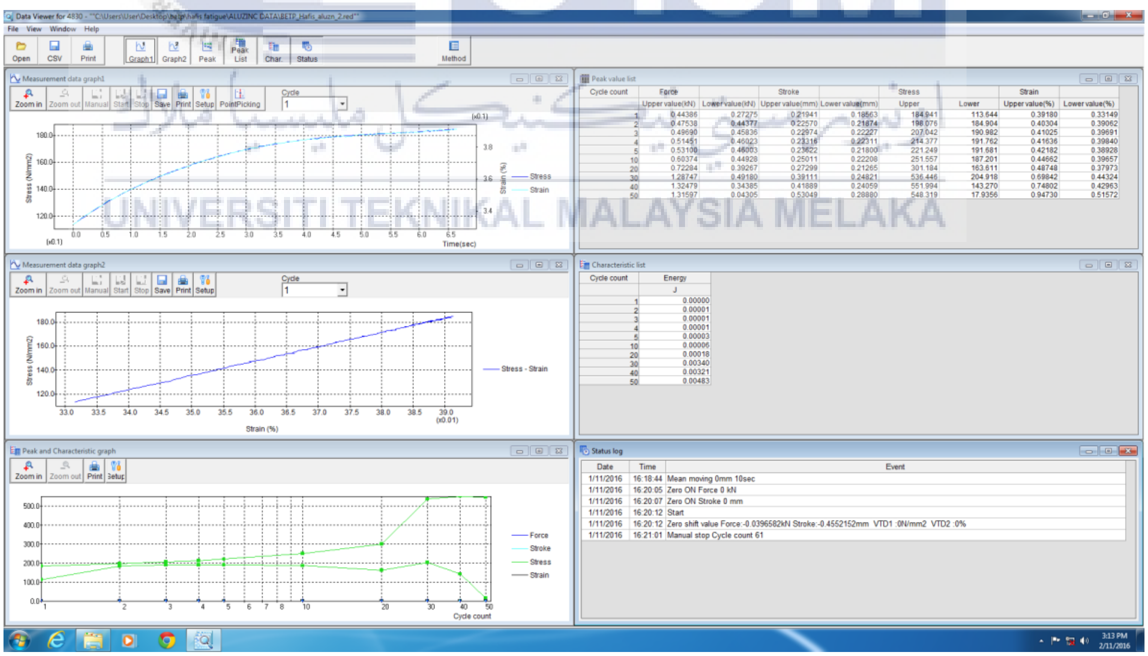
APPENDIX C

List of Fatigue Testing Result for Alu-Zn

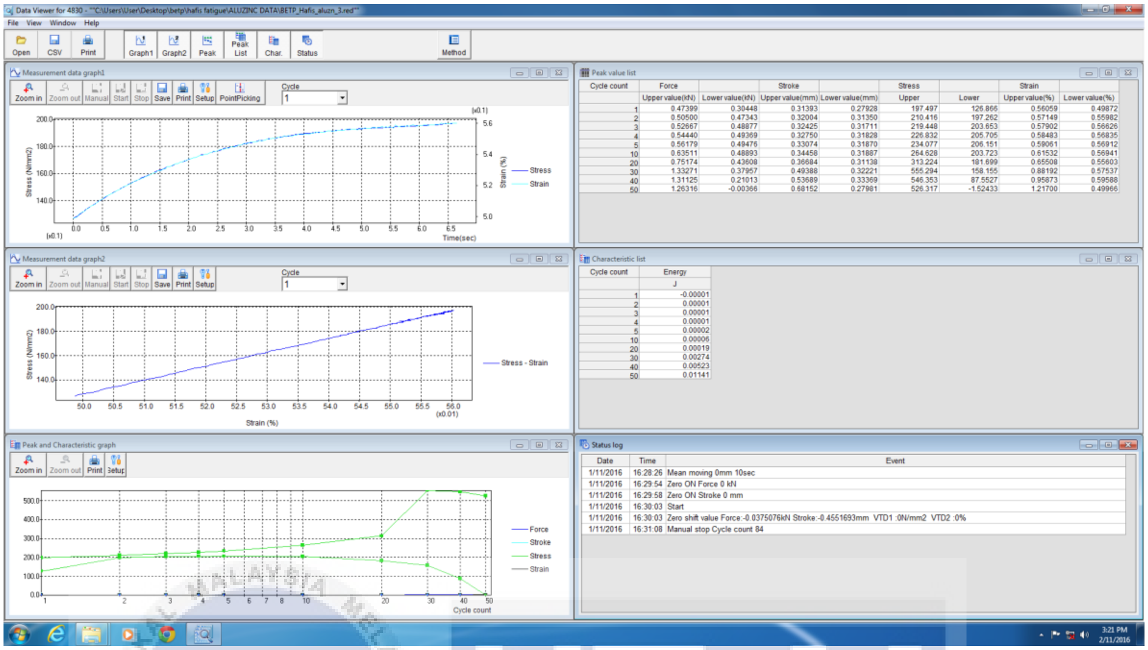
Specimen 1



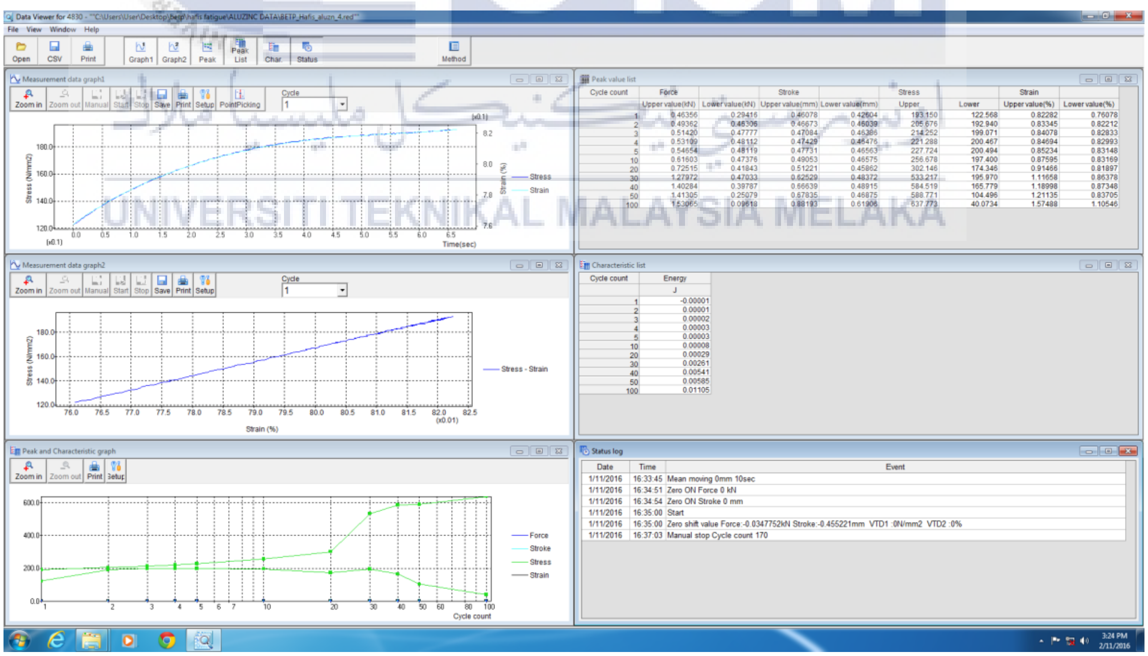
Specimen 2



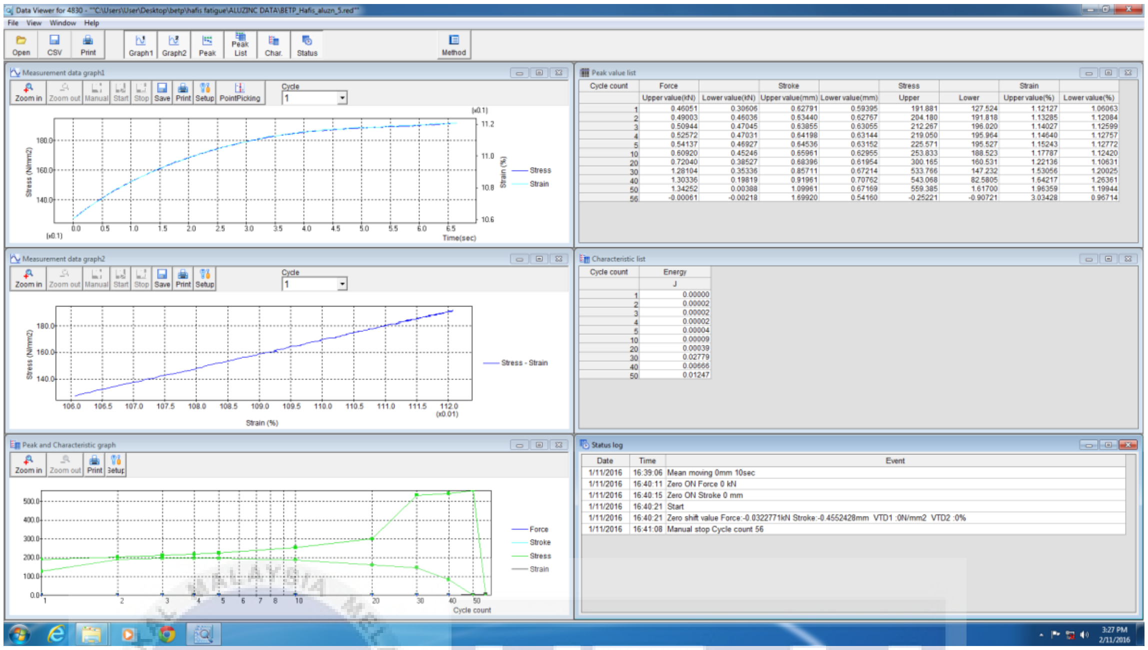
Specimen 3



Specimen 4



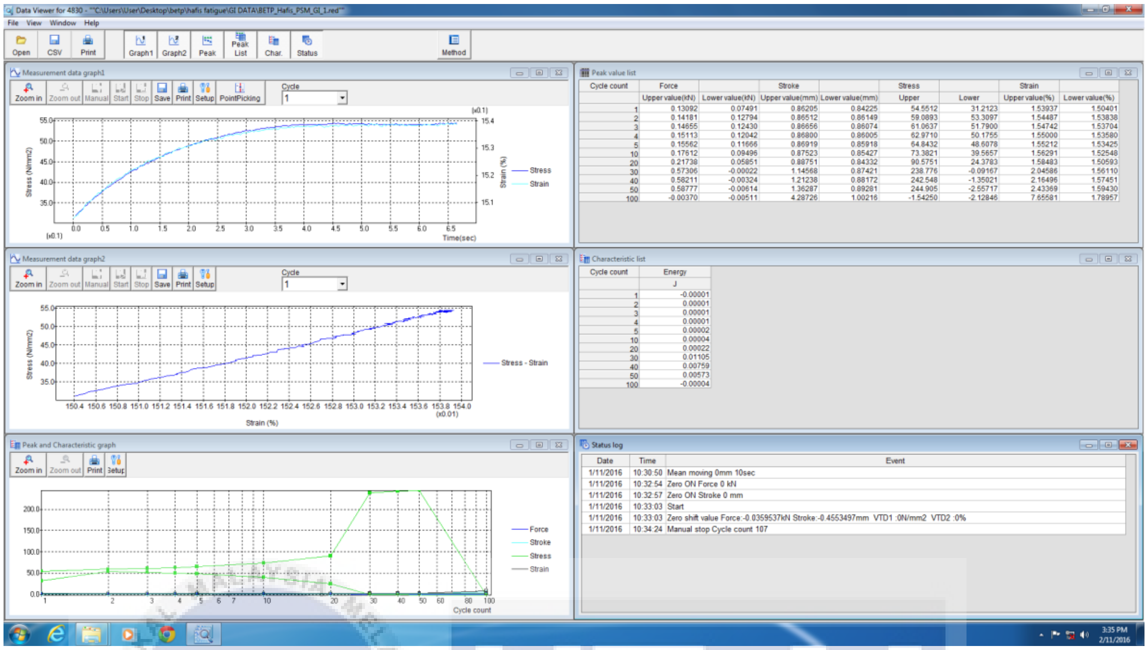
Specimen 5


Measurement data graph1
Stress
Strain
Time(sec)
Measurement data graph2
Stress - Strain
Strain (%)
Peak and Characteristic graph
Force
Stroke
Stress
Strain
Cycle count
Peak value list
Cycle count | Force | | Stroke | | Stress | | Strain |
| Upper value(kN) | Lower value(kN) | Upper value(mm) | Lower value(mm) | Upper | Lower | Upper value(%) | Lower value(%)
1 | 0.46051 | 0.30606 | 0.62791 | 0.59395 | 191.881 | 127.524 | 1.12127 | 1.06063
2 | 0.49003 | 0.46036 | 0.63440 | 0.62767 | 204.180 | 191.818 | 1.13285 | 1.12084
3 | 0.50944 | 0.47045 | 0.63855 | 0.63055 | 212.267 | 196.020 | 1.14027 | 1.12599
4 | 0.52572 | 0.47031 | 0.64198 | 0.63144 | 219.050 | 195.964 | 1.14640 | 1.12757
5 | 0.54137 | 0.46927 | 0.64536 | 0.63152 | 225.571 | 195.527 | 1.15243 | 1.12772
10 | 0.60920 | 0.45246 | 0.65961 | 0.62955 | 253.833 | 188.523 | 1.17787 | 1.12420
20 | 0.72040 | 0.38527 | 0.68396 | 0.61954 | 300.165 | 160.531 | 1.22136 | 1.10631
30 | 1.28104 | 0.35336 | 0.85711 | 0.67214 | 533.766 | 147.232 | 1.53056 | 1.20025
40 | 1.30336 | 0.19819 | 0.91961 | 0.70762 | 543.068 | 82.5805 | 1.64217 | 1.26361
50 | 1.34252 | 0.00388 | 1.09961 | 0.67169 | 559.385 | 1.61700 | 1.96359 | 1.19944
56 | -0.00061 | -0.00218 | 1.69920 | 0.54160 | -0.25221 | -0.90721 | 3.03428 | 0.96714
Characteristic list
Cycle count | Energy
| J
1 | 0.00000
2 | 0.00002
3 | 0.00002
4 | 0.00002
5 | 0.00004
10 | 0.00009
20 | 0.00039
30 | 0.02779
40 | 0.00666
50 | 0.01247
Status log
Date | Time | Event
1/11/2016 | 16:39:06 | Mean moving 0mm 10sec
1/11/2016 | 16:40:11 | Zero ON Force 0 kN
1/11/2016 | 16:40:15 | Zero ON Stroke 0 mm
1/11/2016 | 16:40:21 | Start
1/11/2016 | 16:40:21 | Zero shift value Force:-0.0322771kN Stroke:-0.4552428mm VTD1 :0N/mm2 VTD2 :0%
1/11/2016 | 16:41:08 | Manual stop Cycle count 56

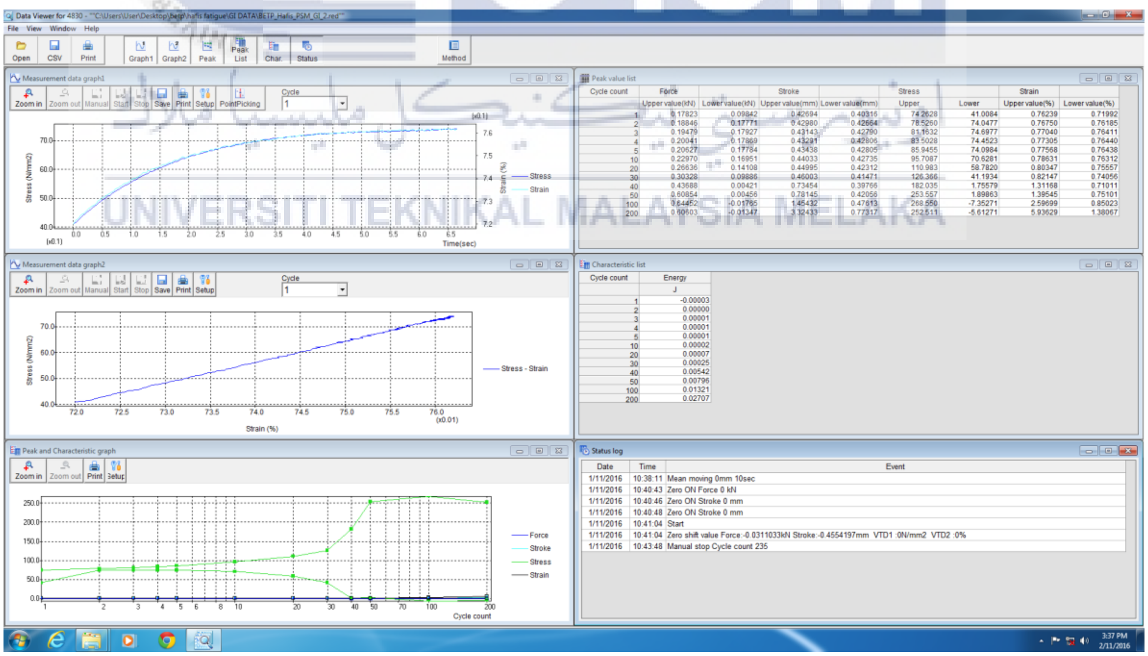
APPENDIX D

List of Fatigue Testing Result for GI

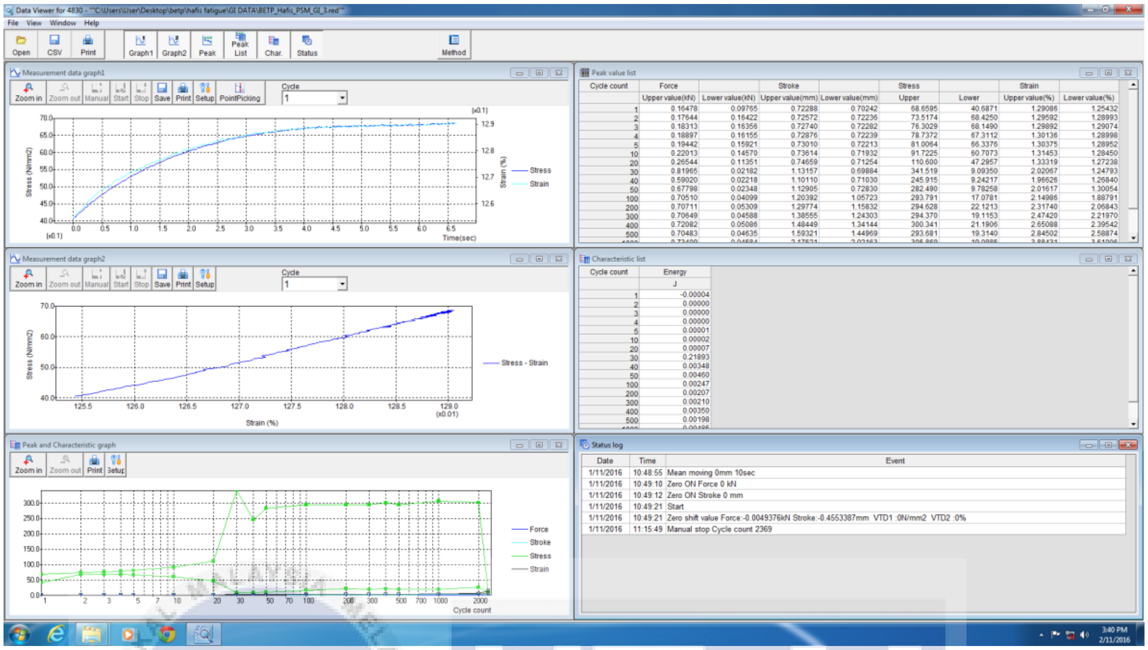
Specimen 1



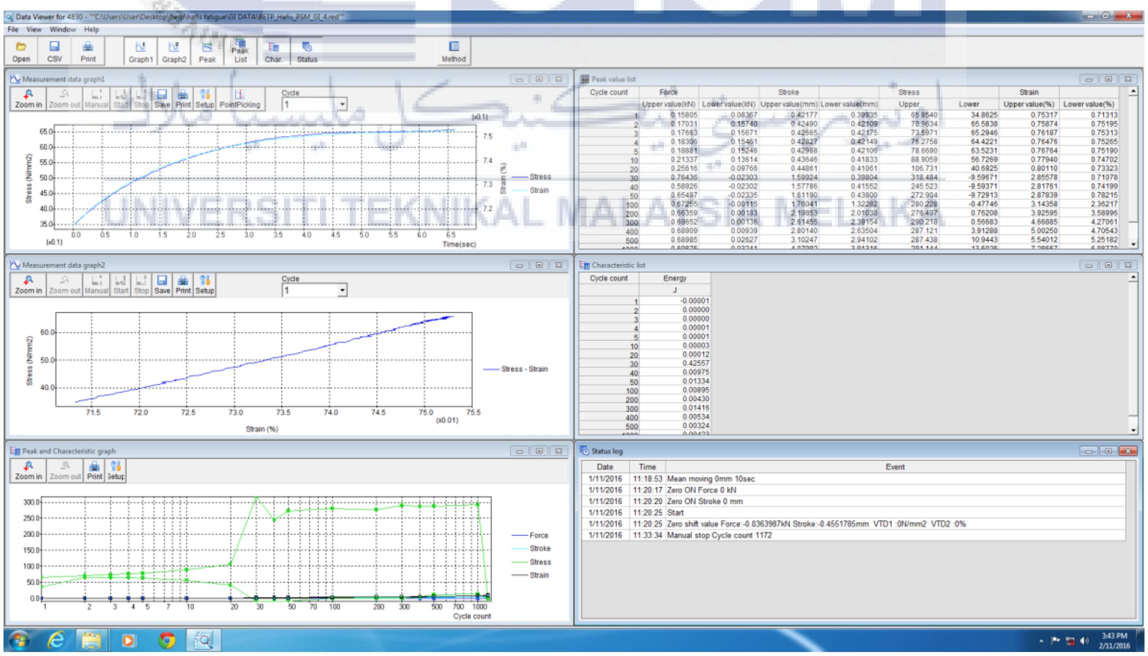
Specimen 2



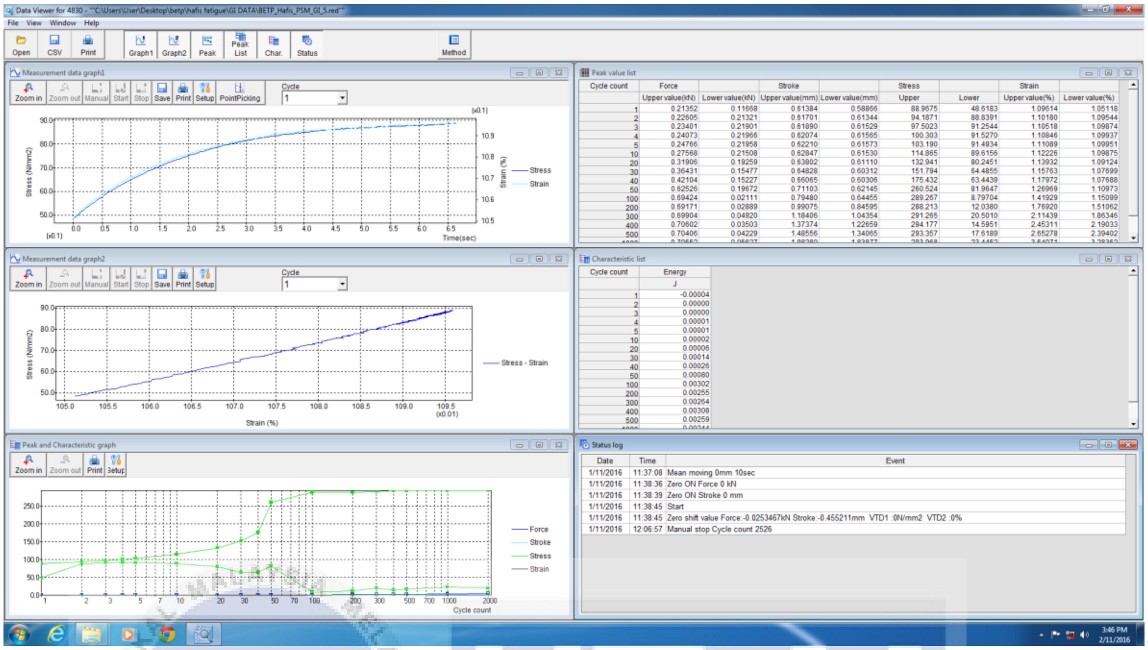
Specimen 3



Specimen 4



Specimen 5



Measurement data graph1
Stress
Strain
Time(sec)
Peak value list
Cycle count
Force
Stroke
Stress
Strain
Measurement data graph2
Stress - Strain
Strain (%)
Characteristic list
Energy
Peak and Characteristic graph
Force
Stroke
Stress
Strain
Cycle count
Status log
Date
Time
Event