A STUDY OF ACOUSTIC EMISSION EVENT IN TENSILE TEST FOR METALLIC MATERIALS

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UNIVERSITI MALAYSIA PAHANG

2010

UNIVERSITI MALAYSIA PAHANG

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JUDUL: **A STUDY OF ACOUSTIC EMISSION EVENT IN TENSILE TEST FOR METALLIC MATERIALS**

SESI PENGAJIAN: 2010/2011

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A STUDY OF ACOUSTIC EMISSION EVENT IN TENSILE TEST FOR METALLIC MATERIALS

MOHD ZAMBRI BIN ABIDIN

Report submitted in fulfilment of the requirements
for the award of the degree of
Bachelor of Mechanical Engineering

Faculty of Mechanical Engineering
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DECEMBER 2010

UNIVERSITI MALAYSIA PAHANG
FACULTY OF MECHANICAL ENGINEERING

I certify that the project entitled "*A Study of Acoustic Emission Event in Tensile Test for Metallic Materials"* is written by *Mohd Zambri Bin Abibin*. I have examined the final copy of this project and in our opinion; it is fully adequate in terms of scope and quality for the award of the degree of Bachelor of Engineering. I herewith recommend that it be accepted in partial fulfillment of the requirements for the degree of Bachelor of Mechanical Engineering.

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STUDENT'S DECLARATION

I declare that this report titled "*A Study of Acoustic Emission Event in Tensile Test for Metallic Materials*" is my result of my own research except as stated in the references. This thesis/report has not been accepted for any degree and is not concurrently submitted for award of other degree.

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Dedicated, truthfully for supports,
encouragements and always be there during hard times, to
my beloved family.

ACKNOWLEDGEMENTS

First and foremost, I wish to express my sincere appreciation to my project supervisor, Mr. Che Ku Eddy Nizwan Bin Che Ku Husin, for constantly guiding and encouraging me throughout this study. Thanks a lot for giving me a professional training, advice and suggestion to bring this thesis to its final form. Without his support and interest, this thesis would not have been the same as presented here. I am very grateful to him for his patience and his constructive comments that enriched this research project.

I would also like to acknowledge with much appreciation the crucial role of the staff in Mechanical Laboratory, for their valuable comments, sharing their time and knowledge on this research project during the project was carried out and giving a permission to use all the necessary tools in the laboratory. They have contributed towards my understanding and thoughts.

In particular, my sincere thankful is also extends to all my colleagues and others who have provided assistance at various occasions. Their views and tips are useful indeed. I cannot find the appropriate words that could properly describe my appreciation for their devotion, support and faith in my ability to attain my goals. I would like to acknowledge their comments and suggestions, which was crucial for the successful completion of this study. And last, but not least thanks to my family for their continuous support and confidence in my efforts.

ABSTRACT

This project is described about the research and experimental study of Acoustic Emission (AE) properties for metallic material during tensile test. This project involves small analysis of the metallic materials which consists of aluminum, copper, zinc, mild steel and galvanized iron. Acoustic emission is defined as the transient elastic energy that is spontaneously released when materials undergo deformation, fracture, or both. It forms the basis of one of the few Nondestructive Testing (NDT) methods that provides means of evaluating structural integrity by the detection of active flaws that may ultimately cause failure of the material or structure. Tensile test is a common and important test that provides a variety of information about the material being tested, including the elongation, yield point, tensile strength, and ultimate strength of the material. Detection of (AE) represents actual detection of fracture events as they occurred when material undergo to crack. The specimens used for tensile test are followed the *American Society for Testing and Material Standard (ASTM)* which is ASTM E8. The Acoustic Emission (AE) total counts obtained in different specimens for specific strain levels have been analyzed by regression analysis approach of data analysis. The results indicate that AE sources are more frequent between yield and ultimate tensile strength. This happen at the crack location where it will emits higher event of acoustic emission. All the material have a different types of properties, it was show the different stress strain curve after the experiment. From the stress-strain curve, the softer material is more plastic behavior compared than hardness materials. Galvanized iron are more strength others than material. It was prove that the galvanized iron reaches the maximum ultimate tensile strength followed by mild steel, zinc, copper and aluminum. Aluminum obtained less of acoustic emission activity. The time taken to finished the deformation of tensile testing also less than others material. However the (AE) activities for each of material are too slow because the small thickness of the specimen has affected the (AE) signal during tensile loading. It was proved that, Acoustic emission is a very versatile, non-invasive way to gather information about a material or structure.

ABSTRAK

Projek ini membentangkan mengenai penyelidikan dan kajian ujikaji untuk bahan logam semasa ujian tegangan dengan menggunakan Pemancaran Akustik (AE) sebagai satu kaedah untuk menganalisis. Projek ini melibatkan analisis terhadap bahan logam yang terdiri dari aluminium, kuprum, zink, keluli lembut dan besi bergalvani. Pancaran akustik (AE) adalah ditakrifkan sebagai tenaga kenyal fana iaitu dengan spontan dikeluarkan apabila bahan-bahan menjalani herotan, retakan, atau kedua-dua. Ia membentuk salah satu asas daripada beberapa kaedah-kaedah Pengujian Tanpa Musnah (NDT) yang menyediakan cara menilai keutuhan struktur oleh pengesanan aktif itu sehingga kecacatan yang akhirnya boleh menyebabkan kegagalan bahan atau struktur. Ujian ketegangan merupakan ujian penting yang memberi maklumat terhadap bahan yang diuji seperti pemanjangan, titik alah, kekuatan tegangan dan kekuatan tegangan muktamad. Spesimen-spesimen yang digunakan untuk ujian ketegangan adalah mengikuti *American Society for Testing and Material Standard* (ASTM) yang mana adalah ASTM E8. Jumlah pemancaran Akustik (AE) yang diperolehi dari spesimen adalah berbeza untuk setiap graf tegangan-terikan yang telah dianalisis dengan pendekatan analisis regresi data. Keputusan kajian menunjukkan bahawa sumber AE lebih kerap antara titik alah dan kekuatan tegangan muktamad. Ini terjadi dilokasi retak yang mana ia akan memancarkan aktiviti pembebasan akustik yang lebih tinggi. Dari graf tegangan-terikan, bahan yang lembut lebih menjadi plastik berbanding bahan yang keras. Besi bergalvani lagi kukuh berbanding dengan bahan lain. Ini dibuktikan apabila besi bergalvani mencapai nilai maksimum dari kekuatan tegangan muktamad, diikuti keluli lembut, zink, kuprum dan aluminium. Aluminium menghasilkan aktiviti pancaran akustik yang rendah. Masa yang diambil ketika perubahan ujian ketegangan juga rendah berbanding bahan yang lain. Bagaimanapun aktiviti-aktiviti (AE) untuk setiap bahan adalah rendah disebabkan oleh ketebalan spesimen yang kecil telah mempengaruhi isyarat (AE) sepanjang pemberian bebanan. Ia telah membuktikan bahawa, pemancaran akustik adalah cara yang amat serbaguna, bersifat invasi semasa mengumpul maklumat tentang bahan dan struktur.

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LIST OF SYMBOLS

mm	Millimeter
MPa	Megapascal
GPa	Gigapascal
%	Percent
HB	Brinell Hardness Number
kN	Kilonewton
lbf	Pound of force
σ	Stress
P	Load
A_o	Cross sectional area
A_f	Final cross sectional area
e	Strain
l	Instantaneous length
l_o	Original length
E	Modulus of elasticity
dB	Decibel
UTS	Ultimate tensile strength
Y	Yield strength
kHz	Kilohertz
V	Voltage
s	Second

LIST OF ABBREVIATIONS

3D	Three Dimension
ADC	Analog Digital Computer
AE	Acoustic Emission
AED	Acoustic Emission Detector
AISI	American Iron and Steel Institute
AST	Auto Sensor Test
ASTM	American Society for Testing and Material
BNC	Bayonet Neill Concelman
DOE	Design of Experiment
EMI	Electromagnetic Interference
FKM	Fakulti Kejuruteraan Mekanikal
FYP	Final Year Project
ISO	International Organization for Standardization
NDT	Nondestructive Testing
PC	Personal Computer
PZT	Piezoelectric Transducer
RFI	Radio Frequency Interference
RMS	Root Mean Square
UMP	Universiti Malaysia Pahang

CHAPTER 1

INTRODUCTION

1.1 PROJECT BACKGROUND

The world "acoustic" is derived from the Greek word akoustikos, which has to do with "hearing" (Miller, 1987). Acoustic emission testing (AET) becomes recognized as Nondestructive testing (NDT) method commonly used to detect and locate fault in mechanically loaded structures and component. Acoustic emission can provide comprehensive information on the origination of a discontinuity (flaw) in a stressed. Basically acoustic emission (AE) is defined as the transient elastic energy that is spontaneously released when materials undergo deformation, fracture, or both. It forms the basis of one of the few nondestructive testing (NDT) methods that provides means of evaluating structural integrity by the detection of active flaws that may ultimately cause failure of the material or structure. Detection of AE represents actual detection of fracture events as they occurred when material undergoes to crack (Sachse, et al, 1991).

This project involves research and study of Acoustic Emission event in tensile test for metallic material. This research would be entirely different from other existing experiment. As the final year project allocates the duration of two semesters, this large man-hour project therefore requires significant efforts of the students to participate. The project involves small analysis of the metallic material which consists of mild steel, aluminum, zinc, galvanized iron and copper. The measurements of the acoustic emission (AE) during tensile testing of these materials are presented and related to the microstructure of the sample material.

A tensile test is used to tests a material strength. This method operates as a mechanical test where a pulling force is applied to a material from one sides of the material until the sample changes its shape or breaks. Tensile test is a common and important test that provides a variety of information about the material being tested, including the elongation, yield point, tensile strength, and ultimate strength of the material (Davis, 2004). This method will apply with acoustic emission equipment by follow the standard experimental procedure and set up of acoustic emission parameters.

When material in a component deforms in response to any type of loading, the deformations tends to relieve and smooth out the local stresses. This means that after an acoustic emission event has taken place, the elastic energy stored in the stress field will have been reduced; some of it will have been released. The energy released from the test filed will used to create new deformation that will warm the material and produce the acoustic emission. Acoustic emission characteristics during tensile test of structural material were investigated. The results are discussed with respect to the variations of activated deformation mechanisms and especially were subjected to tensile loading during deformation.

1.2 PROBLEM STATEMENT

The variety of material has its own characteristics, types of properties and different structural component. Material may fail due to a variety of reasons. This happens when material is subjected to tensile process where it will acts as the failure point for the crack of the component. From a previous research, there are a lot of acoustic emissions applied during tensile test. However the research and method use not an extensive way. These provide less of information to analysis because the research is only based for one type of materials. Without the simulation and experimental process, it’s easier to determine and define the exact failure location of the material when using inspection method. By using this inspection method, there is no evidence input as a data of the results, to analyze it clearly. Therefore, predicting the presence of such defects, as well as identifying the crack initiation is of significant importance from the point of view of failure prevention in structural components.

Since phenomena such as crack initiation and propagation emit high frequency acoustic waves, Acoustic Emission (AE) measurement has been acknowledged as an appropriate technique to monitor such micro-scale events. This Acoustic emission technique is able to characterize various types of micro and macro flaws present in such materials. Therefore in the present study, Acoustic emission (AE) from aluminum, copper, zinc, mild steel and galvanized iron specimen subjected to tensile loading has been used to relate AE events with the various zones on the load deflection curve of the materials. The study ultimately aims at identifying the AE features of a material which act as sign to failure. The correlation between various metallic materials in this method will be apply in order to study the ductility, AE count, total energy released and to define the exact location due to the failure of each material.

1.3 PROJECT OBJECTIVES

The objectives of the project are:

a) To conduct tensile test for metallic materials and measure of Acoustic Emission (AE) signal parameters.

b) To study correlation between stress-strain curves with Acoustic Emission (AE) parameters based on tensile test for different metallic materials.

1.4 PROJECT HYPHOTHESIS

Several hypotheses were developed and tested in this study. They are:

a) All the material have a different types of properties, it will show the different stress strain curve after the experiment.

b) From the stress-strain curve, the softer material is more plastic behavior compared than hardness materials.

c) AE events are more frequent between yield and ultimate points. This happen at the crack location where it will emits higher event of acoustic emission.

d) At higher stress location, at higher event of acoustic emission will occur.

e) The higher the ductility of materials, the more energy will be released.

1.5 PROJECT SCOPE OF WORK

This project is focusing on several metallic materials were subjected to tensile loading and inspection by using Acoustic emission technique. This focus area is done based on the following aspect. The scope of this study includes:

a) Conduct tensile test by using metallic materials; aluminum, copper, zinc, mild steel and galvanized iron.
b) Perform the mechanical test which is tensile test that relate with Acoustic Emission technique.
c) Study of Acoustic Emission properties in order to count number of hit, RMS, and amount of energy released.
d) Analyze the correlation of Acoustic Emission signal parameters with stress-strain curve for each of material used.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Based on the title given, the scope of this project was preferred to choose metallic materials as a specimen to analyze, by using mechanical testing equipment. There are many different material types to choose from and when undertaking any project. In this review, material preparation should identify and each of the materials used must be determined before conduct the experiment.

According to the title given, this project totally operates on tensile test machine. The experimental procedure to conduct this project also needed to ensure tensile machining as a mechanical testing is not error during the experiment. In this studies also review the standard dimension of specimen and machine used. There are several types of tensile machine and more than one of specimen will used to get the accurate results.

The acoustic emission will applied in this study where the signal analysis can determine after the tensile test machining. It is also noted from these studies that the acoustic emission in each materials are totally different. Since phenomena such as crack initiation and propagation emit high frequency acoustic waves, Acoustic Emission (AE) measurement has been acknowledged as an appropriate technique to monitor in this project. The signal analysis of acoustic emission will determined the exact location of each material crack.

2.2 METALLIC MATERIALS

2.2.1 Introduction to Metallic Materials

Metals have been widely used for thousands of years, and traditionally metals have been classified as ferrous and nonferrous. The ferrous category refers to based metals of iron, while the nonferrous metals are free of iron. At the present time there are available for use in excess 45,000 different metallic alloys. Although the steel and cast iron make up the largest use on a weight basis, the numbers of different nonferrous alloys exceed the number of ferrous alloys (Philip & Schweitzer, 2003).

2.2.2 Physical Properties of Metallic Material

Metals in general have high electrical conductivity, thermal conductivity, luster and density, and the ability to be deformed under stress without cleaving. While there are several metals that have low density, hardness, and melting points, these (the alkali and alkaline earth metals) are extremely reactive, and are rarely encountered in their elemental, metallic form. The majority of metals have higher densities than the majority of nonmetals. Nonetheless, there is wide variation in the densities of metals; lithium is the least dense solid element and osmium is the densest (Mortimer, 1975).

2.2.3 Mechanical Properties of Metallic Material

Mechanical properties of metals include their ductility, which is largely due to their inherent capacity for plastic deformation. Thus, elasticity in metals can be described by Hooke's Law for restoring forces, where the stress is linearly proportional to the strain (Mortimer, 1975). Larger forces in excess of the elastic limit may cause a permanent (irreversible) deformation of the object.

This is what is known in the literature as plastic deformation or plasticity. This irreversible change in atomic arrangement may occur because of the some factors which are affected by the action of an applied force and a change in temperature. In the former case, the applied force may be tensile (pulling) force, compressive (pushing) force, shear, bending or torsion (twisting) forces. In the latter case, the most significant factor which is determined by the temperature is the mobility of the structural defects such as grain boundaries, point vacancies, line and screw dislocations, stacking faults and twins in both crystalline and non-crystalline solids.

2.2.4 Ferrous Metal and Alloys

By virtue of their wide range of mechanical, physical, and chemical properties, ferrous metal and alloys are among the most useful of all metals. Ferrous metals and alloys contain iron as their base metal; the general categories are carbon and alloy steels, stainless steel and cast steels (Kalpakjian and Schmid, 2006). This project only required mild steels as a ferrous material to be tested.

a) Mild Steels

Mild steels also called as low carbon steels. It has less than 0.30% C. It often is used for common industrial products (such as bolts, nuts, sheet, plate, and tubes) and for machine components that not required high strength. Mild steels is including inside as carbon steels. These steels generally are classified by their proportion (by weight) of carbon content. Mild steel is the most common form of steel because its price is relatively low while it provides material properties that are acceptable for many applications. Mild steel has a relatively low tensile strength, but it is cheap and malleable; surface hardness can be increased through carburizing (Kalpakjian and Schmid, 2006). The general mechanical properties of carbon and alloy steels are shown in Table 2.1.

Table 2.1: Typical mechanical properties of selected Carbon and Alloy Steels in the hot rolled, normalized, and annealed condition

AISI	Condition	Ultimate tensile strength (MPa)	Yield strength (MPa)	Elongation in 50 mm (%)	Reduction of area (%)	Hardness (HB)
1020	As-rolled	448	346	36	59	143
	Normalized	441	330	35	67	131
	Annealed	393	294	36	66	111
1080	As-rolled	1010	586	12	17	293
	Normalized	965	524	11	20	293
	Annealed	615	375	24	45	174
3140	Normalized	891	599	19	57	262
	Annealed	689	422	24	50	197
4340	Normalized	1279	861	12	36	363
	Annealed	744	472	22	49	217
8620	Normalized	632	385	26	59	183
	Annealed	536	357	31	62	149

Source: Kalpakjian and Schmid 2006

2.2.5 Nonferrous Metal and Alloys

Nonferrous metal and alloys cover a very broad range of materials. They may consist of aluminum, magnesium and copper which have a wide range. This nonferrous metal and alloys also have a wide variety of desirable properties, such as strength, toughness, hardness, and ductility. These metals also have major applications because of properties such as corrosion resistance, high thermal and electrical conductivity, low density, and ease of fabrication. As in all materials, the selection of a nonferrous material for a particular application requires consideration of many factors, including design and service requirements, long term effects, environmental attack, and cost (Kalpakjian and Schmid, 2006).

a) Aluminum and Aluminum Alloys

Aluminum was first produced in 1825. The important factors in selecting aluminum (Al) and its alloys are their higher strength-to-ratio, resistance to corrosion by many chemicals, high thermal and electrical conductivity, appearance and ease of formability (Kalpakjian and Schmid, 2006).

The principal uses of aluminum and its alloys are in containers and packaging (aluminum cans and foil), buildings and other types of construction, transportation (aircraft and automobiles) and portable tools (Kalpakjian and Schmid, 2006). Table 2.2 shows the selected aluminum alloys at room temperature based on their properties.

Table 2.2: Properties of selected Aluminum Alloys at room temperature

Alloy (UNS)	**Temper**	**Ultimate tensile strength (MPa)**	**Yield strength (MPa)**	**Elongation in 50mm (%)**
1100 (A91100)	O	90	35	35-45
1100	H14	125	120	9-20
2024 (A92024)	O	190	75	20-22
2024	T4	470	325	19-20
3003 (A93003)	O	110	40	30-40
3003	H14	150	145	8-16
5052 (A95052)	O	190	90	25-30
5052	H34	260	215	10-14
6061 (A96061)	O	125	55	25-30
6061	T6	310	275	12-17
7075 (A96061)	O	230	105	16-17
7075	T6	570	500	11

Source: Kalpakjian and Schmid 2006

b) Zinc

Zinc (Zn), is bluish-white in color and is the metal fourth most utilized industrial after iron, aluminum and copper. It has two major uses: (1) for galvanizing iron, steel sheet, and wire, (2) as an alloy base for casting. The metal is hard and brittle at most temperatures but becomes malleable between 100 and 150 °C. Above 210 °C, the metal becomes brittle again and can be pulverized by beating. Zinc is a fair conductor of electricity and poor of mechanical properties. The single largest use of zinc is in the application of zinc coating (galvanizing) to permit the most efficient use of steel and to conserve energy (Kalpakjian and Schmid, 2006).

Zinc also is used as an alloying element; brass for example, is an alloy of copper and zinc. Major alloying elements in zinc based alloys are aluminum, copper and magnesium; they impart strength and provide dimensional control during casting of the metal. Zinc based alloys are used extensively in die casting for making such as products as fuel pumps and grills for automobiles. Another use for zinc is in super plastic alloys which have good formability characteristic by virtue of their capacity to undergo large deformation without failure. A very fine grained 78% Zn-22% Al sheet is a common example of a super plastic zinc alloy which can be formed by methods used for forming plastics or metals (Kalpakjian and Schmid, 2006).

c) Galvanized Iron

Galvanized iron is iron which has been coated in a layer of zinc to help the metal resist corrosion **(**Smith, 2003). Steel can also be galvanized. When metal is going to be used in an environment where corrosion is likely, it is often galvanized so that it will be able to withstand the conditions. Even with galvanization, however, corrosion will eventually start to occur, especially if conditions are acidic.

There are two primary techniques which can be used to make galvanized iron. The most common is hot-dip galvanization, in which the iron is moved through an extremely hot bath of molten zinc, which may be mixed with small amounts of lead, depending on the circumstances. When the iron emerges from the bath, the zinc will have bonded, creating a layer of zinc on the surface of the iron. Sometimes, the metal may be passed through a mill to flatten and even out the coating (Smith, 2003).

Another technique which can be used is electro-deposition, also known as electroplating, although this is rare. Once galvanized, iron is covered in a layer of zinc which may be shiny to dull gray. The zinc can be painted, if desired, or left plain. Painting is often done when the iron must match other building materials, or when people want to make it less obvious. As long as the zinc coating remains intact, the galvanized iron should remain in relatively good condition. However, acidic conditions can erode the zinc over time, creating patches where corrosion can occur.

Corrosion can also occur when the coating is penetrated, as when someone drives a nail through a sheet of galvanized iron, exposing the iron inside to the elements. Once corrosion starts, it can spread under the zinc, eventually causing the metal to fail.

There are a wide range of uses for galvanized iron, which comes in pipes, stakes, sheeting, and wire, among other formats (Smith, 2003).

d) Copper

Copper is metal that has a wide range of applications due to its good properties. It is used in electronics, for production of wires, sheets, tubes, and also to form alloys. Copper is resistant toward the influence of atmosphere and many chemicals (Antonijevic and Petrovic, 2007).

Copper is a reddish brown nonferrous mineral which has been used for thousands of years by many cultures. The metal is closely related with silver and gold, with many properties being shared among these metals. The metal is highly ductile, meaning that it can be easily worked and pulled into wire. For cultures which had minimal or crude metalworking abilities, copper would have been easy to shape and work with. Copper is also easy to alloy, and many of the early metal alloys featured copper (Smith, 2003).

Copper is easily worked, being both ductile and malleable. The ease with which it can be drawn into wire makes it useful for electrical work in addition to its excellent electrical properties. Copper can be machined, although it is usually necessary to use an alloy for intricate parts, such as threaded components, to get really good machinability characteristics. Good thermal conduction makes it useful for heat sinks and in heat exchangers. Copper has good corrosion resistance, but not as well as gold. It has excellent brazing and soldering properties and can also be welded, although best results are obtained with gas metal arc welding (David, 2004).

Copper is normally supplied, as with nearly all metals for industrial and commercial use, in a fine grained polycrystalline form. Polycrystalline metals have greater strength than monocrystalline forms, and the difference is greater for smaller grain (crystal) sizes. The reason is due to the inability of stress dislocations in the crystal structure to cross the grain boundaries (William and Javad, 2003).

2.3 SHEET METAL FORMING PROCESS

Sheet metals forming are among the most versatile of all operations. They generally are used on work pieces having high ratios of surface area of surface area to thickness. A sheet metal part produced in presses is called a stamping. The characteristics sheet metal forming processes are include a wide variety of operations, such as blanking, embossing, bending, flanging, and coining. It can produce simple or complex shapes formed at high production rates (Kalpakjian and Schmid, 2006).

2.3.1 Characteristics and Type of Shearing Dies

a) **Compound dies:** Several operations on the same sheet may be performed in one stroke at one station with compound die where shown in Figure 2.1. Such combined operations usually are limited to relatively simple shapes, because (a) the process is somewhat slow and (b) the dies rapidly become much more expensive to produce than those for individual shearing operations, especially for complex dies.

b) **Progressive dies:** Parts requiring multiple operations to produce can be made at high production rates in progressive dies. The sheet metal is fed through as a coil strip, and a different operation (such as punching, blanking, and notching) is performed at the same station of the machine with each stoke of a series of punches where shown in Figure 2.1c. An example of a part made in progressive dies is shown in Figure 2.1d; the part is the small round piece that supports the plastics tip in spray cans.

c) **Transfer dies:** In a transfer die setup, the sheet metal undergoes different operations at different stations of the machine which are arranged along a straight line or circular path. After each step in a station, the part is transferred to the next station for further operations.

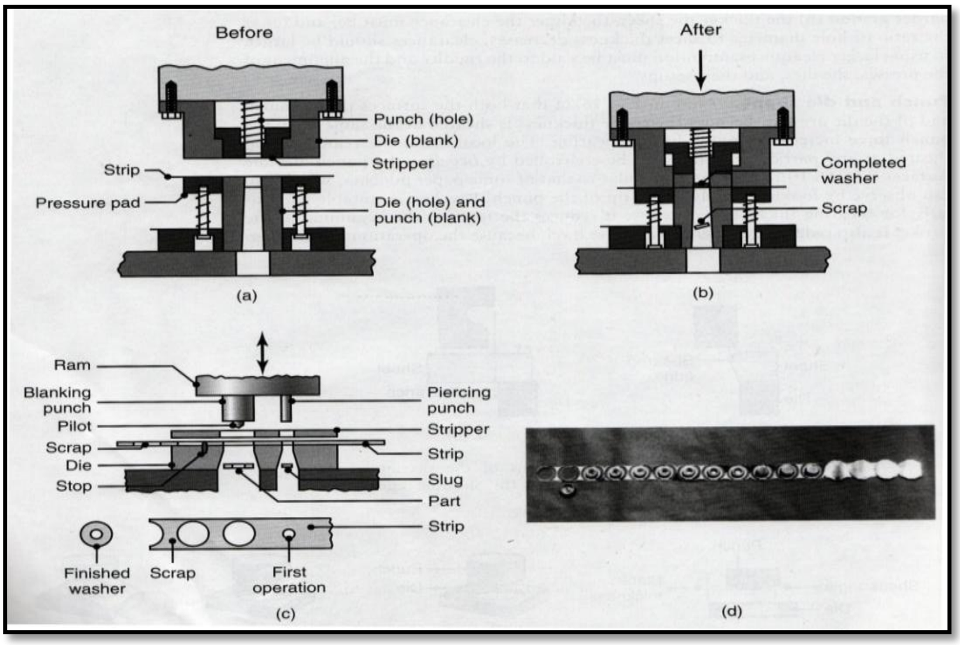

Figure 2.1: Schematic illustration: (a) before and (b) after blanking a common washer in a compound die. (c) Schematic illustrations of making a washer in a progressive die. (d) Forming of the top piece of an aerosol spray can in a progressive die.

Source: Kalpakjian and Schmid 2006

2.4 MECHANICAL TESTING

2.4.1 Introduction to Mechanical Testing

In order to appreciate the results obtained from mechanical tests of materials and to place upon them a proper interpretation, some knowledge of the elementary theory of elasticity is needful. Though materials generally are far from being homogenous, the assumption nevertheless serves as foundation for a vast body of analysis leading to results which the designer can apply with a considerable measure of success. Tensile test is the one of mechanical testing for metallic material, which is, it can obtained the results such as strain, stress and modulus of elasticity (Davis, 2004).

2.4.2 Tensile Test

The tensile test is the most common test for determining such mechanical properties of materials as strength, ductility, toughness, elastic modulus, and strain-hardening capability (Kalpakjian and Schmid, 2006). The first requires the preparation of test specimen, typically as shown in Figure 2.2. Although most tensile test specimens are solid and round, they also can be flat or tubular.

Tensile test is used to evaluate the strength of metals and alloys (Davis, 2004). In this test a metal sample is pulled to failure in a relatively short time at a constant rate. The ability of a material to resist breaking under tensile stress is one of the most important and widely measured properties of materials used in structural applications.

2.4.3 Tensile Testing of Metallic Material (ASTM E8)

ASTM E8 describes tensile testing methods to determine yield strength, yield point elongation, tensile strength, elongation and reduction of area of metal products. It applies to metallic materials in any form, including: sheet, plate, wire, rod, bar, pipe and tube (ASTM E8, 2008).

For each of these specimen types, the standard defines suitable geometries and dimensions, requiring specific gripping solutions that are critical to performing a successful test. The most common types of specimens are rectangular and round (Instron, 2010). Figure 2.2 shows the rectangular tensile test specimen with standard dimension from Table 2.3. The dimension of this standard are divided for each types of sheet metal used.

For testing rectangular type specimens the Instron tensile test machine use a variety of mechanical wedge action grips, including manual, pneumatic and hydraulic, with flat serrated faces. In the case of round specimens, the machine will used vee-serrated or threaded faces, dependent upon the geometry of the specimen ends. For testing fine wires Instron machine typically used pneumatic cord and yarn grips that appropriately distribute the load in a long section of the wire to avoid brakes in the clamping zone. Improper preparation of specimens is often the reason for unsatisfactory test results. In order to ensure accurate and precise test results, specimens should be machined carefully (Instron, 2010).

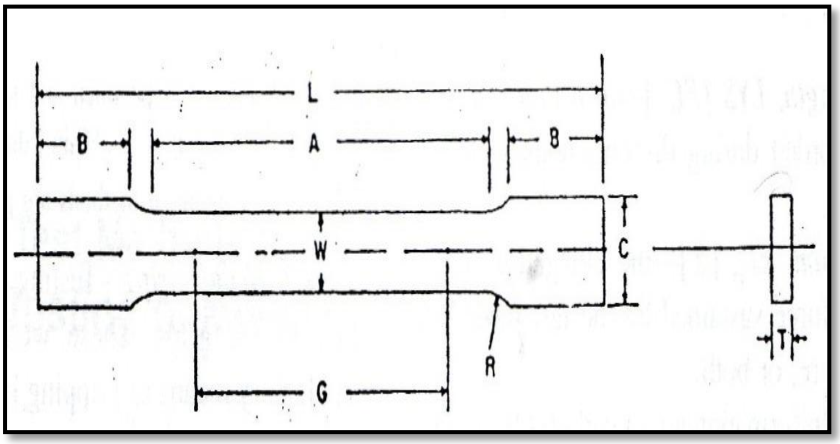

Figure 2.2: Rectangular tensile test specimen

Source: Bailey and Baldini 2008

Table 2.3: Rectangular tensile test specimens (ASTM E8)

Item	**Dimensions**		
	Standard Specimens		**Subsize Specimen**
	Plate Type, 40mm [1.500in.] Wide	**Sheet Type, 12.5mm [0.500in.] Wide**	**6mm [0.250in.] Wide**
	mm [in.]	**mm[in.]**	**mm[in.]**
G (Gage length)	200.0 ± 0.2 8.00 ± 0.01	50.0 ± 0.1 [2.000 ± 0.005]	25.0 ± 0.1 [1.000 ± 0.003]
W (Width)	40.0 ± 2.0 [1.500 ± 0.125, -0.250]	12.5 ± 0.2 [0.500 ± 0.010]	6.0 ± 0.1 [0.250 ± 0.005]
T (Thickness)		thickness of material	
R (Radius of fillet)	25 [1]	12.5 [0.500]	6 [0.250]
L (Overall length)	450 [18]	200 [8]	100 [4]
A (Length of reduced section, min)	225 [9]	57 [2.25]	32 [1.25]
B (Length of grip section)	75 [3]	50 [2]	30 [1.25]
C (Width of grip section, approximate)	50 [2]	20 [0.750]	10 [0.375]

Source: Bailey and Baldini 2008

2.4.4 Tensile Testing of Metallic Materials (ISO 6892-1)

This European standard was introduced in September 2009, and replaces the withdrawn EN 10002-1:2001 standard (Instron, 2010). It specifies the method for tensile testing of metallic materials and defines the mechanical properties which can be determined at ambient temperature. The test involves straining a test piece in tension, generally to fracture, for the purpose of determining one or more mechanical properties. Product's that may be tested in accordance with this standard include metallic sheets and plates, wire, bar or section, and also tubes. Specimens are gripped to ensure that the specimen is aligned axially in order to minimize bending. The specimen is then strained in tension until failure, and load and strain data are recorded.

The standard provides for two methods, one uses strain rate control to minimize the variation of strain rates during the determination of strain rate sensitive parameters, and the second method's testing rate is based on the stress rate. The choice of method and rates are at the discretion of the test laboratory, but must be clearly stated when reporting test results (Instron, 2010).

The standard also includes recommendations for specimen types and dimensions, advice concerning the use of computer controlled tensile testing machines, and methods for estimating the uncertainty of measurement. Results determined typically include yield and proof strengths, ultimate tensile strength, and elongation at fracture. A typical testing system will include a universal testing machine, such as the 5500 Series, with suitable wedge or hydraulic grips, and a clip-on or non-contacting video extensometer to measure strain directly at the specimen for the determination of proof strength (Instron, 2010).

2.4.5 Tensile Test Specimens

Consider the typical tensile test specimen is shown as Figure 2.2. It has enlarged ends or shoulders for gripping. The important part of the specimen is the gage section. The cross sectional area of the gage section is reduced relative to that of the remainder of the specimen so that deformation and failure will be localized in this region.

The gage length is the region over which measurements are made and is centered within the reduced section. The distances between the ends of the gage section and the shoulders should be great enough so that the larger ends do not constrain deformation within the gage section, and the gage length should be great relative to its diameter (Davis, 2004).

There are various ways of gripping the specimen, some of which are illustrated in Figure 2.3. The end may be screwed into a threaded grip, or it may be pinned; butt ends may be used, or the grip section may be held between wedges. The most important concern in the selection of gripping method is to ensure that the specimen can be held at the maximum load without slippage or failure in the grip section. Bending should be minimized (Davis, 2004).

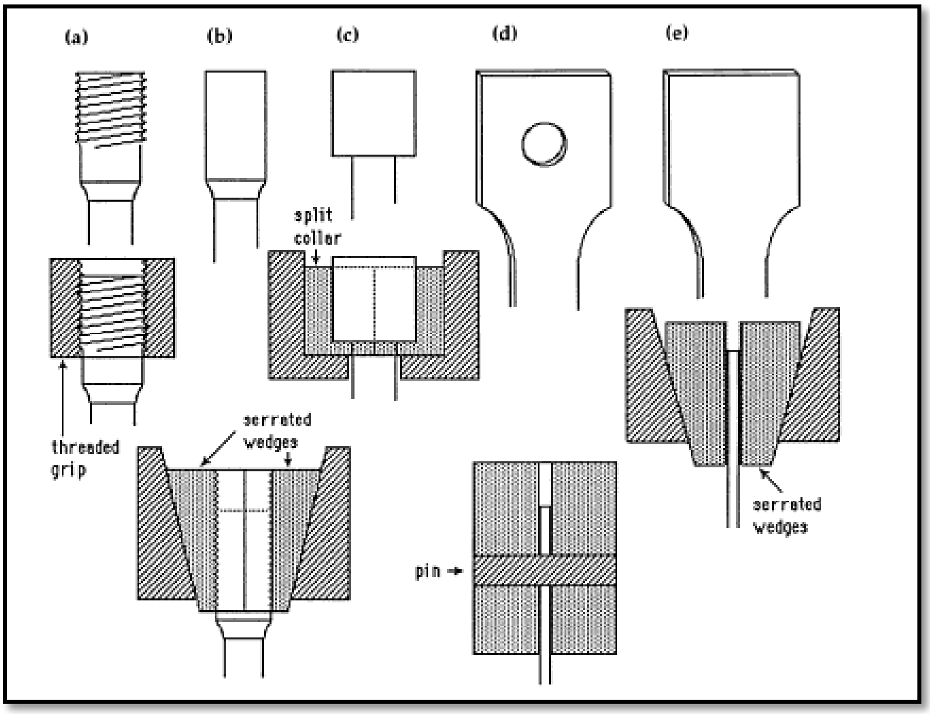

Figure 2.3: System for gripping tensile specimens. For round specimen, these includes (a) threaded grips, (b) serrated wedges and for butt end specimen (c) split collars constrained by a solid collar. Flat specimens maybe gripped with (d) pins, or (e) serrated wedges

Source: Davis 2004

2.4.6 Tensile Test Machines

The most common testing machines are universal testers, which test materials in tension, compression or bending. Their primary function of this machine is to create the stress-strain curved. Testing machines are either electromechanical or hydraulic. The principal difference is the method by which the load is applied. Electromechanical machines are based on a variable speed-speed electric motor; a gear reduction system; and one, two or four screws that move the crosshead up or down. This motion loads the specimens in tension and compression (Instron, 2010).

Hydraulic testing machine are based on either a single or dual-acting piston that moves the crosshead up or down. However, most static hydraulic testing machines have a single acting piston or ram. In a manually operated machined, the operator adjust the orifice of a pressure-compensated needle valve to control the rate of loading (Instron, 2010).

In general electromechanical machines are capable of a wider range of test speeds and longer crosshead displacement; whereas hydraulic machines are more cost-effectives for generating higher force Figure 2.4 show the Instron testing machine that used for tensile testing method especially for sheet metal or flat metal product. Instron’s testing machines cover a range of load capacities, including table mounted machines with maximum capacities of 50 kN (11,200 lbf) and floor-mounted machines with capacities from 50 kN (11,200lbf) to 3000 kN (600,000 lbf). The ability of all systems to measure force very accurately over a wide measurement range means that a range of product can be tested without changing the load cell (Instron, 2010). Figure 2.4 shows the Instron testing apparatus.

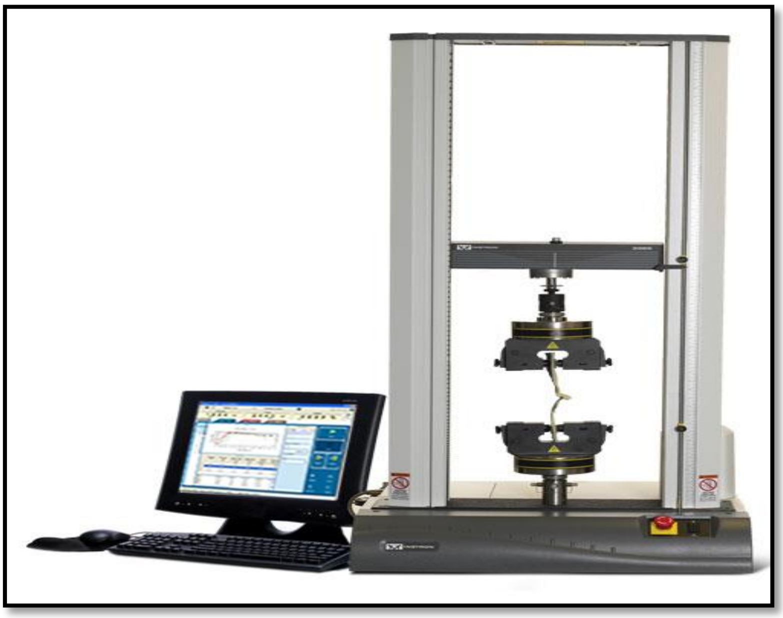

Figure 2.4: Instron testing apparatus

Source: Davis 2004

2.4.7 Stress and Strain Curves

A typical sequence of deformation of the tensile test specimen is shown in Figure 2.5a and Figure 2.6. When the load is first applied, the specimen elongates in proportion to the load; this behavior is called linear elastic. If the load is removed, the specimen returns to its original length and shape in an elastic manner similar to stretching a rubber and releasing it.

The engineering stress (nominal stress) is defined as the ratio of the applied load, P, to the original cross-sectional area, A_o of the specimen (Kalpakjian and Schmid, 2006):

$$\text{Engineering stress,} \quad \sigma = \frac{P}{A_o} \tag{2.1}$$

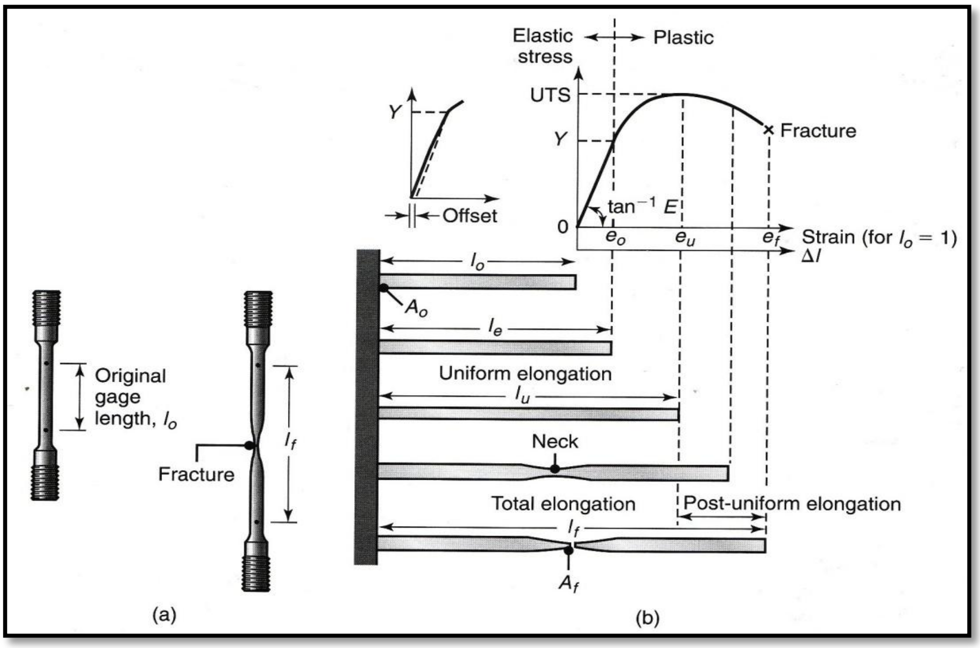

Figure 2.5: (a) A standard tensile test specimen before and after pulling, showing original and final gage lengths. (b) A tensile test sequence showing different stages in the elongation of the specimen

Source: Kalpakjian and Schmid 2006

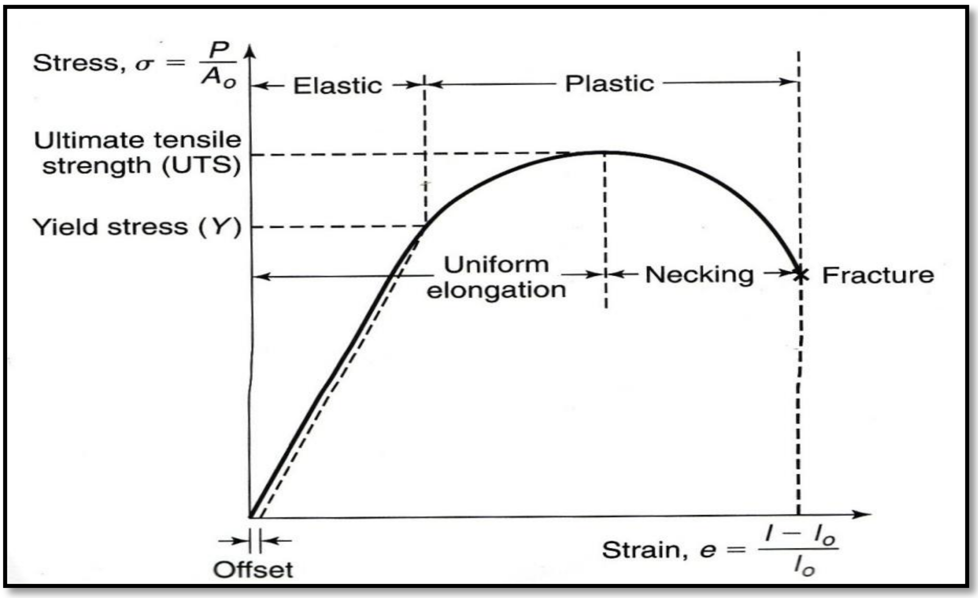

Figure 2.6: A typical stress strain curve obtained from a tensile test, showing various features

Source: Kalpakjian and Schmid 2006

The engineering strain is found by dividing the change in the specimen's gage length, $(l - l_o)$ by the specimen's original gage length, l_o (Kalpakjian and Schmid, 2006).

$$\text{Engineering strain, } e = \frac{(l - l_o)}{l_o} \tag{2.2}$$

where l is the instantaneous length of the specimen.

As the load is increased, the specimen begins (at some level of stress) to undergo permanent (plastic) deformation. Beyond that level, the stress and strain are no longer proportional, as they were in the elastic region. The stress at which this phenomenon occurs is known as the yield stress, Y , of the material. The yield stress and other properties for various metallic materials are given in Table 2.4.

For soft and ductile materials, it may not be easy to determine the exact location on the stress strain curves at which yielding occurs, because the slope of the straight (elastic) portion of the curve begins to decrease slowly. Therefore, Y usually is defined as the point on stress strain curve that is offset by a strain of 0.002, or 0.2% elongation (Kalpakjian and Schmid, 2006). This simple produce is shown on Figure 2.6.

As the specimen (under a continuously increasing load) begins to elongate, it's cross sectional area decreases permanently and uniformly throughout its gage length. If the specimen is unloaded from a stress level higher than the yield stress, the curve follows a straight line downward and parallel to the original slope of the curve (Kalpakjian and Schmid, 2006) (see Figure 2.7). As the load is further increased, the engineering stress eventually reaches a maximum and then begins to decrease.

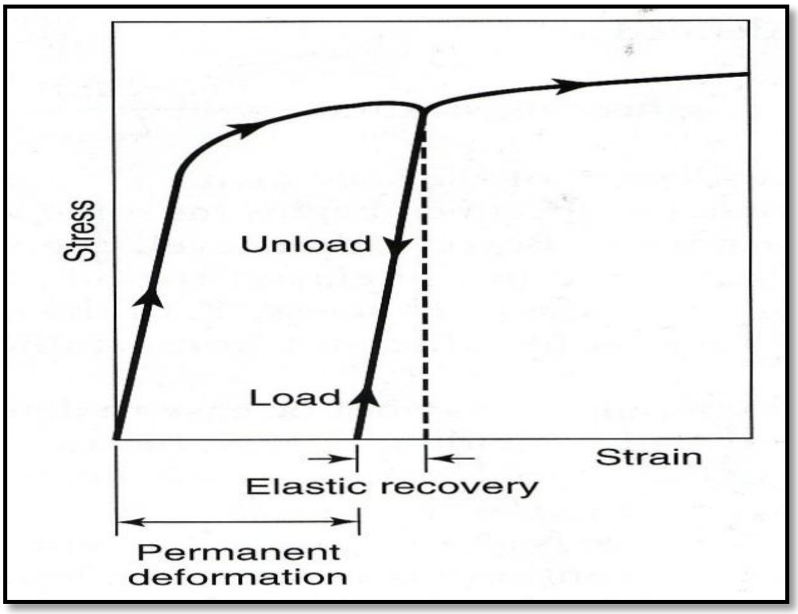

Figure 2.7: Schematic illustration of the loading and the unloading of a tensile test specimen. Note that, during unloading, the curve follows a path parallel to the original elastic slope

Source: Kalpakjian and Schmid 2006

The maximum engineering stress is called the tensile strength or Ultimate Tensile Strength (UTS) of the material. Values for the UTS for various materials are given in Table 2.4. If the specimen is loaded beyond its ultimate tensile strength, it begins to neck or neck down. The cross sectional area of the specimen is no longer along the gage length and is smaller in the necked region. As the test progresses, the engineering stress drops further and the specimen finally fractures at the necked region (Figure 2.5a). The engineering stress at fracture is known as the breaking or fracture stress. The ratio of stress to strain in the elastic region is the modulus of elasticity, E or Young's modulus. The modulus of elasticity is essentially a measure of the slope of the elastic portion of the curve and, hence, the stiffness of the material. The higher the E value, the higher the load required to stretch the specimen to the same extent (Kalpakjian and Schmid, 2006). Values for the Young modulus for various metal materials are shown in the Table 2.4 below.

$$\text{Modulus of elasticity, } E = \frac{\sigma}{e} \tag{2.3}$$

Table 2.4: Mechanical properties of various materials at room temperature

Metals (Wrought)	E (GPa)	Y (MPa)	UTS (MPa)	Elongation in 50mm (%)	Poisson's ratio (v)
Aluminum and its alloys	69-79	35-550	90-600	45-4	0.31-0.34
Copper and its alloys	105-150	76-1100	140-1310	65-3	0.33-0.35
Lead and its alloys	14	14	20-55	50-9	0.43
Magnesium and its alloys	41-45	130-305	240-380	21-5	0.29-0.35
Molybdenum and its alloys	330-360	80-2070	90-2340	40-30	0.32
Nickel and its alloys	180-214	105-1200	345-1450	60-5	0.31
Steels	190-200	205-1725	415-1750	65-2	0.28-0.33
Titanium and its alloys	80-130	344-1380	415-1450	25-7	0.31-0.34
Tungsten and its alloys	350-400	550-690	620-760	0	0.27
Zinc and its alloys	50	80-2070	240-550	65-5	0.27

Source: Kalpakjian and Schmid 2006

2.4.8 Ductility of Material

An important behavior observed during a tensile test is ductility: the extent of plastics deformation that the material undergoes before fracture. There are two common measures of ductility. The first is the total elongation of the specimen (Kalpakjian and Schmid, 2006):

$$\text{Elongation} = \frac{(l_f - l_o)}{l_o} \times 100 \qquad (2.4)$$

where l_f and l_o are measured, as shown in Figure 2.5a. Note that the elongation is based on the original gage length of the specimen and that it is calculated as a percentage.

The second measure of ductility is the reduction of area (Kalpakjian and Schmid, 2006):

$$\text{Reduction of area} = \frac{(A_o - A_f)}{A_0} \times 100 \qquad (2.5)$$

where A_o and A_f are the original and final (fracture) cross sectional areas, respectively, of the test specimen. Reduction of area and elongation generally are interrelated, as shown in Figure 2.8 for some typical metals.

Thus the ductility of a piece of chalk is zero, because it does not stretch at all or reduce in cross section. By contrast, a ductile specimen, such as putty or chewing gum, stretches and necks considerably before it fails (Kalpakjian and Schmid, 2006). Figure 2.9 show the different stages elongation of round metal bars after tensile testing.

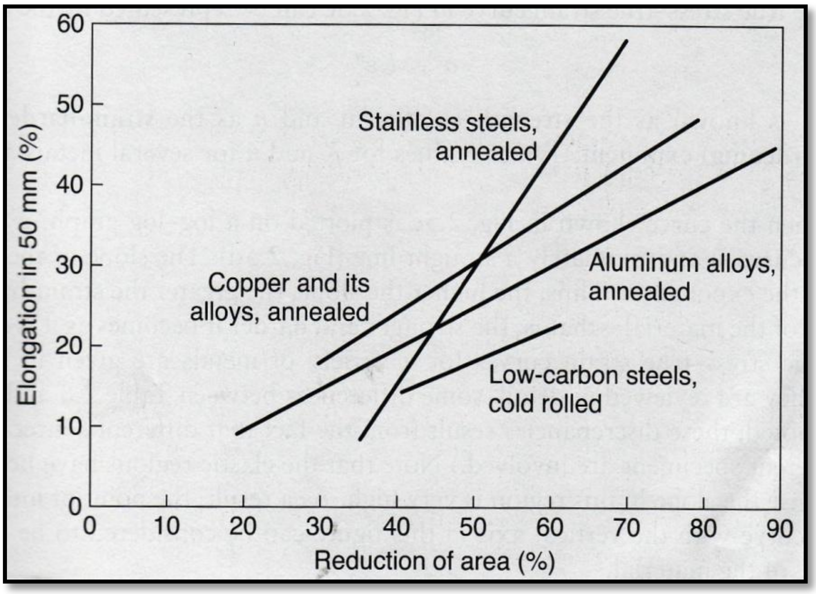

Figure 2.8: Approximate relationship between elongation and tensile reduction of area for various groups of metals

Source: Kalpakjian and Schmid 2006

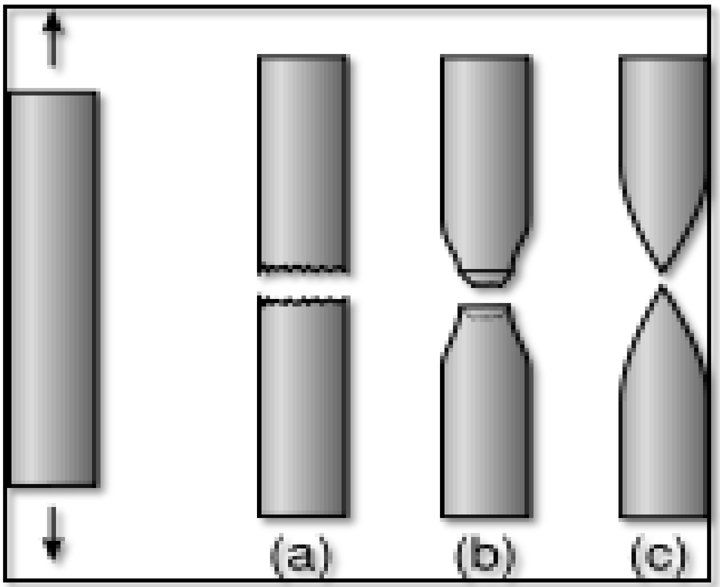

Figure 2.9: Schematic appearance of round metal bars after tensile testing. (a) Brittle fracture (b) Ductile fracture (c) Completely ductile fracture

Source: Dieter 1986

2.5 ACOUSTIC EMISSION

2.5.1 Historical of Acoustic Emission

The technology of Acoustic emission (AE) traditionally had its beginning in 1950 with the work of Joseph Kaiser. During the 1950s and '60s researchers delved into the fundamentals of acoustic emission, developed instrumentation specifically for AE, and characterized the AE behavior of many materials. Acoustic emission was starting to be recognized for its unique capabilities as a Nondestructive testing (NDT) method for monitoring dynamic processes (Drouillard, 1996).

In the decade of the 1970s research activities became more coordinated and directed with the formation of the working groups, and its use as an NDT method continued to increase for industrial applications. In the 1980s the computer became a basic component for both instrumentation and data analysis, and today it has sparked a resurgence of opportunities for research and development (Drouillard, 1996).

Today, waveform-based acoustic emission analysis has become common place and there is a shift in acoustic emission activities with more emphasis on applications than on research. From the beginning, the developing field of acoustic emission has been nurtured by a plethora of dedicated savants with a diverse range of scientific and engineering disciplines, who have contributed in a collective way to bring AE to a mature, fully developed technology and to leave a legacy of knowledge recorded in its literature. Acoustic emission literature has been a key indicator of the amount of activity, the proportion of research to application, the emphasis on what was of current interest, and the direction AE has taken (Drouillard, 1996).

2.5.2 Introduction of Acoustic Emission

Acoustic emission AE is the phenomenon in which elastic or stress waves are emitted from a rapid, localized changed of strain energy in a material (Sachse, 1991). Acoustic emission as a technology has rapidly become accepted as a nondestructive testing methodology. A wide variety of nondestructive testing methods and procedures are utilized during the fabrication of structures when the consequences of failure are costly, constitute a hazard to the public, or both. It has become in recent years the basis of a number of recommended practices and inspection codes of several societies.

The application of AE which involves the detection of AE signals and possibly their characterization are diverse. Most commonly, they include the monitoring of manufacturing and other dynamical processes, the integrity of structural components as well as fundamental investigations of failure processes of engineering as well as geological materials. Acoustic emission is the transient elastic energy that is spontaneously released when materials undergo deformation, fracture or both (Sachse, 1991). Materials investigated have included both metal and nonmetals, although most of the work published to date has been concerned with metallic specimens or structures.

2.5.3 Acoustic Emission Techniques and Principle

The basic acoustic emission measurement system consist of an AE sensor, amplifier and AE signal analyzing equipment, as schematically shown in Figure 2.10. Some phenomenon occurs in the specimen and it emits AE. Then an acoustic emission wave propagates through the specimen and is detected by the acoustic emission sensor, where the AE changes from an elastic wave to an electrical signal. Then the AE signals are processed by using electronic devices and technology. The AE sensor is the most important part of the AE equipment.

Acoustic emissions are the stress waves generated by the sudden internal stress redistribution in materials or structures when changes in their internal structure are produced (crack initiation and growth, crack opening and closure, deformation, dislocation movement, void formation, interfacial failure, corrosion, fibre-matrix de-bonding in composites, etc) (Piotrkowski, 1999) . These waves propagate through the material and eventually reach the surface, producing small temporary surface displacements.

Usually the stress waves are of low amplitude and of high frequency (normally, ultrasonic) (Piotrkowski, 1999). This is the reason why very sensitive piezoelectric transducers (sensors) are required to capture them. Due to the low amplitude of AE waves, several steps must be sequentially incorporated after their capture and before the subsequent recording and analysis. A preamplifier is necessary to minimize the interference and prevent the signal loss, a filter to remove the noise and finally an amplifier.

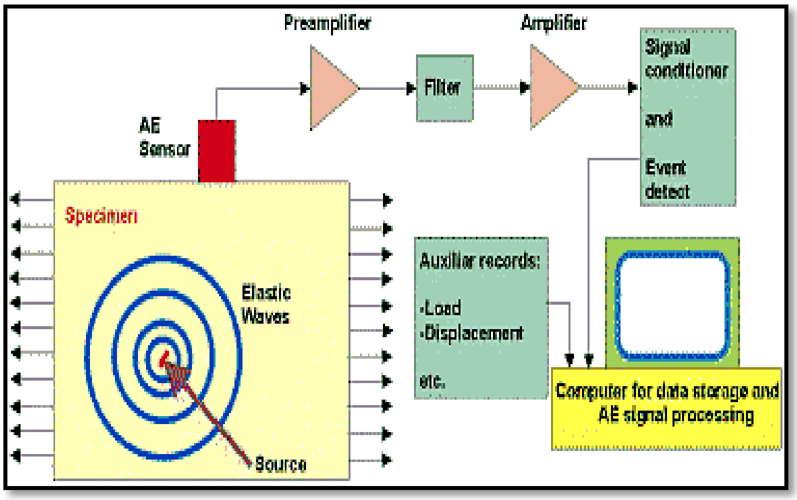

Figure 2.10: Block diagram of signal flow in AE measurement system

Source: Piotrkowski 1999

Depending on noise conditions, further filtering or amplification at the mainframe may still be necessary. After passing the AE system mainframe, the signal comes to a detection or measurement circuit as shown in the Figure 2.11. Note that multiple-measurement circuits can be used in multiple sensor or channel systems for source location purposes. At the measurement circuitry, the shape of the conditioned signal is compared with a threshold voltage value that has been programmed by the operator. Signals are either continuous or burst-type. Each time the threshold voltage is exceeded, the measurement circuit releases a digital pulse. The first pulse is used to signify the beginning of a hit.

A hit is used to describe the AE event that is detected by a particular sensor. One AE event can cause a system with numerous channels to record multiple hits. Pulses will continue to be generated while the signal exceeds the threshold voltage. Once this process has stopped for a predetermined amount of time, the hit is finished (as far as the circuitry is concerned). The data from the hit is then read into a microcomputer and the measurement circuit is reset.

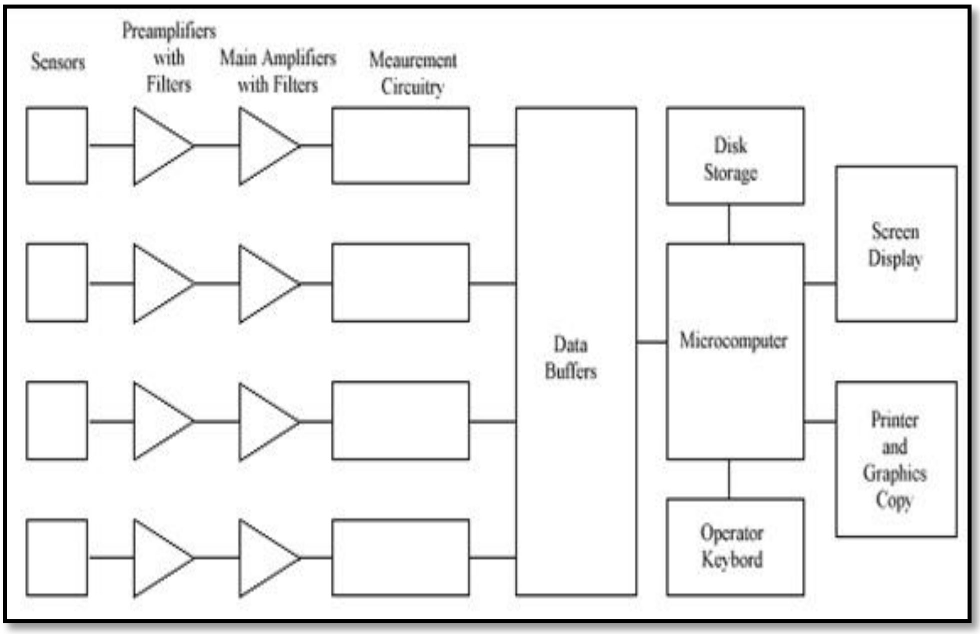

Figure 2.11: Schematic diagram of a basic four-channel acoustic emission system

Source: National Science Foundation 2000

2.5.4 Acoustic Emission Tool and Equipment

Acoustic emission testing can be performed in the field with portable instruments or in a stationary laboratory setting. Typically, systems contain a sensor, preamplifier, couplant and holders, filter, and amplifier, along with measurement, display, and storage equipment (e.g. oscilloscopes, voltmeters, and personal computers). However the important part in AE equipment is AE sensor (National Science Foundation, 2000).

2.5.5 Acoustic Emission Sensor

Acoustic emission sensors respond to dynamic motion that is caused by an AE event (National Science Foundation, 2000). This is achieved through transducers which convert mechanical movement into an electrical voltage signal. The transducer element in an AE sensor from that show from Figure 2.12 is almost always a piezoelectric crystal, which is commonly made from a ceramic such as lead zirconate titanate (PZT).

Transducers are selected based on operating frequency, sensitivity and environmental characteristics, and are grouped into two classes: resonant and broadband (National Science Foundation, 2000). This literature review will discuss more about integral preamplifier sensors, and frequency required during the experiment.

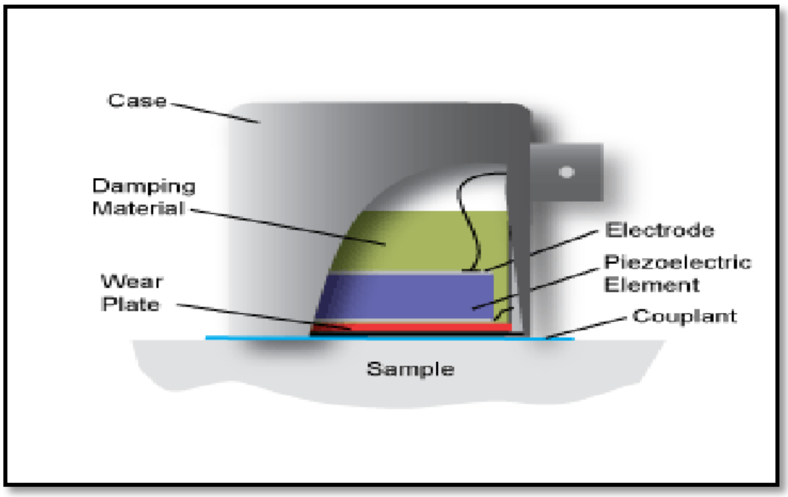

Figure 2.12: Inside view for sample of transducer sensor

Source: National Science Foundation 2000

a) Integral Preamplifier Sensors

These transducers were specifically engineered to attain high sensitivity and have the capability to drive long cables without the need for a separate preamplifier. The elimination of separate preamplifiers, cables and vulnerable connectors greatly improves the reliability in tough environments and significantly reduces set up time (Physical Acoustic Corporation, 2010).

Incorporating a low-noise input, 40dB preamplifier and a filter all inside the sensor housing, this integral preamp sensor operate at 60, 150, 300 or 500 kHz resonant frequencies or wideband. Their integrated Auto Sensor Test (AST) capability allows the sensors to pulse as well as receive. This feature allows user to verify sensor coupling and performance at any time throughout the test (Physical Acoustic Corporation, 2010).

All these sensors are completely enclosed in metal stainless steel (or aluminum) housings that are treated to minimize RFI/EMI (Radio Frequency and Electromagnetic Interference). Care has also been taken to thermally isolate the critical input stage of the preamplifier in order to provide excellent temperature stability over the range of -35º to 75º C. Figure 2.13 show the integral preamplifier acoustic emission sensors (Physical Acoustic Corporation, 2010). The features of this integral preamplifier sensor are:

i. Built-in, low noise preamplifier.
ii. Wide dynamic range (>80dB).
iii. All metal construction is immune to EMI/RFI pickup.
iv. Single BNC (Bayonet Neill Concelman) (power in or signal out on center conductor).
v. Ideal for field or lab testing.
vi. Auto Sensor Test (AST) standard for sensor pulsing or self-test.
vii. Many different frequency models to choose from.

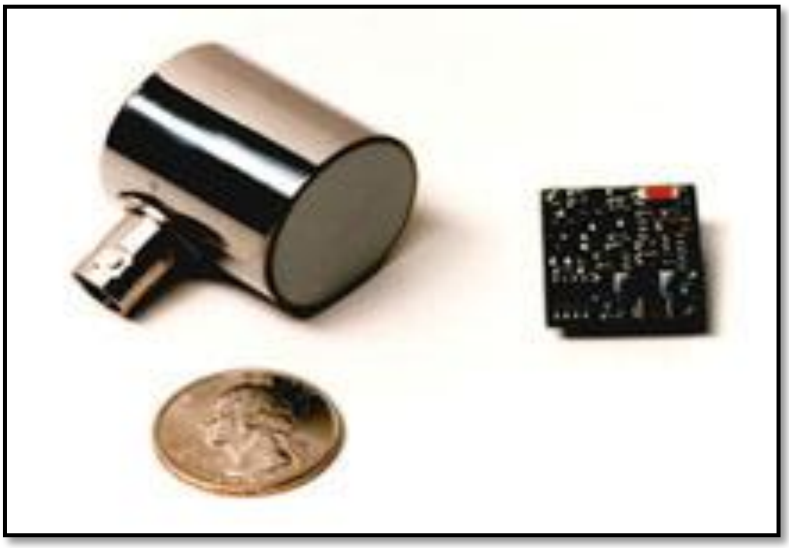

Figure 2.13: Integral preamplifier acoustic emission sensor

Source: Physical Acoustic Corporation 2010

2.5.6 General Problem of AE Sensors

The acoustic emission sensor is the most important part of the AE equipment. However the AE sensor has many kinds of unclarified problems to be solved. The general problems of the sensors are:

a) Effect of mounting condition on sensitivity.
b) Sensors sensitivity.
c) Degradation of the sensitivity and its method evaluation.

This factor mentioned above affect detected AE signals, and it will cause changes in peak voltage, duration time and so on. Therefore even if the same sensor and AE equipment are used under the same measurement conditions, the results of AE event count may be changed depending on the mounting condition. This leads to difficulty in exchanging and comparing actual AE signals data among different research groups using different equipments and sensors, even if sensors sensitivities have been calibrated. Thus, it is quite important to find some solution to make it possible to compare AE data and for producing an AE data base near future (Sachse, 1991). Figure 2.14 show the location of mounting of acoustic emission sensor.

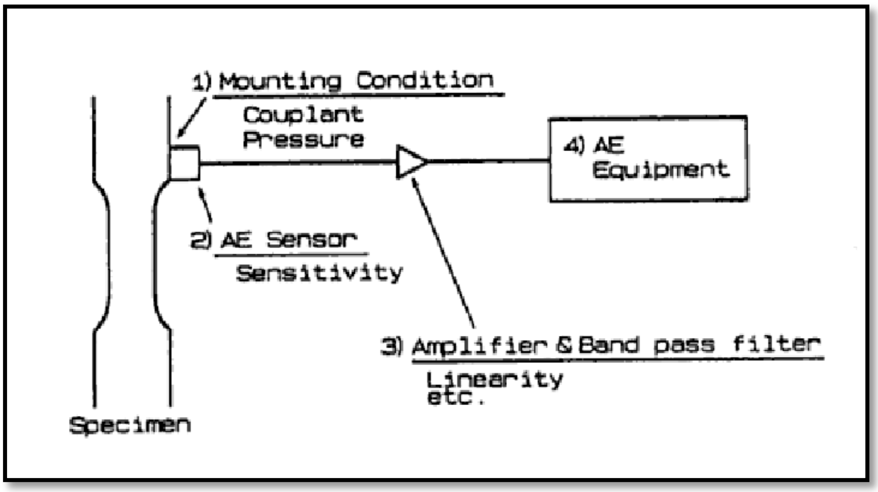

Figure 2.14: Location of acoustic emission sensor

Source: Sachse 1991

2.5.7 Couplant and Holders

Couplant and holders also the one of important equipment in acoustic emission technique. They are mainly used to aid in easy and complete conduction of acoustic waves generated from the source. This happen because the energy released will not be transmitted for all from the material to piezoelectric transducer. Several types of this equipment are list and described below with the advantage and limitation of using each types (Physical Acoustic Corporation, 2010).

a) Liquid Couplant.

i. Good for smooth surfaces.
ii. Generally provide lower acoustic.
iii. Good longitudinal wave transmission.
iv. Low viscosity and have a tendency to drip run out or dry up with time.
v. Not suitable for vertical mounting.
vi. Shear motion is hard to detect.

b) Gel Couplant

i. Slightly higher acoustic impedance than liquid based couplants.
ii. Less likely to drip than liquid based couplants making them suitable for vertical mounting.
iii. Appropriate for rougher surfaces.
iv. Due to their relatively low viscosity they are very good at forcing out trapped air from the contact region with a small amount of force on the sensor.
v. Glycerin offers the highest acoustic impedance of the most common liquid and gel couplants therefore producing better transmission in most cases.
vi. A clamping fixture is required for all gel-based couplants.

c) Grease Couplant

i. Grease-based couplants have a much higher viscosity than gels or liquid.
ii. High application force is required on the sensor to remove all the trapped air but enables the sensor to be mounted vertically.
iii. Grease based couplants sometimes benefit from a small amount of lateral movement during application of the sensor to encourage displacement of the trapped air.
iv. Cleaning the surface after use is more difficult, particularly for silicon based greases.
v. Most commonly used couplant.

d) Adhesive Couplant

i. Ideal for applications where the sensor will not be removed very often, if at all, and for measurements where absolute stability in the coupling or the sensor position is required.

e) Shear Wave Couplant

i. A high viscosity couplant should be used to provide a good coupling of transverse forces.
ii. Specialized shear wave couplants can be purchased which provide a highly viscous contact and good transmission of in plane or shear surface motion.
iii. Honey is a more convenient alternative, which offers comparable transmission of shear waves to that of the more expensive specialist couplants.
iv. These couplants can also provide good transmission of longitudinal waves.
v. Require a mounting fixture and a large applied force to achieve an even layer with no trapped air.

2.5.8 Acoustic Emission Signal

Basically, there are two types of AE signals, transient and continuous signals. With transient AE signals, also called bursts, start and end points deviate clearly from background noise. With continuous AE signals, it showed the amplitude and frequency variations but the signal never ends (Hartmut, 1999). Figure 2.15, showed the example of both types of AE signals.

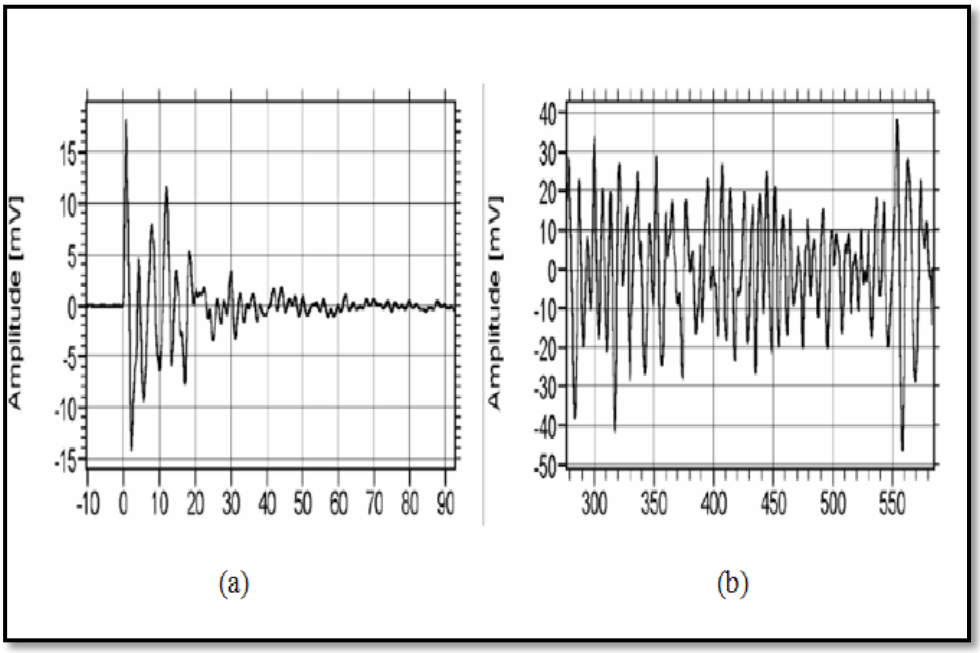

Figure 2.15: (a) Transient and (b) continuous of AE signals

Source: Hartmut 1999

Mostly the acoustic emission signals that make up this frequency signal occurred by the cracking on the product test. These factors are caused the signal formed according to their wave's propagation during the deformation of the material used (Hartmut, 1999). There are several an incident roots which affects acoustic transmission signal for each type:

a) Transient AE Signals

i. Formation and growth of cracks.
ii. Crack Closure (friction).
iii. Corrosion processes (change of volume) and cracking of corrosion product.
iv. Cracking of brittle surface layers.
v. Breaking of fibers, matrix.
vi. Delamination.
vii. Debonding.
viii. Phase transition (change of volume).

b) Continuous AE Signals

i. Drilling, bearing, cutting, grinding, machining.
ii. Leakages (laminar and turbulent flow), e.g. in valve, pipelines.
iii. Continuous friction, wear.
iv. Process noise from pump, motors, reactors, etc.
v. Flow of material, liquid or powder.

2.5.9 Signal Parameters and Features of AE Signal

With the equipment configured and setup complete, AE testing may begin. The sensor is coupled to the test surface and held in place with tape or adhesive. An operator then monitors the signals which are excited by the induced stresses in the object. When a useful transient, or burst signal is correctly obtained, parameters like amplitude, counts, measured area under the rectified signal envelope (MARSE), duration, and rise time can be gathered (National Science Foundation, 2000). Each of the AE signal feature are shown in the Figure 2.16.

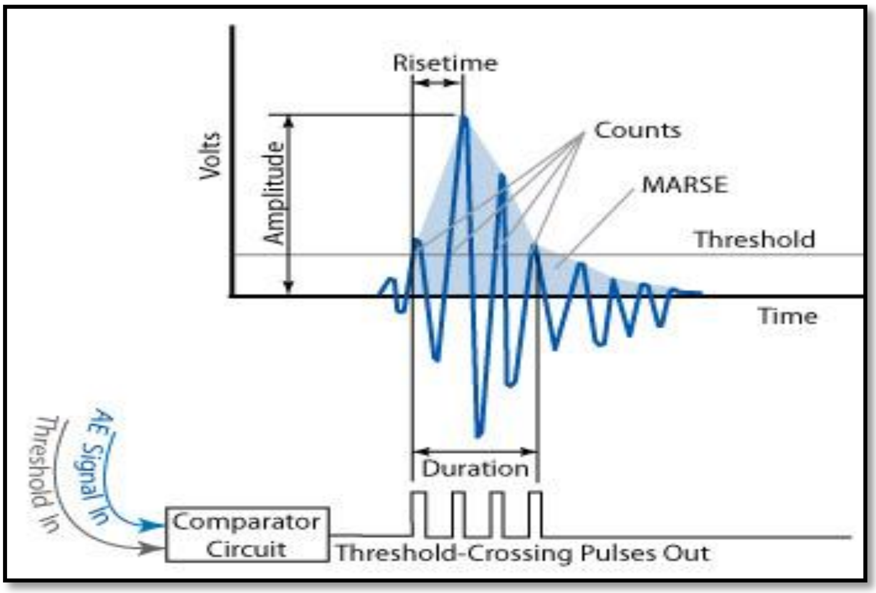

Figure 2.16: Features of transient signals

Source: National Science Foundation 2000

Amplitude, A, is the greatest measured voltage in a waveform and is measured in decibels (dB). This is an important parameter in acoustic emission inspection because it determines the detect ability of the signal. Signals with amplitudes below the operator-defined, minimum threshold will not be recorded (National Science Foundation, 2000).

$$\text{Amplitude, } A = A_o e^{-\beta t} sinwt \quad (2.6)$$

where A_o amplitude of pulse, β is damping of coefficient, w is angular frequency and t is time.

Rise time, R**,** is the time interval between the first threshold crossing and the signal peak. This parameter is related to the propagation of the wave between the source of the acoustic emission event and the sensor. Therefore, rise time is used for qualification of signals and as a criterion for noise filter (National Science Foundation, 2000).

Duration, D**,** is the time difference between the first and last threshold crossings. Duration can be used to identify different types of sources and to filter out noise. Like counts (N), this parameter relies upon the magnitude of the signal and the acoustics of the material (National Science Foundation, 2000).

MARSE, E**,** sometimes referred to as energy counts, is the measure of the area under the envelope of the rectified linear voltage time signal from the transducer. This can be thought of as the relative signal amplitude and is useful because the energy of the emission can be determined. MARSE is also sensitive to the duration and amplitude of the signal, but does not use counts or user defined thresholds and operating frequencies. MARSE is regularly used in the measurements of acoustic emissions (National Science Foundation, 2000). Energy measurement is means squaring the pulse and measure the area under the curve.

$$\text{Energy,}\ E = \int_a^b z(t)^2\, dt \qquad (2.7)$$

Counts, N**,** refer to the number of pulses emitted by the measurement circuitry if the signal amplitude is greater than the threshold. Depending on the magnitude of the AE event and the characteristics of the material, one hit may produce one or many counts. While this is a relatively simple parameter to collect, it usually needs to be combined with amplitude and/or duration measurements to provide quality information about the shape of a signal (National Science Foundation, 2000).

2.5.10 Advantages and Limitations of Acoustic Emission Testing

In contrast with most other NDT methods, AE testing the discontinuity itself is the release of energy, making its own signal (in response to stress). AE testing detects movement (other methods detect geometric discontinuities) (Habegar, 2002).

a) Advantages of AE testing

i. Preservice (proof testing).
ii. In service (requalification) testing.

iii. On-line monitoring of components and systems.
iv. Leak detection and location.
v. In-process welds monitoring.
vi. Mechanical property and characterization.
vii. Material anisotropy is good.
viii. Global monitoring.
ix. Real time evaluation.

b) Limitations of AE testing

i. Repeatability: Acoustic emissions stress unique and each loading is different.
ii. Attenuation: The structure under test will attenuate the acoustic stress wave.
iii. Noise: Acoustic emissions can be subject to extraneous noise.
iv. History: Tests are best performed if the loading history of a structure is known.

2.6 APPLICATION OF ACOUSTIC EMISSION

Acoustic emission is a very versatile, non-invasive way to gather information about a material or structure. Acoustic Emission testing (AET) is applied to inspect and monitor pipelines, pressure vessels, storage tanks, bridges, aircraft, and bucket trucks, and a variety of composite and ceramic components. It is also used in process control applications such as monitoring welding processes. The other examples of AET applications are described as follows (National Science Foundation, 2000):

2.6.1 Acoustic Emission for Laboratory Testing

Acoustic emission inspection is a powerful aid to materials testing and the study of deformation, fracture and corrosion. It gives an immediate indication of the response and behavior of a material under stress, intimately connected with strength, damage and failure. Acoustic emission is used also for monitoring chemical reactions including corrosion process, liquid solid transformations, and phase transformations (National Science Foundation, 2000).

2.6.2 Acoustic Emission in Field Testing

Many codes and standards exist for Acoustic emission testing of vessels, from transportation gas cylinders and railroad tanks to thousands tons storage tanks. Because only active defects and deterioration produce Acoustic emission no time is wasted on inactive defects which are not threatening structural integrity (National Science Foundation, 2000).

2.6.3 Global Monitoring - 100% Inspection of the Structure

A major advantage of Acoustic emission inspection is that does not require access to the whole examination area. E.g. for covering a total area of a 16m-diameter sphere 30-40 sensors are needed. Thus, the cost of the test is significantly less than inspection with conventional NDT methods (for 100% inspection and scanning of the whole area). Identified problem areas can be inspected using conventional NDT methods (National Science Foundation, 2000).

2.6.4 Testing With Insulation and High Temperature Processes

In cases of insulation, only small holes in insulation are required for sensors mounting, resulting in more cost savings. In cases of high temperature processes, wave-guides are used to guide the Acoustic emission waves from the hot surface to the edge where the sensor is mounted (National Science Foundation, 2000).

2.7 REVIEW STUDY OF ACOUSTIC EMISSION IN TENSILE TESTING

The present paper deals with the analysis of the deformation behavior of differently extruded magnesium alloys taken from the AZ series. Rods were extruded using indirect and hydrostatic extrusion which results in a different behavior with respect to mechanical properties and microstructure. In situ measurements of the acoustic emission (AE) during tensile testing of these materials are presented and related to the microstructure of the sample material. The results are discussed with respect to the variations of activated deformation mechanisms and especially twinning during deformation. It was also found during tensile testing by in-situ measuring the AE count rate that a finer grain size leads to an overall decrease in the AE count rate. It was discussed that dislocation glide and twinning are the most important sources for AE and therefore concluded that these deformation mechanisms are reduced in their activity or the fraction of accommodated strain during deformation for a finer grain sized material (Bohlen, et al, 2003).

A set of experiments has been carried out to examine the characteristics of the acoustic emission (AE) generated during tensile deformation of AISI type 304 stainless steels. Two grades of steels nuclear and commercial; and two types of specimens unnotched and notched, have been used in this study. The analysis was done in the following manner. First the average total count for specimens with different thickness and for the specific strain levels was determined. Then the difference in the average values between the two types of specimens and also between the two grades of stainless steels was determined as a function of percentage deviation. The AE total counts obtained in different specimens for specific strain levels have been analyzed by regression analysis approach of data analysis. The results indicate that the AE counts from notched specimens are usually higher than those from unnotched specimens in the nuclear grade steel, unlike the opposite results obtained for the commercial grade steel in the present study and also reported results for other materials. These results have been explained with the help of the different sources of AE in the two grades of stainless steels (Mukhopadhyay, et al, 1998).

The paper review study is about the effect of metal foams during tension by using acoustic emission technique. The high-energy signals and cracks appear at both alloys right after the end of the quasi-linear stage. The comparison of the AE measurements on bulk and foam materials shows that the AE gives information on both the cell edge material (composition and microstructure) and the foam structure. In the case of foams with large pores, the AE activity is much higher than the AE response of the bulk materials, which indicates that the deformation mechanisms are controlled by the structure. In contrast, the foams with small pores exhibit lower and different AE activity suggesting that in this case, the microstructure and the composition of the cell-edge material is more important. The acoustic emission response during tension of saltreplicated aluminum foams of different pore-sizes and different cell-edge materials was recorded and evaluated with respect to the controlling deformation processes. For foams with pore-size of about 3.5 mm, the deformation is controlled rather by the structure (pore-size and cell-edge thickness) and not by the cell-edge material, while for foams with pore-size of about 1.5 mm, the effect of the constitutive material is important (Csilla, et al, 2006).

Flat mild-steel specimen with central and off-center holes were subjected to tensile loading, while simultaneously monitoring their acoustic emissions (AE). The effect of hole diameter and location were studied. A wideband AE sensor (100 kHz -1 MHz) has been used to capture the AE from the specimen. The sensor was attached to the specimen at the center in all the samples. In order to obtain proper acoustic contact, vacuum grease was used at the interface between the sensor and the specimen surface. The sensor was attached to the specimen by means of a C-clamp. The results indicate that AE signals have a strong relationship with load–deflection characteristics, and particularly the yield and ultimate points. Also, the effect of positions of holes on AE signals has been presented. From this study it was conclude that AE events are more frequent between yield and ultimate points and the specimens with holes start emitting AE earlier than those without holes (Sanjay, et al, 2003).

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

Research methodology is one of the most important parts in the making of thesis. The procedure, method, experiment setup, and material selection are necessary to follow to get a good result when experiment is running. Nevertheless, to avoid unnecessary things from happen, American Standard for Testing and Materials (ASTM) has provided the Design of Experiment (DOE) for all the testing and method that have pattern.

This chapter will further describe the study about this research which is Acoustic emission event in tensile test for metallic material. In order to complete the project, methodology is the one of the most important things to be considered. This workflow is needed to ensure that the project can run smoothly and the results are accurate based on what objective needed. In this methodology, there are several steps must be followed, to ensure that the objective of the project can be achieved starting from the literature finding until submitting the report.

Generally this project involved the testing of selected material by using tensile test machine. The Acoustic emission methods will apply during the experiment. The data will collect after completed the experiment. Then it become the important part to analysis and study the correlation of stress strain curve with acoustic emission parameters for each of material used. The steps of the project are briefly explained in shortlisted of the flow chart as shown from Figure 3.1.

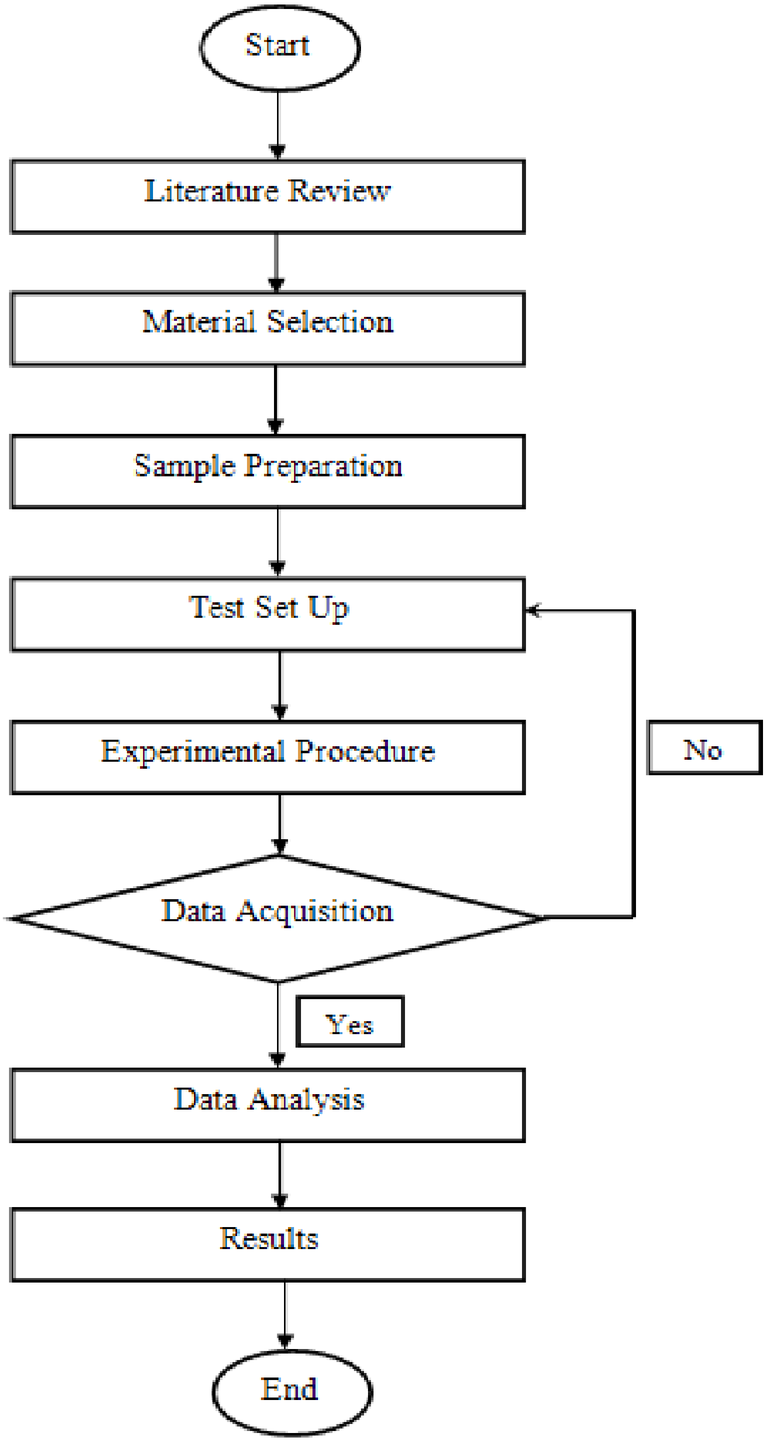

Figure 3.1: Overall project flow chart

3.2 MATERIAL SELECTION

In this study, the material selection is very important part to consider before conduct the experiment. The material selection should not be solely based on cost. The proper material selection technique involves carefully defining the application requirement in terms of mechanical, thermal, environmental, electrical and chemical properties. However the cost for each material to use is too high. Therefore, the best solution is use the existing material in the mechanical laboratory.

According to the scope of this project, there are metallic materials only to be considered to conduct the experiment. These metallic materials are used by different types to obtain the different results. The existing material in the mechanical laboratory was selected with the same thickness of 1mm. They are aluminum, copper, zinc, mild steel and galvanized iron that can be used during the fabrication process. All the existing material from the lab was fabricated as a tensile test specimen by using shearing and stamping process. The selecting materials are listed and shown from Figure 3.2.

Figure 3.2: Selecting of materials. Consist of aluminum, copper, zinc, mild steel and galvanized iron

These materials are categorized by two types of its properties. One of the types is ferrous metals, which is including of mild steels. This material basically contains iron as their base metals. Aluminum, zinc, copper and galvanized iron are categorized as nonferrous metal. All of this material was used with the same dimension for 1mm thickness. However both of this type are commonly used and have a wide variety of desirable properties, such as strength, toughness, hardness, and ductility.

The fabrication process was started with measuring the material into the required dimension needed. This process involved the setting of the dimension with shearing machine as shown in Figure 3.3. The dimension was set in the machine with constant value of width at 29.5mm. These will produce several pieces of materials after the blade cut it into desired length. After cutting all the material, the next process is more focused on specimen preparation which is form it as a tensile test specimen. The fabrication of these pieces of material was done by used stamping machined.

Figure 3.3: Cutting process with shearing machine

3.3 SPECIMEN PREPARATION

The others important part before run the experiment is the preparation of the specimen used. The specimen must follow the standard dimension required to ensure it will conducted properly during the experiment. The sample usually was made into multiple specimens for testing. This project required 3 pieces of specimen for each types of material used. The most specimen used the better results obtained. The sample was made into several pieces because to allow the project can be conducted without any problem and other interfere. If the one of the specimen damaged, it can be replaced by using another perfect specimens.

The dimension of specimen must follow the ASTM standard. Therefore ASTM E8 was selected to produce this specimen. ASTM E8 describes tensile testing methods to determine yield strength, yield point elongation, tensile strength, elongation and reduction of area of metal products. It applies to metallic materials in any form, including: sheet, plate, wire, rod, bar, pipe and tube.

Table 3.1 shows the design and detailed dimension based on ASTM E8 (Rectangular tensile test specimen). The selected design of the specimen was drawn into solid modeling and engineering drawing by using SolidWorks Software. Figure 3.4 shows the top view of rectangular specimen.

Table 3.1: Detail dimension of rectangular tensile test specimen

No.	Item	Dimension (mm)
1	G (Gage length)	50
2	W (Width)	12.5
3	T (Thickness)	1.0
4	R (Radius of fillet)	63.5
5	L (Overall length)	200
6	A (Length of reduced section, min)	57
7	B (Length of grip section)	50
8	C (Width of grip section, approximate)	20

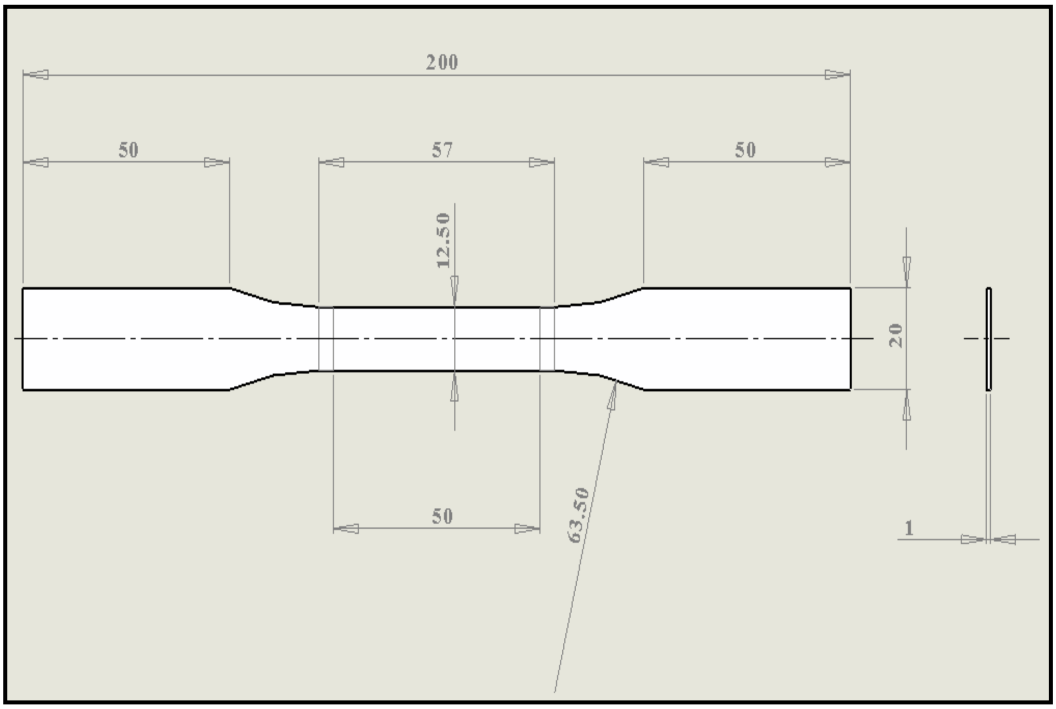

Figure 3.4: Top view of rectangular tensile test specimen. Dimension in millimeter (mm). Modeling by SolidWorks Software

Then the selected material was cut by using stamping machine where the blanking process will completely produce the specimen. This method was choosing because it's easier to used and be able to run. The cavity die also already have in mechanical laboratory. Before conduct the stamping machined, the die cavity was set up first. This process is needed to ensure the upper and lower cavity die stand at the same positioned. After set up was done, the hydraulic button is pressed for testing purposed in order to get the same alignment for die cavity transition.

The fabrication process for the other specimen are repeated and continuously for others materials (copper, zinc, mild steel and galvanized iron). Figure 3.5 shows the stamping machine used to fabricate the specimen and Figure 3.6 shows the sample of galvanized iron specimen after the stamping machine process was done.

Figure 3.5: Stamping machine

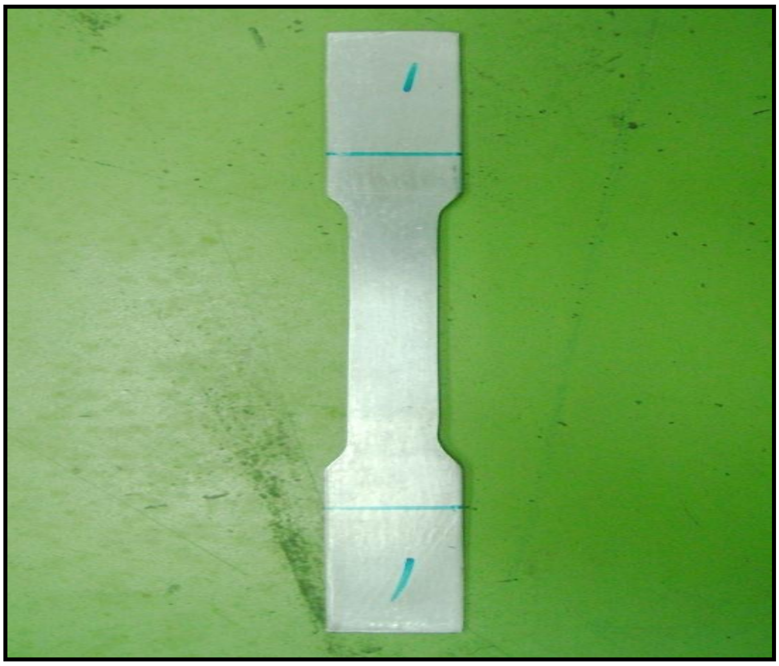

Figure 3.6: Sample of the specimen (Galvanized Iron)

3.4 TEST SET UP

The test set up, requires that equipment be properly matched the experimental procedure. The set up is very important measures before run the experiment. This entire requirement will complete the test to be done properly. The subchapter above will explain detailed the set up process that required before conduct the experiment based on tensile test and acoustic emission technique.

3.4.1 Tensile Test

There are several requirements set up of the tensile testing machine; sufficient force capacity to break the specimen, test preparation and types of grip use before conduct the experiment.

a) Machine used: Instron testing machine was used for this tensile testing method because this machine is suitable especially for sheet metal or flat metal product.

b) Capacity force applied: The force will applied continuously until the specimen break. The maximum capacity load can be done by this machine is 50kN (11,200lbf).

c) Parameter required: Before conduct the experimental several parameters are required to identify, measure and record. The important parameters should be tabled are including their gage length and cross sectional area. The speed movement of the loaded force for this experiment is 2.5mm/min. The results will display as stress versus strain graph after the test done.

d) Types of grip: The most important concern in the selection of gripping method is to ensure that the specimen can be held at the maximum load without slippage or failure in the grip section. The different shape of specimen used, the different types of grip needed. For this experiment (rectangular specimen) the suitable grip was used is serrated wedges.

3.4.2 Acoustic Emission and Data Acquisition

For this experiment, USB Acoustic Emission (AE) Node has chosen to use because it is suitable and can work smoothly with Windows-based personal computer (PC) or laptop to provide completed set up, data acquisition control, real time graphics, and data storage.

The USB-AE Node system has all the performance features, of a larger, more expensive AE system including AE bandwidth, speed, AE features, sampling rates and waveform processing capabilities, all in a compact packaging. Some of the key features of this system include one channel of AE instrument and 4 channel parametric inputs for correlating load or stress with AE activity. Figure 3.7 shows the connection system of USB AE Node unit.

Figure 3.7: USB AE node unit

The data from the computer will evaluate as AE signal processing. All the signals are display as transient AE signal. Mostly the acoustic emission signals that make up this frequency signal occurred by the cracking on the specimen test. Software-based AeWin systems are able to generate variable graphical displays for analysis of the signals recorded during AE inspection. These displays provide valuable information about the detected events for each types of material used.

The signal got from the sensor need to be amplifier before analyzed and apply it to the specimen. The way to checking the sensitivity of the sensor by using the sensor calibration method. A different type of material is different value of threshold to set up. The USB AE Node is a complete, one channel, 18 bit A/D, Acoustic Emission subsystem controlled and operated by a powerful, internal microprocessor, communicating with a PC over a high speed USB 2.0 data connection.

AEwin for USB software allows the viewing and recording of all acquired data using the typical data sets expected of all of full AE system. This including time of hit, hit rise time, hit duration, peak amplitude, counts, energy, waveforms, and parametric data acquisition to name a few. All of the data are saved as a text file by utilize it into ASCII waveform.

The elements of a modern AE instrumentation and design for the whole experiment are shown schematically in Figure 3.8 and they consist of several apparatus and device to set up. The equipments are listed below with detailed explanation of its application.

a) AE sensors: Located at the gage length at the upper side of the specimen and working with frequency range of (20-500) kHz. The type of sensor used is integral preamplifier acoustic emission sensor. This sensor will detect the propagation stress wave and convert the surfaces displacement with the elastic waves into electric signals.

b) Integral preamplifier sensor: Provide gain to boost signals amplitude.

c) Computer data storage: Allows managing all the acquisition, graphing and analysis of the AE system by using “AEwin for USB” AE Node Software version E3.34.

d) Type of couplant: To get more surfaces tough between the sensor surface and the tensile test specimen surface, grease couplant has been use for this experiment.

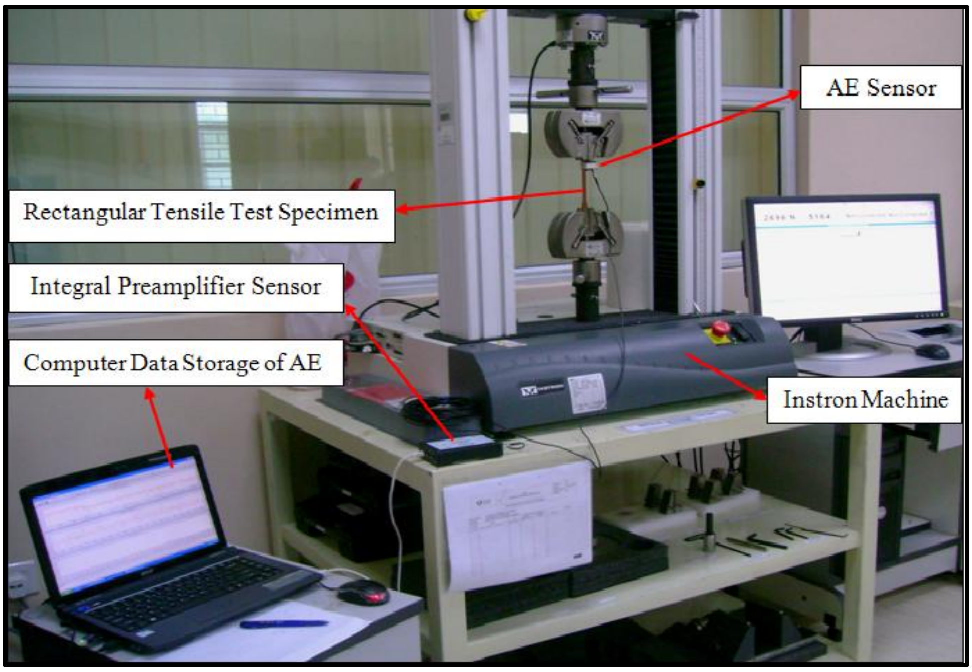

Figure 3.8: Design of whole experiment where tensile testing combined with acoustic emission equipment

Before starting in acquisition the requirements data was measured and recorded into the AeWin software. This parameters set up was set and listed below with some of explanation.

a) Hardware set up: Channel 1.

b) Threshold: This value is depending on the sensor calibration where done by pencil break test for each of material used. The range of thresholds was set for this experiment is between 25dB-40dB meanwhile different materials its different thresholds because the right choice of gain to make sure optimum errors and to get to get the accurate data.

c) Analog filter: The available analog filter values for low and high pass filter is between 20 kHz (lower) and 500 kHz (upper).

d) Sampling frequency: This is the rate at which the data acquisition board samples waveform on a per second basis. The experiment had use sample rate of 5MSPS.

e) Pre-trigger: This value tells the software how long to record (in μsec) before the trigger point (the point at which the threshold is exceeded). It was set that the pre-trigger value in this experiment is 45.

f) Hit length: This determines the size of a waveform message. The length value for this parameter is 1k.

g) Data set parameters: This experiment only required hits, energy, counts and root mean square (RMS) for hit data set.

h) Graphing set up: The display of the graph had selected are hit, count, RMS and energy for y-axis and versus by time for x-axis.

3.5 SENSOR CALIBRATION

As a preparatory stage before using the proposed methodology to detect uneven events in material, using the pencil lead break method, calibration tests were carried out to validate the technique of locating the acoustic sources. The pencil lead break method was employed to generate repeatable amplitudes and frequencies of acoustic burst signals. This method is the most widely used to simulate the AE source where the breaking of a pencil lead pressed against a structural member, as illustrated in Figure 3.9.

When the lead of the pencil with 2H type is pressed against the structural member, the applied force produces a local deformation that is suddenly relieved when the lead breaks. With good technique, it will produce the best resulting of stress wave. The breaking of the lead creates a very short duration, localized impulse that is quite similar to a natural acoustic emission source such as crack. The pencil break test has become so well accepted as a simulated AE source, that in some procedures for wide monitoring, the maximum permissible sensor spacing is based on the ability to detect lead breaking form anywhere in the inspection area.

Figure 3.9: Sensor calibration by using pencil break test

3.5.1 Procedure of Sensor Calibration

a) The 2H lead pencils shall be sharpened to produce a usual conical point.

b) The point of each pencil lead shall be "squared" prior to each test by abrading vertically on the sandpaper, so as to provide a truncated cone shape with a small end at least one half diameter of the lead.

c) The lead is pressed into the surface to be tested at the writing angle (see Figure 3.9). Sufficient pressure is applied in a forward direction to crumble the lead but not enough to break the main piece of lead.

d) Testing should be started with pencil leads of relative softness, applying the next harder grade until the ink film is penetrated before the lead crumbles.

e) The signals from the pencil lead breaks were captured and used as a reference source for experiments.

f) Calibration is done by comparison of results of reference and tested transducer (sensor). Data from this calibration are the same type as from primary, but are more limited (in frequency, absence of shift characteristics, and greater error of calibration).

3.6 EXPERIMENTAL PROCEDURE

After set up and design of the experiment, then the experimental procedure must be followed to ensure the experiment can run smoothly. The specimen is then being test using tensile test with acoustic emission equipment.

3.6.1 Tensile Test Procedure

The tensile load is applied after the all of the parameters set up has done. The experiment must be run using this test to get their strength data. Below show the step by step for tensile test procedure.

a) The "IX series" icon on the computer is twice clicked.
b) The specimen (Aluminum) into the upper grip is given load. The specimen must sure to be straight.
c) "Method" icon is clicked and the specimen parameter and crosshead speed are set.
d) "Test" icon is clicked and sample file name is entered, then operator's name.
e) A test method is choosing according to our application (Tensile, compressive, Flexural, etc).
f) The load and strain is reset.
g) "Start Test" is clicked.
h) When the test finished, the utilities in the main screen is clicked to view the result of the experiment.
i) The stress-strain diagram is saved as graph display.
j) The experiment for the other specimen are repeated and continuously for others materials (copper, zinc, mild steel and galvanized iron).

3.6.2 Acoustic Emission Procedure

a) The “AEwin for USB E3.34” icon on the computer is twice clicked.
b) Layout (.LAY) files is used and selected as a file names.
c) “AE Hardware set up” icon is clicked and AE parameters are set. This parameter including AE channel, threshold, analog filter, sample rate, pre-trigger and hit length value.
d) The “Graph Set up” icon is clicked and variable parameters such as hit, counts, RMS and energy are plotted as a graph display.
e) The “Acquire” icon then is clicked. The icon shaped like a traffic light with the green light showing indicating that AEwin is ready to go into acquisition.
f) “Start” icon is clicked. The system is now in data acquisition and is collecting and displaying it on the graphs.
g) When the test finished, the data is utilize by clicking “Utilization” icon.
h) Then “ASCII Waveforms” icon is clicked and the raw data is saved on the folder based on layout file location.
i) The experiment for the other specimen are repeated and continuously for others materials (copper, zinc, mild steel and galvanized iron).

3.7 DATA ANALYSIS

After the test and investigation has finished, the raw data was analyzed as the final results of acoustic emission parameters. When reading the value, MATLAB® Software was used to analysis the data into the others form. This software is suitable for data logging and easy uploading to PC, with real time graphics, windows base. The important information such sample rate and hit data length was define before start simulate this raw data.

Then the data is loaded by replace each name of data file and the software has use the data to plot the graph of amplitude versus frequency and amplitude versus time. The coding was developed to simulate the text file data and it shows as below.

```
load Steel2_1_1_5831901.txt;                    (load data)
Data=Steel2_1_1_5831901;                        (change name)

Fs=5000000;                                     (sampling rate)
N=1024;                                         (value of hit length)
T=1/Fs;                                         (period)
t=[1/Fs:1/Fs:N/Fs];                             (time discrete)

plot(t,Data);
xlabel('Time(s)');
ylabel('Amplitude(V)');
title('Data 1');

FA=fft(Data);                                   (convert to fast Fourier transform)
A=abs(FA);                                      (absolute fast Fourier transform)
A1=A(1:512);                                    (one side of fast Fourier transform)
W=[Fs/N:Fs/N:Fs/2];                             (frequency discrete)

figure
plot(W,A1);
xlabel('Frequency(Hz)');
ylabel('Amplitude(V)');
title('Data 1');

RMS=sqrt(mean(Data).^2)                         (display of root mean square)
Energy=trapz(abs(Data))                         (display of energy)
Maximum_Amplitude =max(Data)                    (display of maximum amplitude)
```

After simulate it, the important value of frequency, RMS, energy and maximum amplitude is recorded and tabled. The acoustic emission parameters to be measure from the analysis are:

a) The count of data hit each types of the material.

b) The energy emitted each types of the material.

c) The RMS value each types of material.

Then the analysis continued by comparison each of material used. All the material must have the different value for its energy emit and location of crack. The counts of acoustic emission are also different for each type of materials.

The discussion of the results is based on the scope and the objective of this investigation. The graphs are displayed together with stress versus time in order to correlate this distribution. Figure 3.10 show the example of graphing for aluminum specimen based on energy value where plotted together with stress versus time.

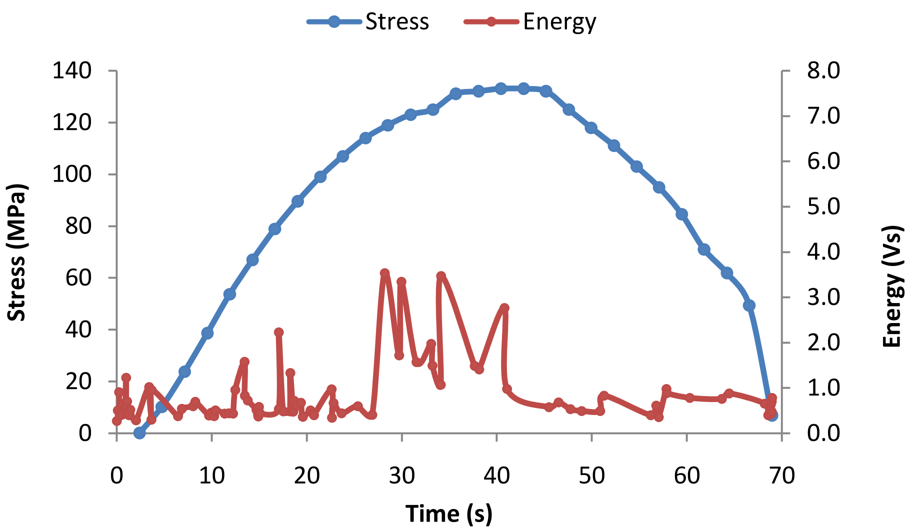

Figure 3.10: Correlation of stress and energy versus time for aluminum specimen

CHAPTER 4

RESULT AND DISCUSSIONS

4.1 INTRODUCTION

This chapter discuss about the result obtained from the experiment of tensile testing with acoustic emission method. The objective of the project is to conduct tensile test for metallic material and measure of Acoustic Emission (AE) signal parameters. The objective also requires studying correlation between the stress-strain curves with Acoustic Emission (AE) event based on tensile test for different metallic materials. The results were discussed for each of material used by selecting the best and accurate sample of experiment test. The graph has plotted based on the data analysis where appeared on Appendix C.

As mentioned on previous chapter, several acoustic emission parameters will discuss and relate it with the distribution of stress strain curve. The parameters are including the number of data hit detected of the signal amplitude, RMS value and energy released for each of the material used. The parameters also are easier to understand and explained by showing the graph of the results below. All of these parameters are plotted against time and the graph plotted by different types of material used. The discussion also will explain about the possible error occurred during the experiment and problem exist in the selection of the material.

4.2 MATERIAL STRENGTH PROPERTIES

After done the analysis of the raw data, there are different value for each types of material strength where shows on Table 4.1. The strength of the specimen was described as the ability of the material to withstand an applied stress without failure. Based on the table, galvanized iron shows the higher of its ultimate tensile strength at 379MPa different than aluminum where shows the minimum value of ultimate tensile strength which is at 133.1MPa. However mild steel can withstand long period of time because it reaches higher maximum of elongation at value of 24.83mm. Each of the material shows the different values for its yield strength, ultimate tensile strength and maximum extension. Each type of material shows a closely value and the results are not away for each of specimen used.

Table 4.1: Material strength properties based on tensile testing experiment

Material	**Test specimen**	**Yield strength YS, (MPa)**	**Ultimate tensile strength UTS, (MPa)**
Aluminum	Test 1	106.2	115.3
	Test 2	123.1	133.1
	Test 3	107.5	116.6
Copper	Test 1	193.8	219.5
	Test 2	189.6	216.9
	Test 3	193.8	219.5
Zinc	Test 1	165.2	240.4
	Test 2	168.2	245.1
	Test 3	162.5	241.5
Mild Steel	Test 1	230.5	309.6
	Test 2	224.2	310.5
	Test 3	212.4	294.8
Galvanized Iron	Test 1	200.8	379.6
	Test 2	340.3	368.1
	Test 3	297.2	373.7

4.3 RESULTS BASED ON AEWIN SOFTWARE

The results obtained from the software are plotted together with different of acoustic emission parameters. This acoustic emission parameter was set in the software before run the experiment, there are including the number of hit, counts, RMS and energy value. All of these parameters were plotted against time and each of material used was shows the different values of time recorded. The sample results of aluminum shows from Figure 4.1. The time taken to complete the tensile testing for this sample is 68s. The number of data hit detected from this software is 93.

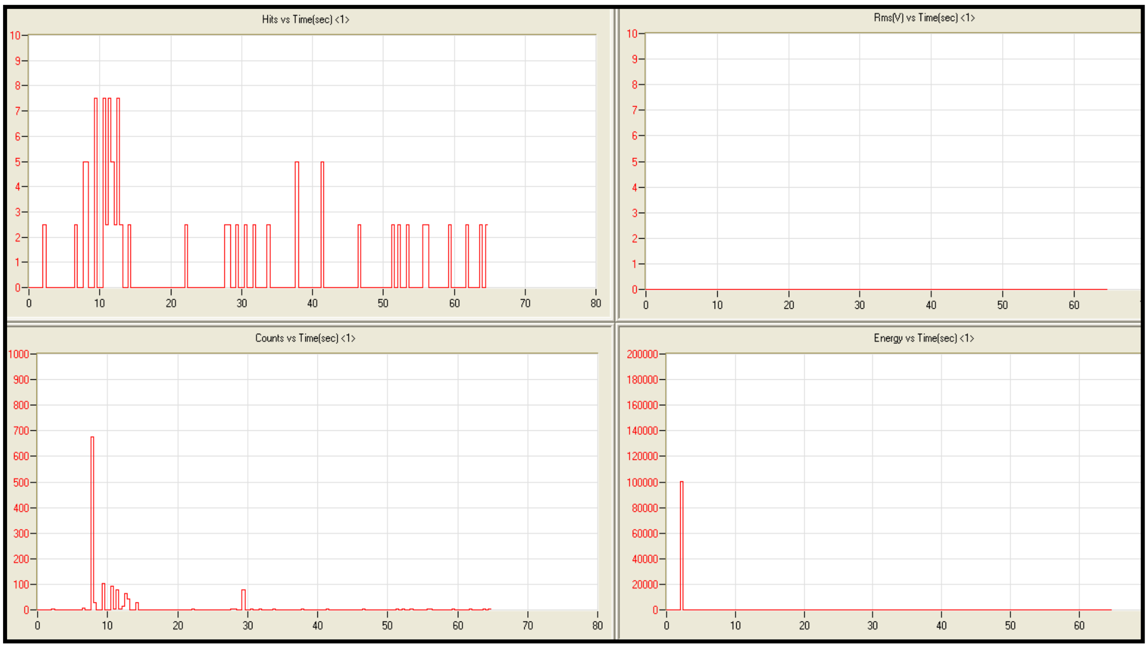

Figure 4.1: Result based AEwin software for aluminum

For copper material, it was shows that the loading profile for its acoustic emission parameter is different than aluminum sample. The time taken during the activity of acoustic properties is 360s and the number data hit recorded is 168. The result for this material was shows from Figure 4.2.

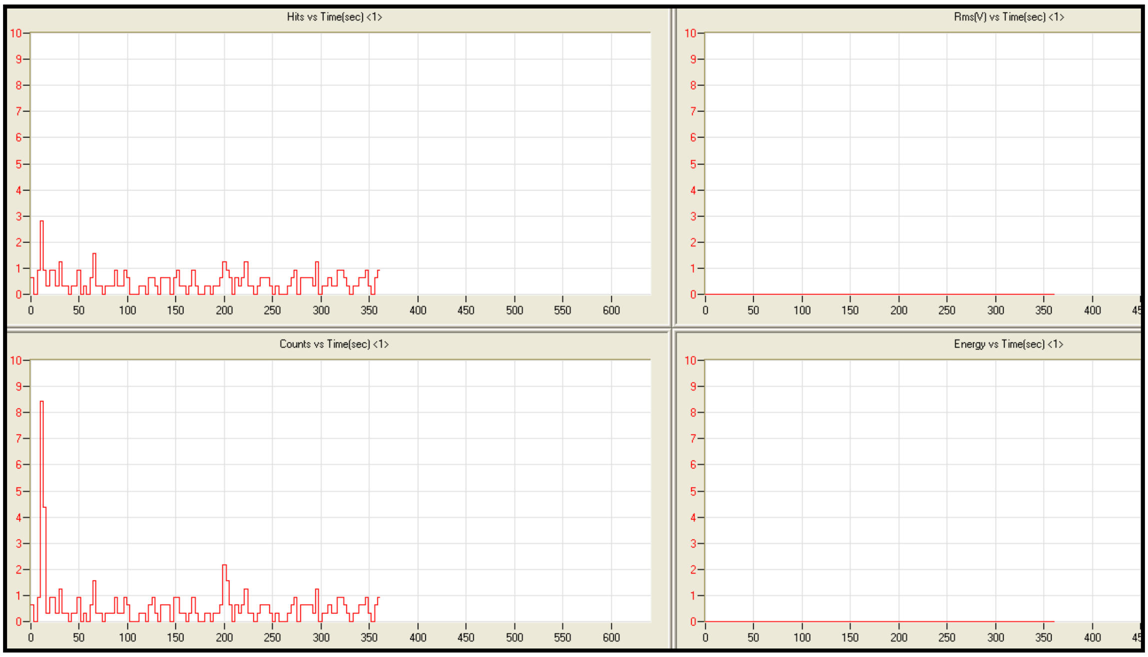

Figure 4.2: Result based AEwin software for copper

Figure 4.3, shows the results of zinc based on AEwin software. The time taken for this material is 200s which is lower than time taken by copper. It has a less number of data hit detected which is at 10 hit.

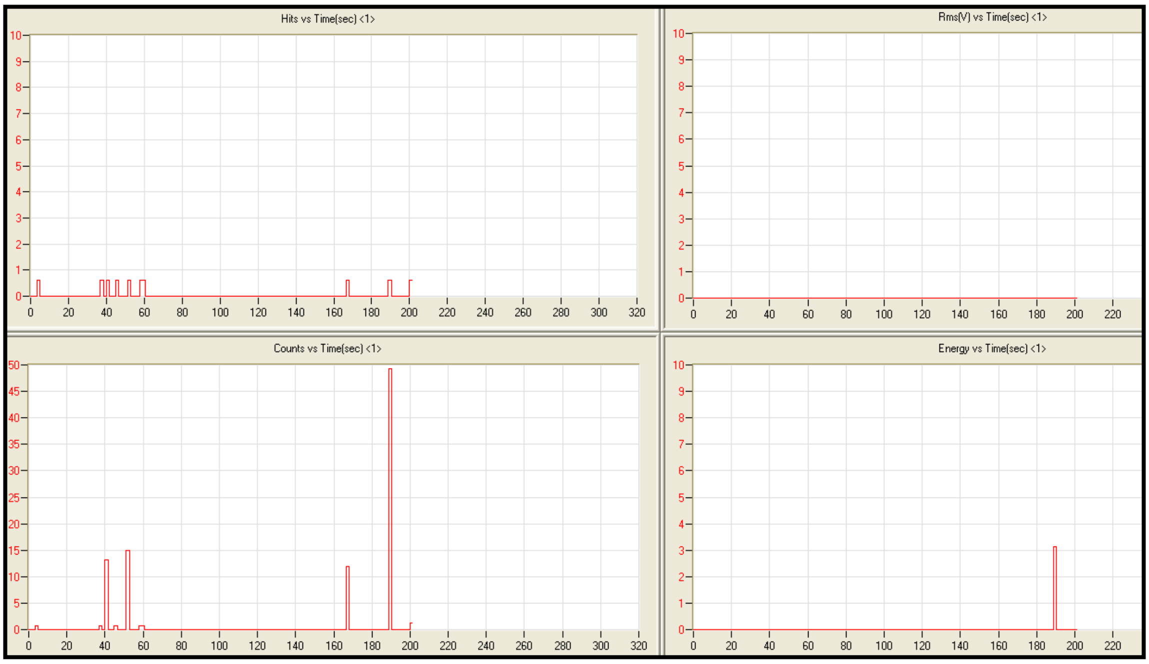

Figure 4.3: Result based AEwin software for zinc

From Figure 4.4, it was shows that mild steel take a higher of time taken after its complete the tensile test process which is at 432s. The time taken for this material is higher than the time taken for others material. The number of data hit detected is 26.

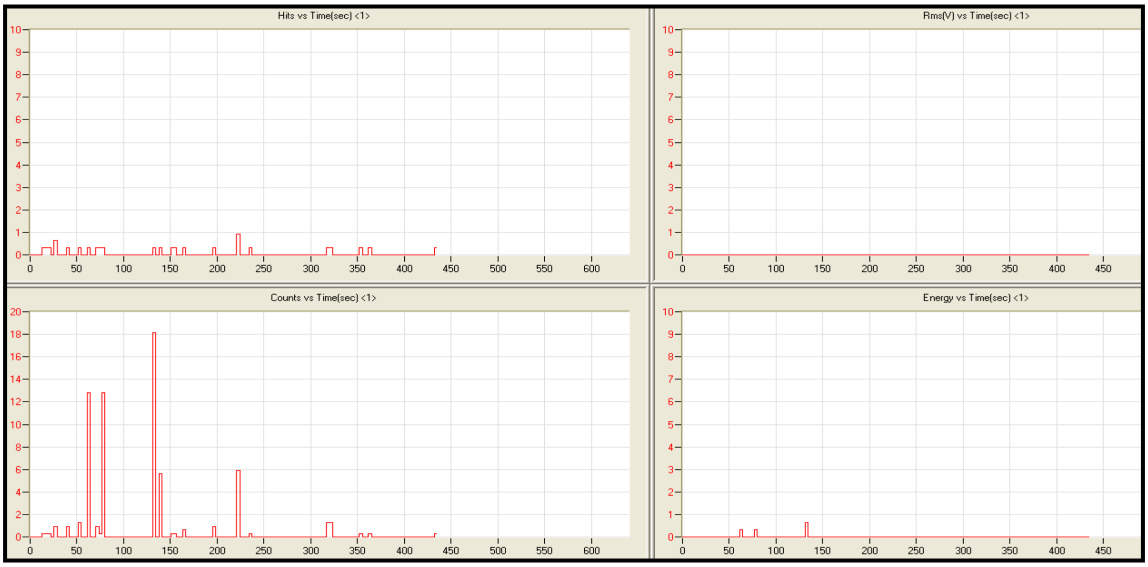

Figure 4.4: Result based AEwin software for mild steel

Figure 4.5, shows the results of galvanized iron. The time taken for this material is 384s which is higher than time taken by others material. It also had higher of data hit detected which is at 487 point.

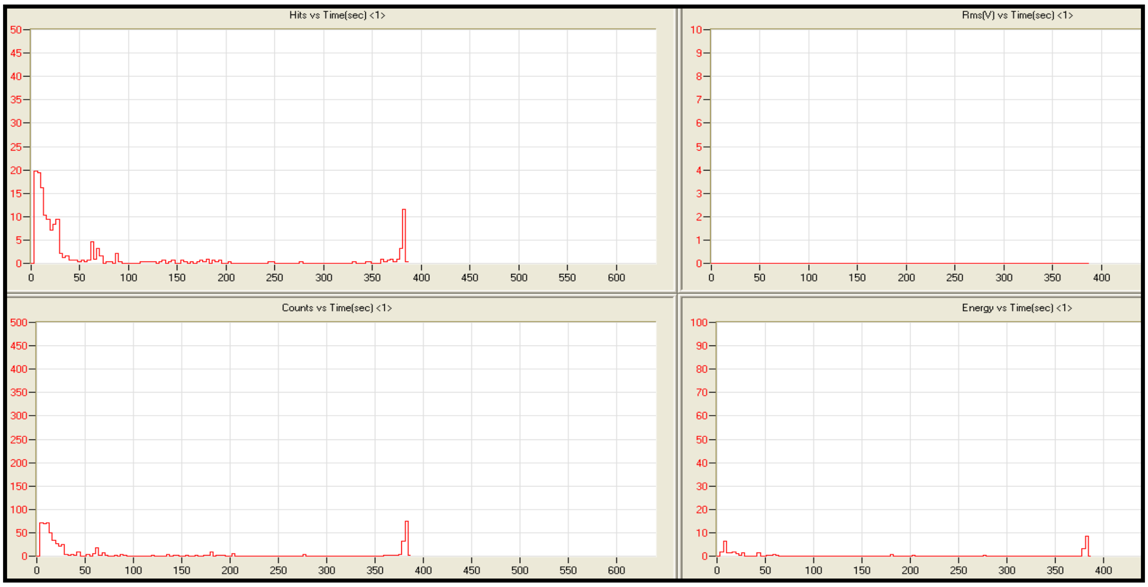

Figure 4.5: Result based AEwin software for galvanized iron

4.4 ACOUSTIC EMISSION SIGNAL OF ELASTIC AND PLASTIC REGION

There are two types of acoustic emission signals were analyzed during the analysis of the raw data. The signals are represented as amplitude and frequency versus by time. The important signals, where needed to analyzed is a transient signals. This signal represent by amplitude against time. The maximum frequency value in the elastic region is higher than maximum frequency at plastic region. This is because each of materials obtained different properties of its mechanical strength which is different stages elongation such brittle and ductile material after tensile testing. When the load is applied, the specimen elongates in proportion to the load; this behavior is called linear elastic region. The plastic region describes the deformation of a material undergoing non-reversible changes of shape in response to applied forces. Both of these regions were discussed and shows from the subchapter below.

4.4.1 Signal of Acoustic Emission for Ductile Material

The signals were differentiate by its region which is at elastic and plastic region. Brittle fracture is characterized by rapid crack propagation with low energy release and without significant plastic deformation. The fracture may have a bright granular appearance. Brittle materials have undergone very little strain when they reach their elastic limit, and tend to break at that limit.

a) Elastic Region

Figure 4.6 shows the example signal of acoustic emission parameters of aluminum material for amplitude versus time. Figure 4.7 shows the graph of amplitude versus frequency. The signals were taken from the third number of raw data hit. The maximum value of frequency on this region is 156.30 kHz.

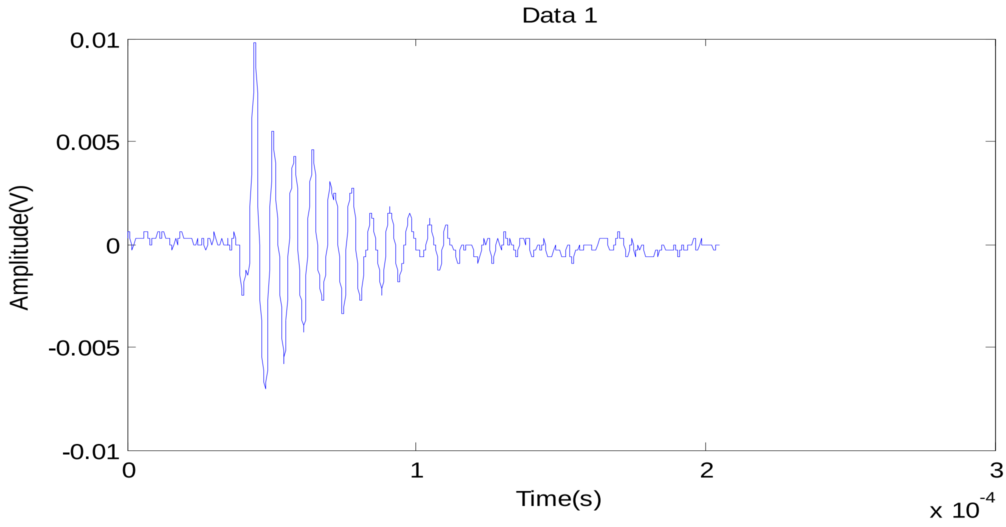

Figure 4.6: Amplitude versus time for elastic region of aluminum

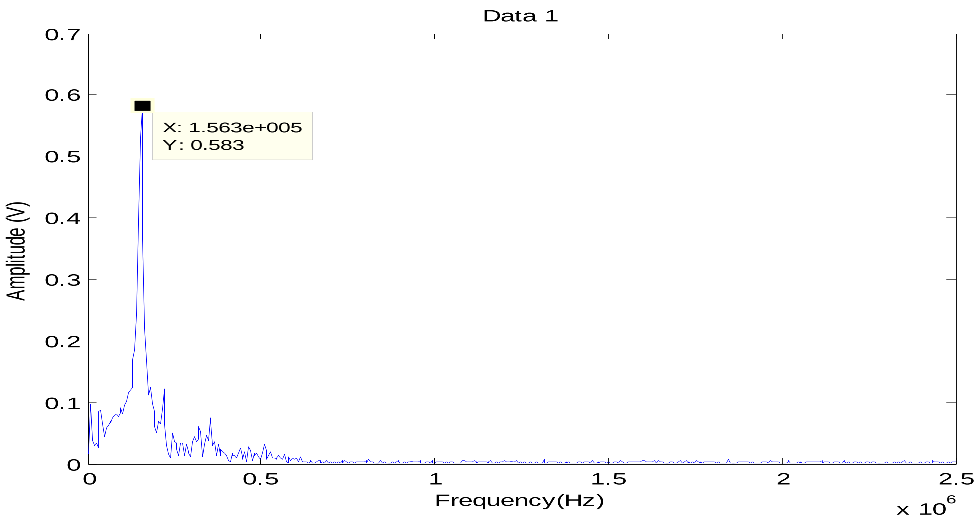

Figure 4.7: Amplitude versus frequency for elastic region of aluminum

b) Plastic Region

Figure 4.8 shows the example signal of acoustic emission parameters of aluminum material for amplitude versus time. Figure 4.9 shows the graph of amplitude versus frequency. The signal was obtained during the deformation of tensile testing at plastic region. The raw data hit number was taken is at 87. It was shows that the frequency obtain is 4.88 kHz which is lower than frequency at elastic region.

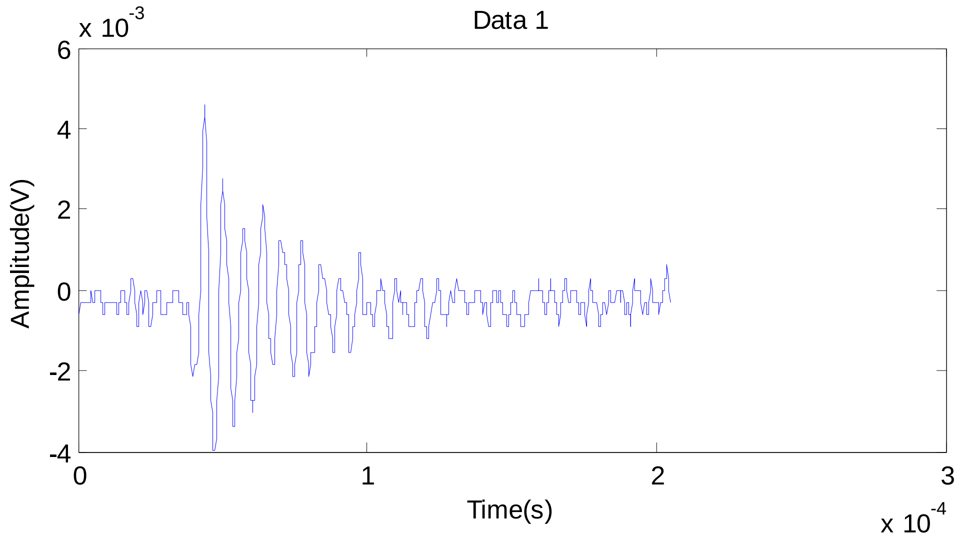

Figure 4.8: Amplitude versus time for plastic region of aluminum

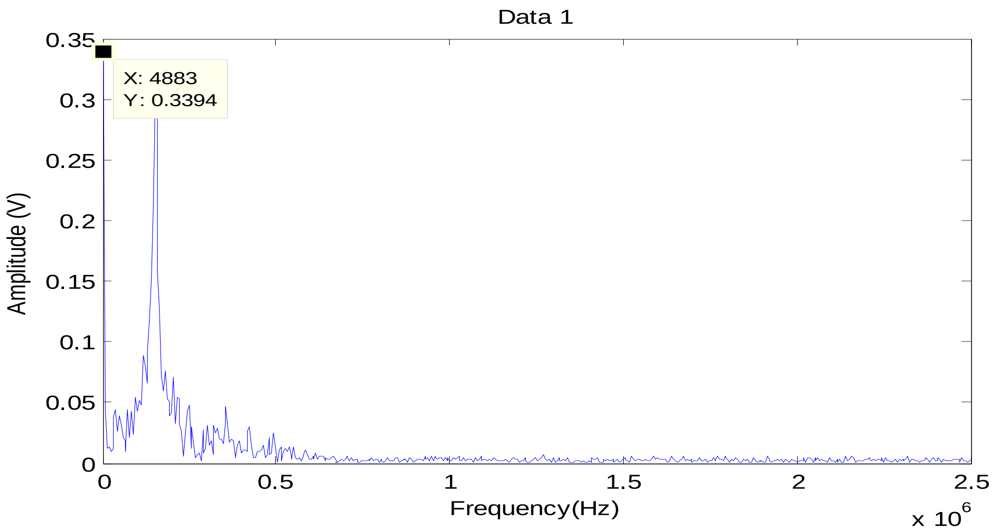

Figure 4.9: Amplitude versus frequency for plastic region of aluminum

4.4.2 Signal of Acoustic Emission for Brittle Material

The signals also were differentiate by its region which is at elastic and plastic region. Ductility is a mechanical property that describes the extent in which solid materials can be plastically deformed without fracture. Tensile strength examines how far the material can stretch without breaking.

a) Elastic Region

Figure 4.10 shows the example signal of acoustic emission parameters of galvanized iron material for amplitude versus time. Figure 4.11 shows the graph of amplitude versus frequency. The signals were taken from number 56 of raw data hit. At this elastic region, the frequency recorded of this material is higher than plastic region which is at 283.20 kHz.

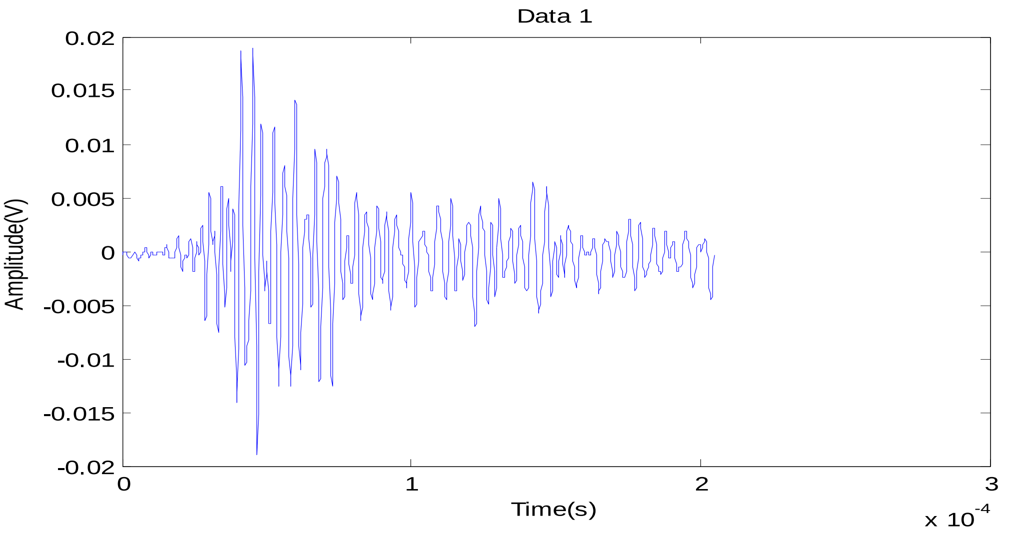

Figure 4.10: Amplitude versus time for elastic region of galvanized iron

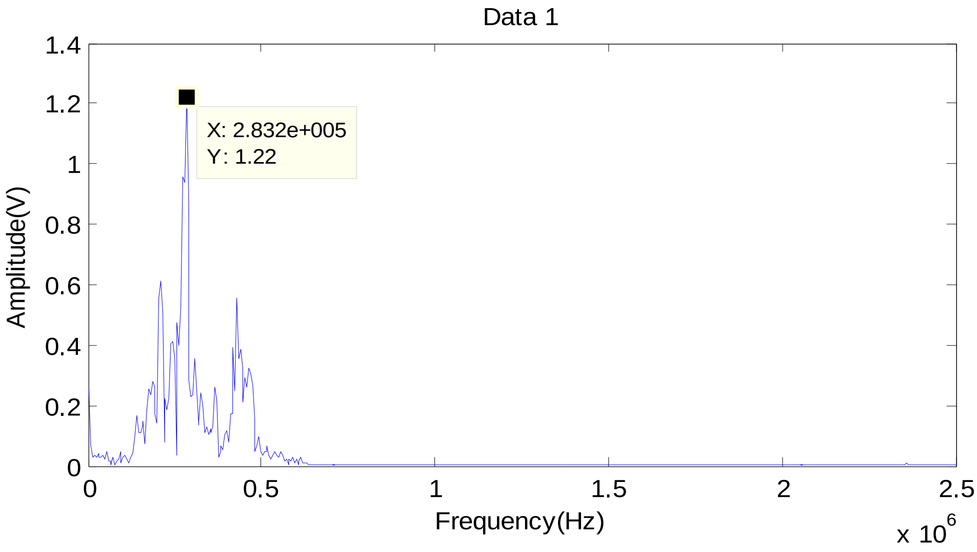

Figure 4.11: Amplitude versus frequency for elastic region of galvanized iron

b) Plastic Region

Figure 4.12 shows the example signal of acoustic emission parameters of galvanized iron material for amplitude versus time. Figure 4.13 shows the graph of amplitude versus frequency. The raw data hit was taken is at number of 439. It was shows different value of frequency range at this region which is at 146.50 kHz. This frequency is lower than frequency at elastic region.

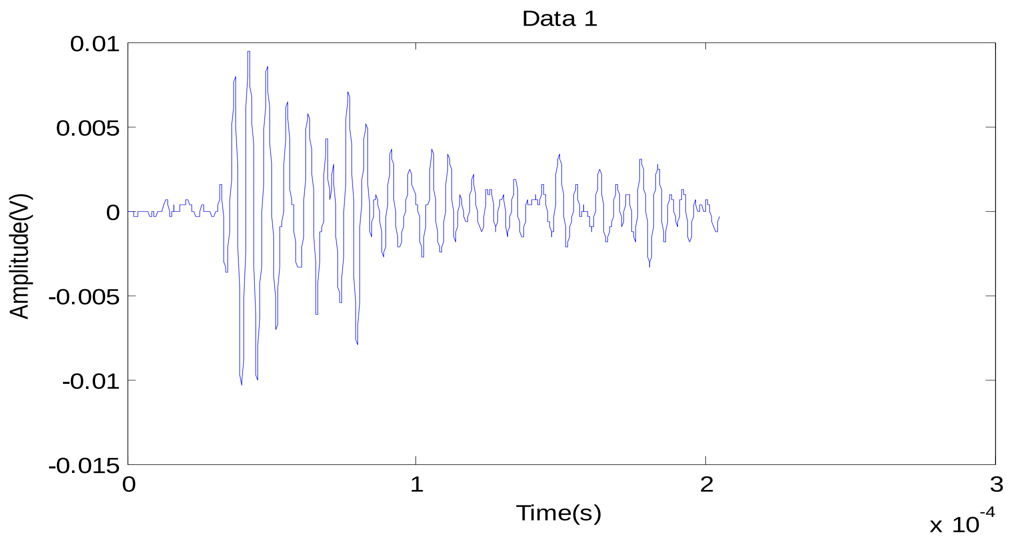

Figure 4.12: Amplitude versus time for plastic region of galvanized iron

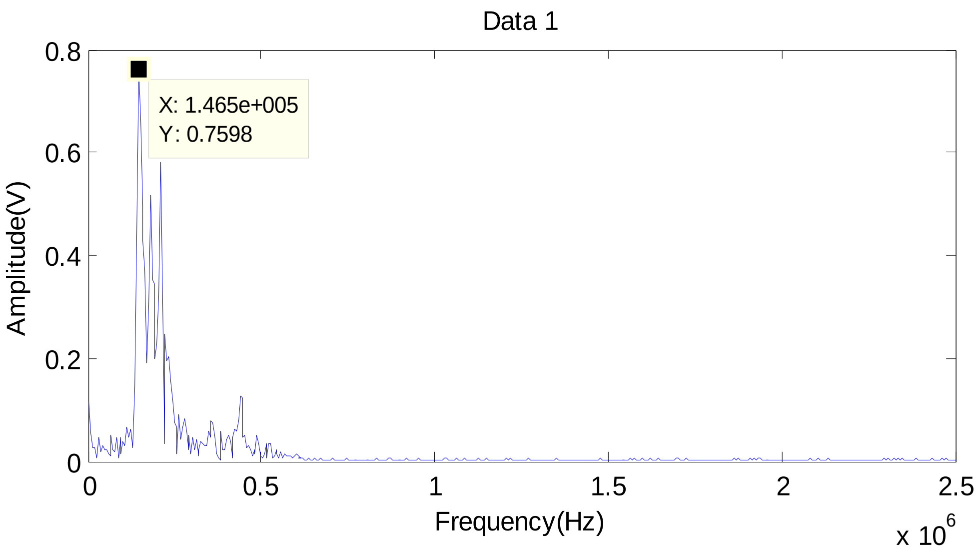

Figure 4.13: Amplitude versus frequency for plastic region of galvanized iron

4.5 CORRELATION OF ACOUSTIC EMISSION PARAMETERS WITH TENSILE TEST PROPERTIES

This subtopic above will further study and analysis on the graph distribution of stress strain curve with acoustic emission parameters. The graphs of stress against time are plotted together with number of data hit, RMS, and energy value. The accurate and smooth graphs for each of sample test are selected and discussed as below.

4.5.1 Aluminum

The best sample of aluminum specimen was selected and the graphs are plotted as shown from Figure 4.14. The figure shows the stress versus time for the blue color and data hit value for the red color. The number of data hit recorded for this material is 93. From the graph, the distributions of data hit number are more occurred at elastic region than the plastic region. The time taken after the specimen fracture is 68s. According to the Table 1, the value of yield strength of this aluminum is 123.1MPa and the ultimate tensile strength is 133.1MPa.

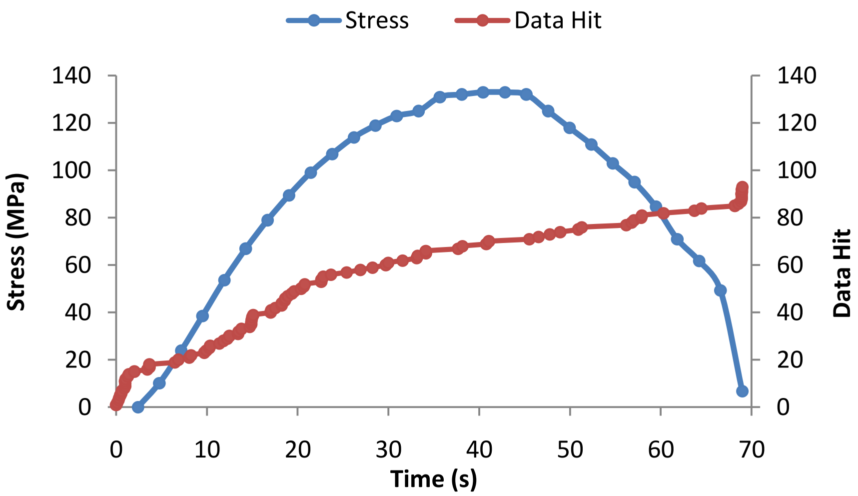

Figure 4.14: Stress and data hit versus time for aluminum

The Figure 4.15 shows the same stress distribution of aluminum versus time. The red color is the graph of RMS value that occurs during the loading of this specimen. It was shows that, the maximum RMS value for this material is 0.00132V. Most of its value is higher between yield and ultimate tensile strength. The value of RMS is too small in a range between (0.00001V to 0.00132V).

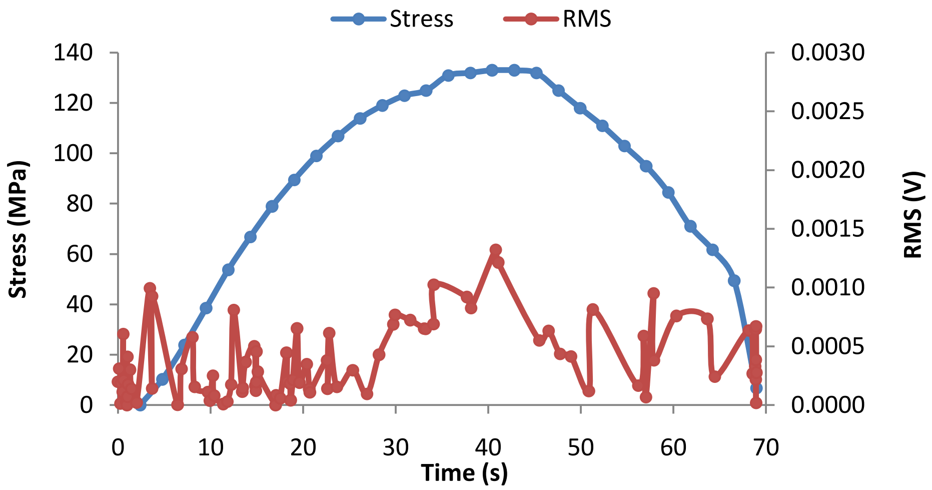

Figure 4.15: Stress and RMS versus time for aluminum

From the graph on Figure 4.16, it shows the distribution of energy emitted during the loading of the specimen. The graph also plotted together with the stress against time distribution. The higher energy released is 3.53110Vs and most of it occur between the yield and ultimate tensile strength. The graph shows that AE energy is too low at the first loading and at the end of the phase.

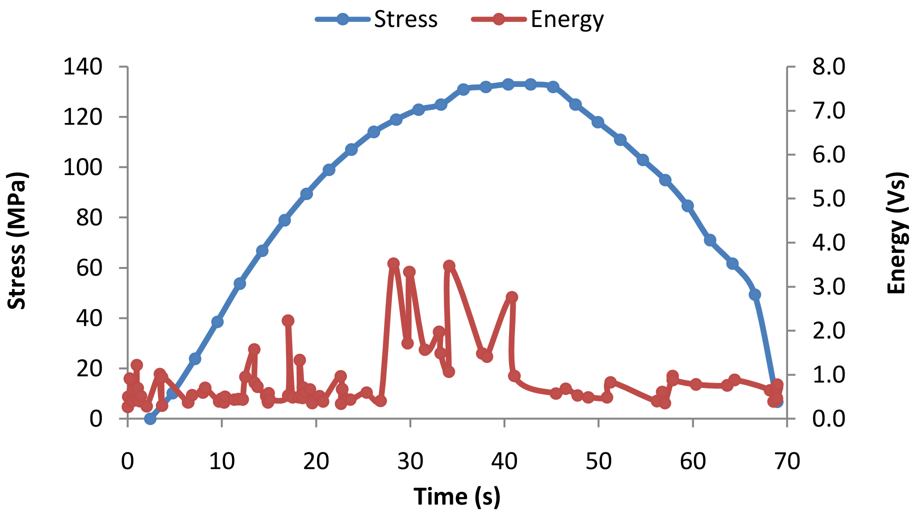

Figure 4.16: Stress and energy versus time for aluminum

4.5.2 Copper

The sample of copper from Figure 4.17 shows the accurate data distribution based on its hit, RMS and energy value. The distribution of data hit number is more occurred during the loading deformation. The maximum number of data hit is 168 and this material takes 360s before fracture. From the stress graph, it shows that the yield strength and ultimate tensile strength occurs at 193.8MPa and 219.5MPa. The sample can reaches its maximum strength based on its ultimate tensile strength which is at 219.5MPa.

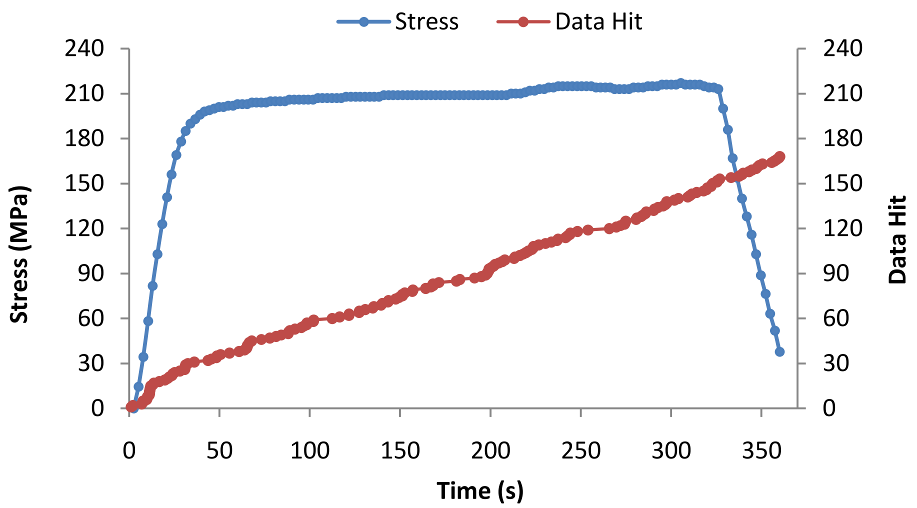

Figure 4.17: Stress and data hit versus time for copper

Figure 4.18 shows the same stress distribution of copper versus time. The red color shows the graph of RMS value. It was shows that, the maximum RMS value for this material is 0.00227V. Most of this RMS value occurred along of the tensile loading and its reaches the maximum value between yield and ultimate tensile strength. This value of RMS is too small in a range between (0.00001V to 0.00227V). The AE activity was start at the beginning of the loading of the material and it increase after the elastic region phase. Then the value of RMS decreases in constant distribution during unloading phase before the specimen fracture.

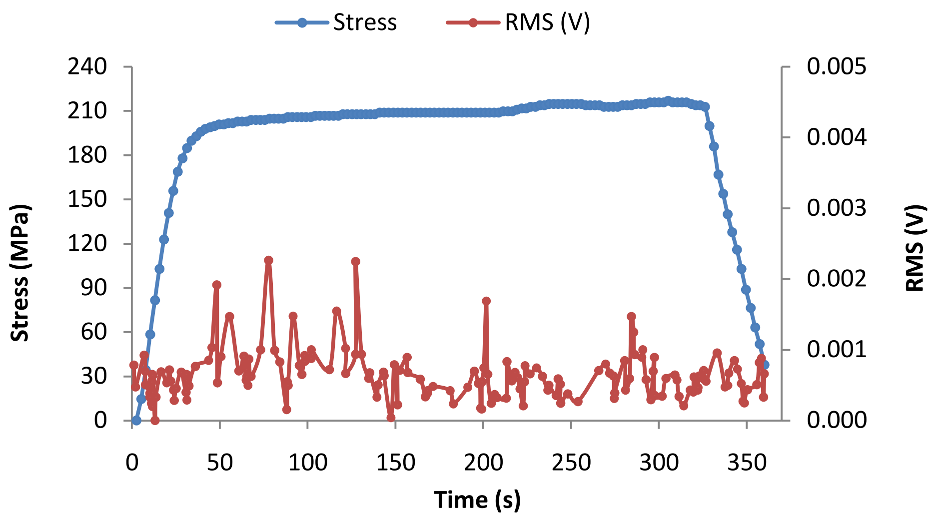

Figure 4.18: Stress and RMS versus time for copper

From the graph on Figure 4.19, it shows that most energy emitted during the loading of the specimen and occurred between the yield and ultimate tensile strength. The higher energy reaches its maximum value at 2.6880Vs. The region shows that AE energy value is too low at the first loading and increase in the beginning of yield strength phase. The distribution of energy emitted is closely similar and the values sometimes rise and fall with uneven distribution. Then the energy was decreases after it reaches ultimate tensile strength phase.

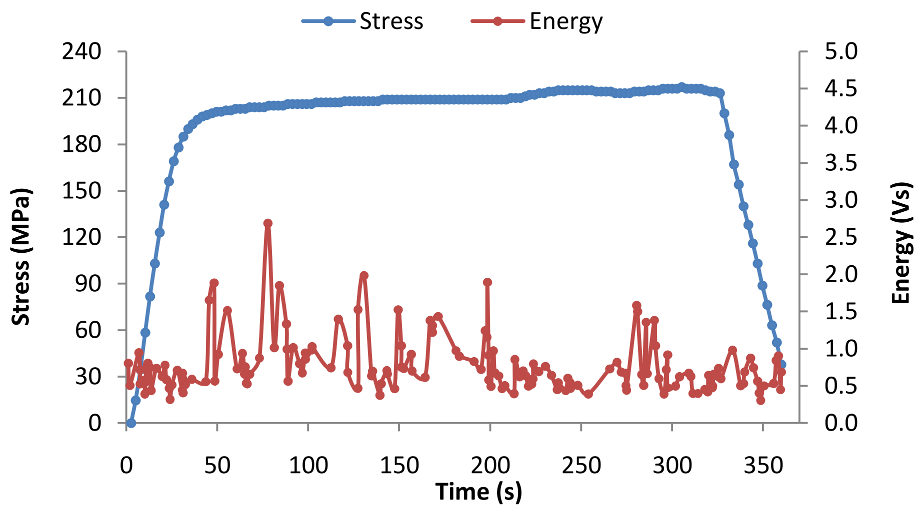

Figure 4.19: Stress and energy versus time for copper

4.5.3 Zinc

The best sample of zinc was selected and the graphs are plotted as shown as Figure 4.20. The graph shows the distribution of stress versus time for the blue color and number of data hit for the red color. The amount of data hit for this specimen consists of 10 and most of the hit distribution occurred during the elastic region. The time taken after this material fracture is 200s. According to the Table 1, the value of yield strength and ultimate tensile strength is 165.2MPa and 240.4MPa.

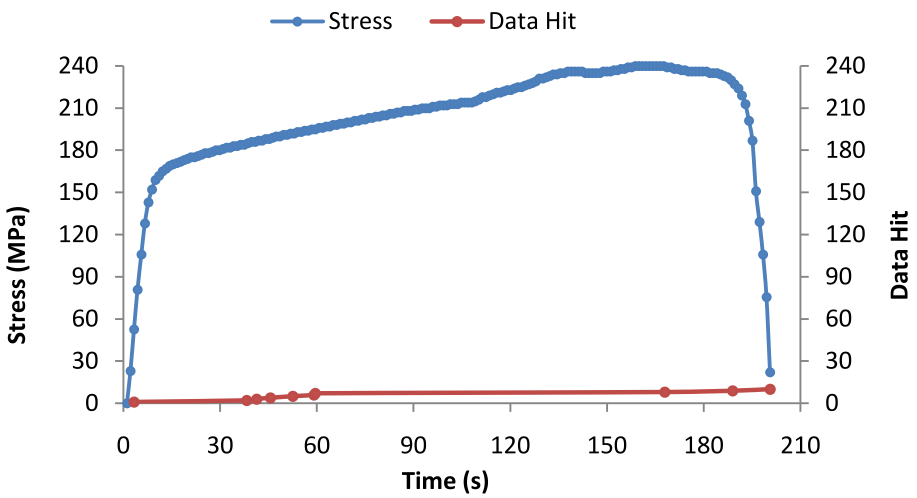

Figure 4.20: Stress and data hit versus time for zinc

The Figure 4.21 shows the same stress distribution of zinc versus time. The red color is the graph of RMS value that occurs during the loading of this specimen. It was shows that, the maximum RMS value for this material is 0.00041V and it also occurred between yield and ultimate tensile strength. The RMS value is also too small in a range between (0.00006V to 0.00041V). The AE activity is too low and almost zero. The RMS value is increase when it reaches the yield strength level, and then it decreases at the middle of the graph before decreased again after reaches the ultimate tensile strength level. The RMS value is still frequent at this phase of yield strength and ultimate tensile strength.

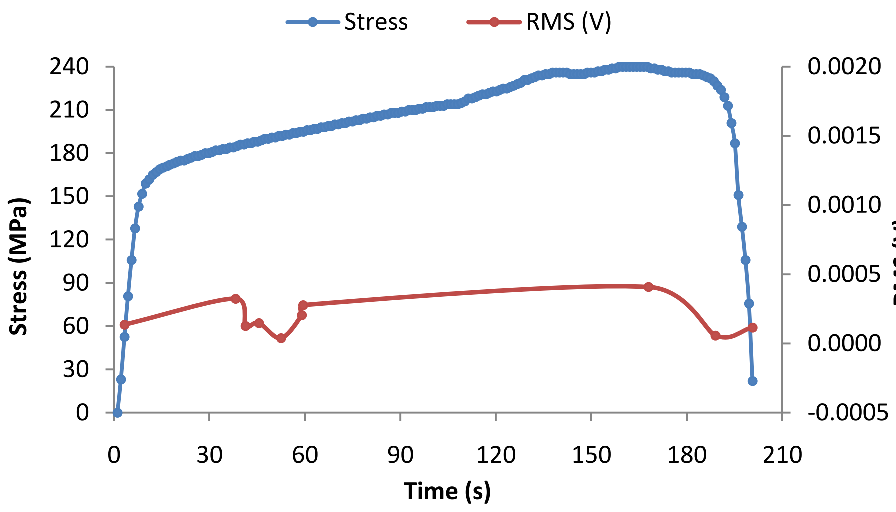

Figure 4.21: Stress and RMS versus time for zinc

From the graph shows on Figure 4.22, the energy emitted during the loading of the specimen is represented by the red color. The higher energy released is 11.11070Vs and it occurred at ultimate tensile strength before the specimen necking. The region shows that AE energy value is too low at the first loading but it increase during the loading at yield strength until ultimate tensile strength. Then the energy value was decrease before the specimen fracture.

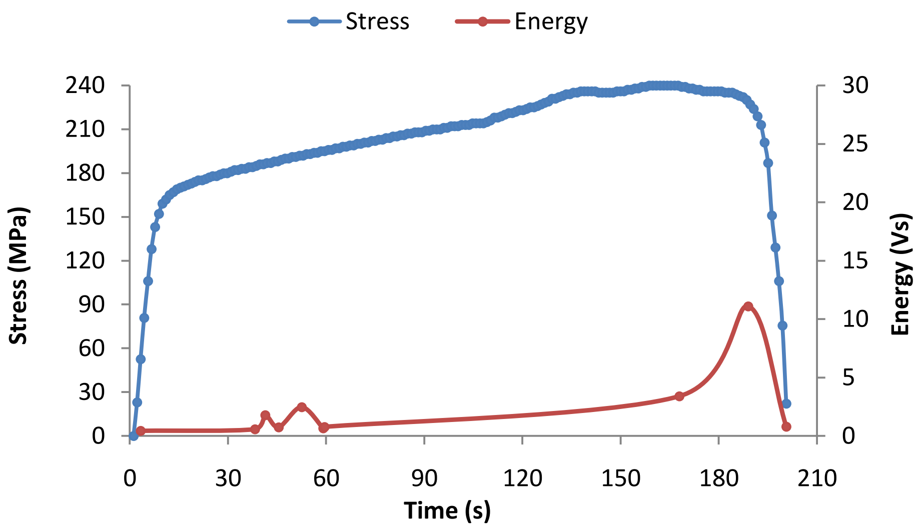

Figure 4.22: Stress and energy versus time for zinc

4.5.4 Mild Steel

Figure 4.23 shows the graph of stress and data hit distribution versus time where represented by blue and red color. The number of data hit distributed from the acoustic emission testing is 26. The time taken to complete the tensile test process is 430s. Based on the graph, the distributions of data hit number more occurred at the first loading phase. Then the hit detected most occur at the middle of the elastic region. The data hit distribution is less detected during the necking of the specimen. From the Table 1, the value of yield strength and ultimate tensile strength is 212.4MPa and 294.8MPa.

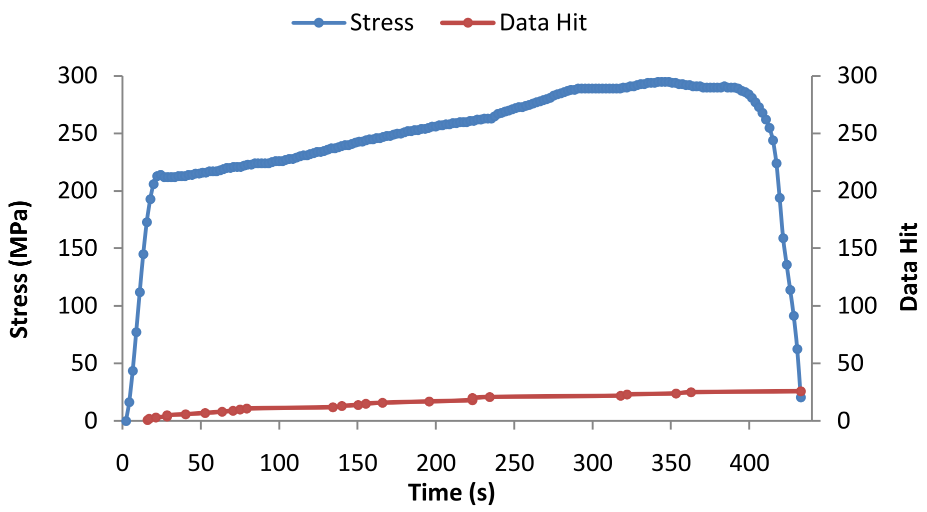

Figure 4.23: Stress and data hit versus time for mild steel

Figure 4.24 shows the same stress distribution of mid steel versus time. The red color is the graph of RMS value that occurs during the loading of this specimen. It was shows that, the maximum RMS value for this material is 0.00048V. The values are higher between the yield and ultimate tensile strength. However the RMS value is too small in a range between 0.00001V to 0.00048V. The AE activity is also too low and almost zero. The distribution of the RMS value seems scattered along the profile loading of tensile test.

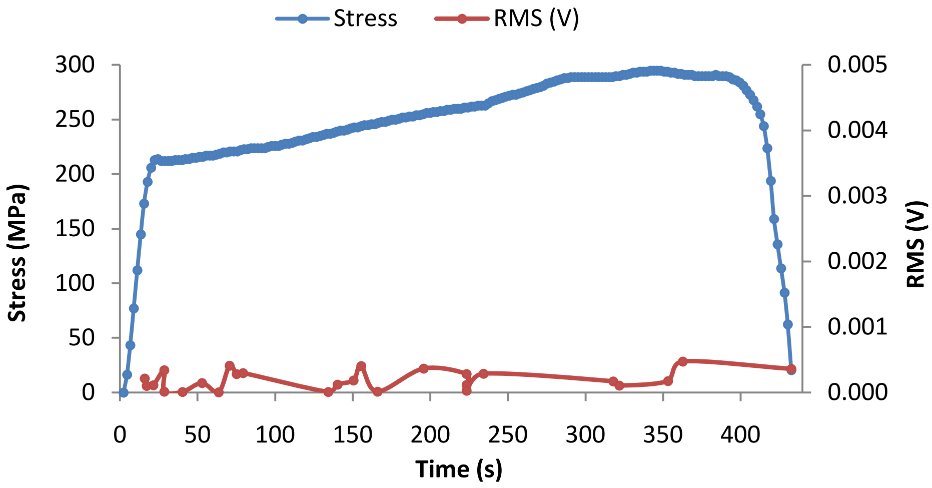

Figure 4.24: Stress and RMS versus time for mild steel

From the graph on Figure 4.25, it was shows that most energy emitted during the loading of the specimen occurs between the yield and ultimate tensile strength. The higher energy reaches its maximum value and released at 5.6029Vs. The region shows that AE energy value is too low at the first loading and increase in the beginning of yield strength phase. Then it increases randomly until reaches the maximum value of energy at the middle of yield and ultimate tensile strength. Then the energy decreases rapidly and constant at the medium of the plastic region.

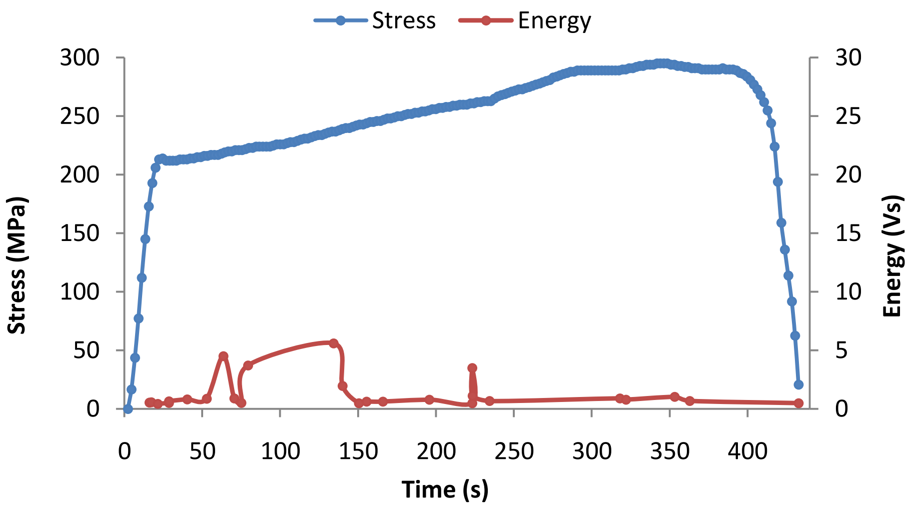

Figure 4.25: Stress and energy versus time for mild steel

4.5.5 Galvanized iron

The best sample of galvanized iron was selected and the graphs are plotted as shown from Figure 4.26. The figure shows the graph of stress versus time for the blue color and data distribution hit value versus time for the red color. The data hit reaches its maximum value at 487. As shown from the graph, the distribution of the data hit number most occurred at elastic region. The distribution then less of it data hit number where occurred at the end of plastic region. The maximum time taken of this galvanized iron to fracture is 384s. According to the Table 1, the value of yield strength of this sample is 200.8MPa and the ultimate tensile strength is 379.6MPa.

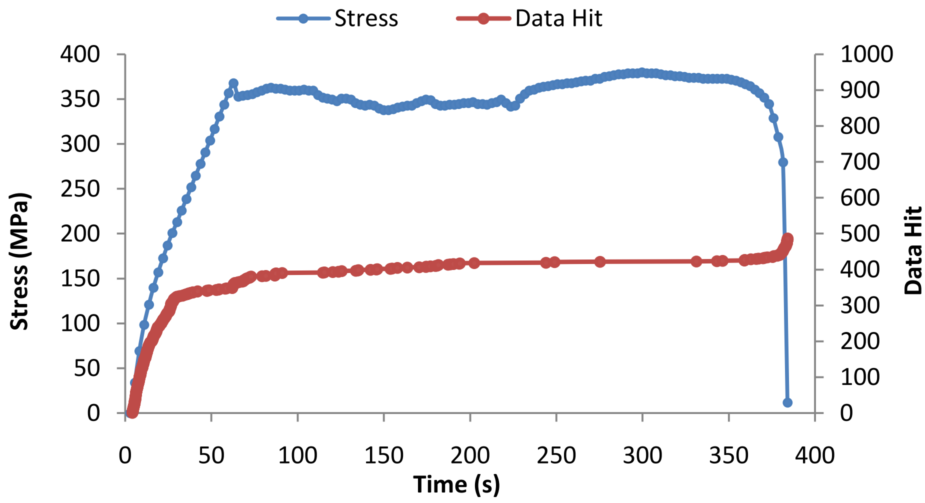

Figure 4.26: Stress and data hit versus time for galvanized iron

The Figure 4.27 shows the same stress distribution of galvanized iron versus time. The red color is the graph of RMS value that occurs during the loading of this specimen. It was shows that, the maximum RMS value for this sample is 0.00191V and it occurred after the yield strength level at time 69.49s. The RMS value is too small in a range between 0.00001V to 0.00191V. AE activity is also too low and almost zero. Most AE activity also occurred at first phase of loading and at the end of the unloading specimen.

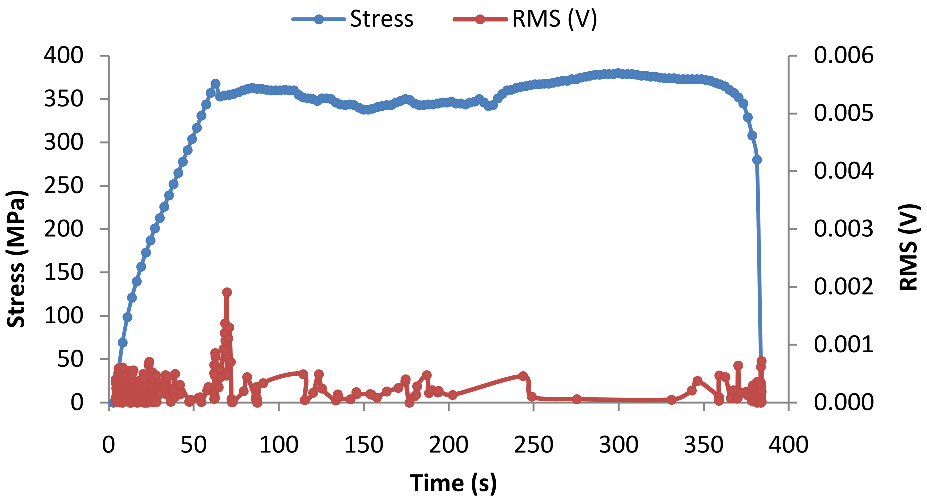

Figure 4.27: Stress and RMS versus time for galvanized iron

From the graph on Figure 4.28, it shows the distribution of energy emitted during the loading of the specimen. The higher energy released occurred at the first of elastic region and at the end of plastic region. However this value is not counted for this analysis, because most of energy frequent at yield strength and ultimate tensile strength. Material only released energy during the deformation of its structure. So that the higher energy emit from this testing is 9.2842Vs.

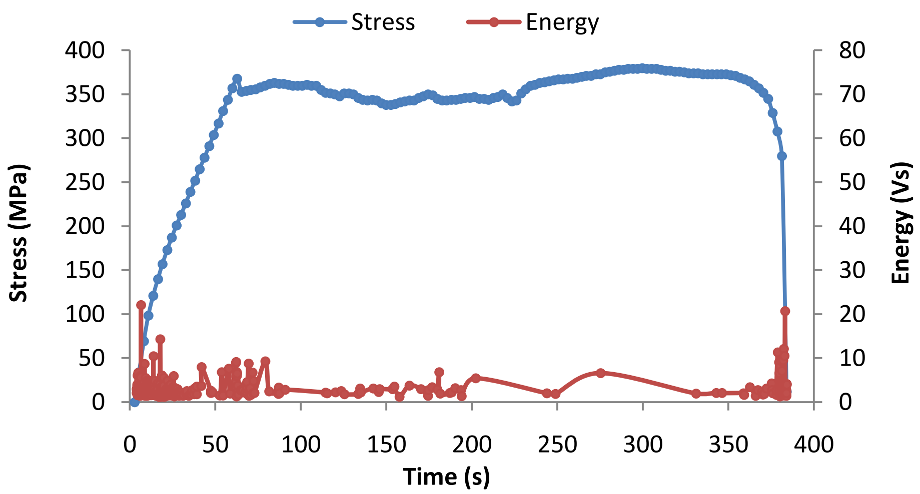

Figure 4.28: Stress and energy versus time for galvanized iron

4.6 DISCUSSION

This subchapter will discuss the overall analysis of the project based on the graph for each of material used. The correlation between the stress strain curves with Acoustic Emission (AE) event was described as below.

a) The amount of data hit is more frequent at elastic and plastic region. This was proved by the entire of the graph for each of material used. As the stress strain curves build its region there will produce more data hit until the machine of tensile testing done. The amount detection of data hit also effected with the types of material used. Some of the information of AE is immediate but some of it is delayed. Delayed deformation of nonmetallic materials is quite familiar (Drouillard, et al, 1996).

b) According from the all graph of RMS versus time, it was shows that the AE activity is almost zero for the RMS value. Each of the material was show the minimum value at a range between 0.00001V- 0.00227V. Based on the experiment the specimen thickness was used is too small which is at 1mm. This was effected the AE activity and counts to be low as obtained from the results. AE total count generated up to any strain level increases monotonically with increase in the specimen thickness irrespective of type of specimen and nature of material (Mukhopadhyay, et al, 1998).

c) There was an energy emitted from all of the material used. However the amount of this energy value also is too small. The highest energy was released occurred at galvanized iron and the smallest energy released at aluminum. This energy released along the deformation of the tensile test specimen. Energy emitted more frequent between yield strength ultimate tensile strength. Acoustic emission is generated during tensile deformation by the very rapid release of transient energy from the localized sources such as regions of relaxation of stress and strain fields (Mukhopadhyay, et al, 1998).

4.7 THE PROBLEM ENCOUNTERED

This chapter is mainly about the problems encountered during the whole project, and it has been carried out to discuss for further recommendation. This chapter also will discuss the unwanted results of the project where concluding all the process that involved. There are two main problems during the project and was described as below.

a) Material preparation - Very hard to find the suitable material because the material at (UMP) Mechanical Lab is limited amount to used. The rules to get some materials are very tight and entail more procedure. The material also hard to find and some of the part for this project also need a budget to buy it. The preparation also must follow the schedule to make the project done at the time. The existing tensile test specimens in Material Testing Lab are only used for student practice for Engineering Materials subject. The specimen also are limited quantity to be used for others purpose especially for final year project. The diversity types of the material also are not enough to fulfill the objectives of the project. There are only brass, mild steel and aluminum that been provided to the student. So that other types of material required a fabrication process in order to produce a tensile test specimen before running the experiment.

b) Unexpected results - According to the Figure 4.29, it was shows that the energy is emit at the first AE was start. This is because some vibrations occur when specimen starts given a load. The sensitivity of the acoustic emission sensor is higher because it can detect any noise or jolt during the loading of the specimen. This situation also effect at the last phase after the specimen fracture. At this point, the energy was emit very high differ value between yield strength and ultimate tensile strength. This value should be ignoring as encountered and unexpected results. It was shows from the graph below where tagged by the circle at the first and last phase of the energy distribution.

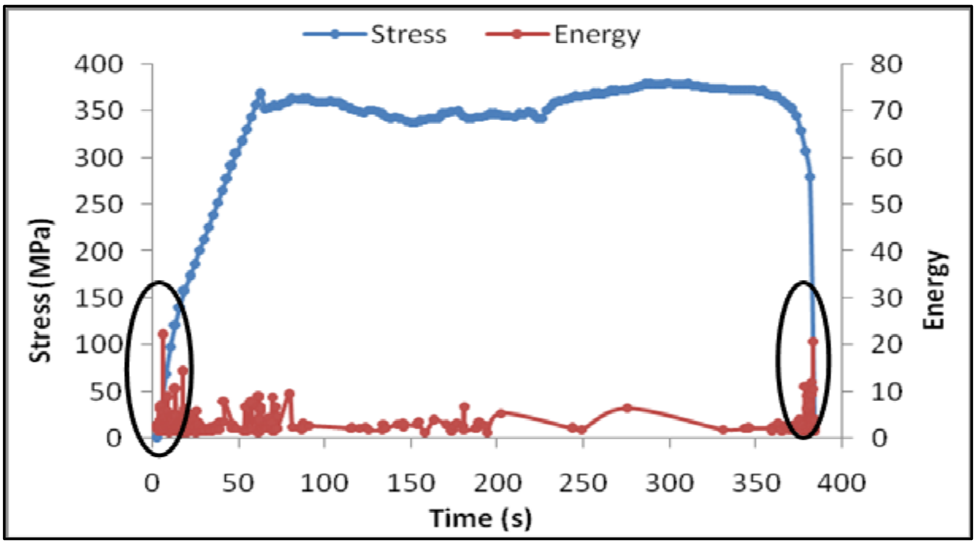

Figure 4.29: Unexpected results. Sample taken from galvanized iron

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 INTRODUCTION

This chapter will conclude the research and briefly discussed about the recommendation that can applied for the future work. The conclusion were done according to the result obtain in Chapter 4. In order to study the acoustic emission parameters based on tensile test, other aspects of future work also will be discussed.

5.2 CONCLUSION

There are several factors that affecting the results of acoustic emission parameters where based on tensile testing method. These factors are types of material used, material properties and the material thickness. By using these different factors it will result the different acoustic emission parameters such as number of data hit, counts, RMS and energy value. The stress strain diagram also was become different if these different factors are applied. However most of this metallic material produced a higher distribution of data hit RMS and energy value between the yield and ultimate tensile strength. Based on the results obtained for each of material used there was a different value of acoustic emission parameters.

Based on material properties, it was shows that galvanized iron is more hardness than others material used. Galvanized iron has their ultimate tensile strength at higher value which is at 379.6MPa, followed by mild Steel (310.5MPa), zinc (245.1MPa), copper (219.5MPa) and aluminum (133.1MPa). It was proved that galvanized iron can held more load at higher of its tensile strength. Galvanized iron also more toughness than others material because it reaches the maximum amount of energy during the elongation of the material. The energy can absorb before fracturing, which is different from the amount of force that can be applied. Toughness tends to be small for brittle materials, because elastic and plastic deformations allow materials to absorb large amounts of energy. Materials whose properties are different in different directions (because of an asymmetrical crystal structure) are referred to as anisotropic.

The strength of aluminum properties had place at a low level. This was demonstrated by evaluating the ultimate tensile strength obtained from the stress strain curve. The value of its yield strength and ultimate tensile strength is low than others material. During the deformation of the material, aluminum is getting less of acoustic emission activity than others material. The time taken to finished the deformation of this material also less than others material. Aluminum only achieved 68s to complete the tensile testing process. The amount average of its RMS value also almost to zero. The materials also had a lower of total energy released than others material. This can be proved because aluminum has a very low of its maximum elongation values. The maximum extension value is 2.54mm.

All the hypothesis are achieved from the study and several conclusions could be drawn from this study are:

a) All the material have a different types of properties, it was show the different stress strain curve after the experiment.
b) From the stress-strain curve, the softer material is more plastic behavior compared than hardness materials.
c) AE events are more frequent between yield and ultimate points. This happen at the crack location where it will emits higher event of acoustic emission.
d) At higher stress location, at higher event of acoustic emission occurred.
e) The higher the ductility of materials, the more energy will be released.

5.3 RECOMMENDATIONS

For the future work in order to study the Acoustic emission parameters based on tensile test for metallic material, the following aspect could be taken into consideration:

a) Comparing the results with other type of material such as alloy or composite material.
b) Use different types of thickness by several types of material.
c) Use the different testing type of tensile machine such a compression method.
d) Determine the others parameters of acoustic emission such as power, count, amplitude, frequency and correlate it with stress strain curve.
e) Comparing the results among different type of mechanical testing such fatigue and torsion application.
f) Comparing the results from tensile deformation of notch and unnotched of tensile test specimen.

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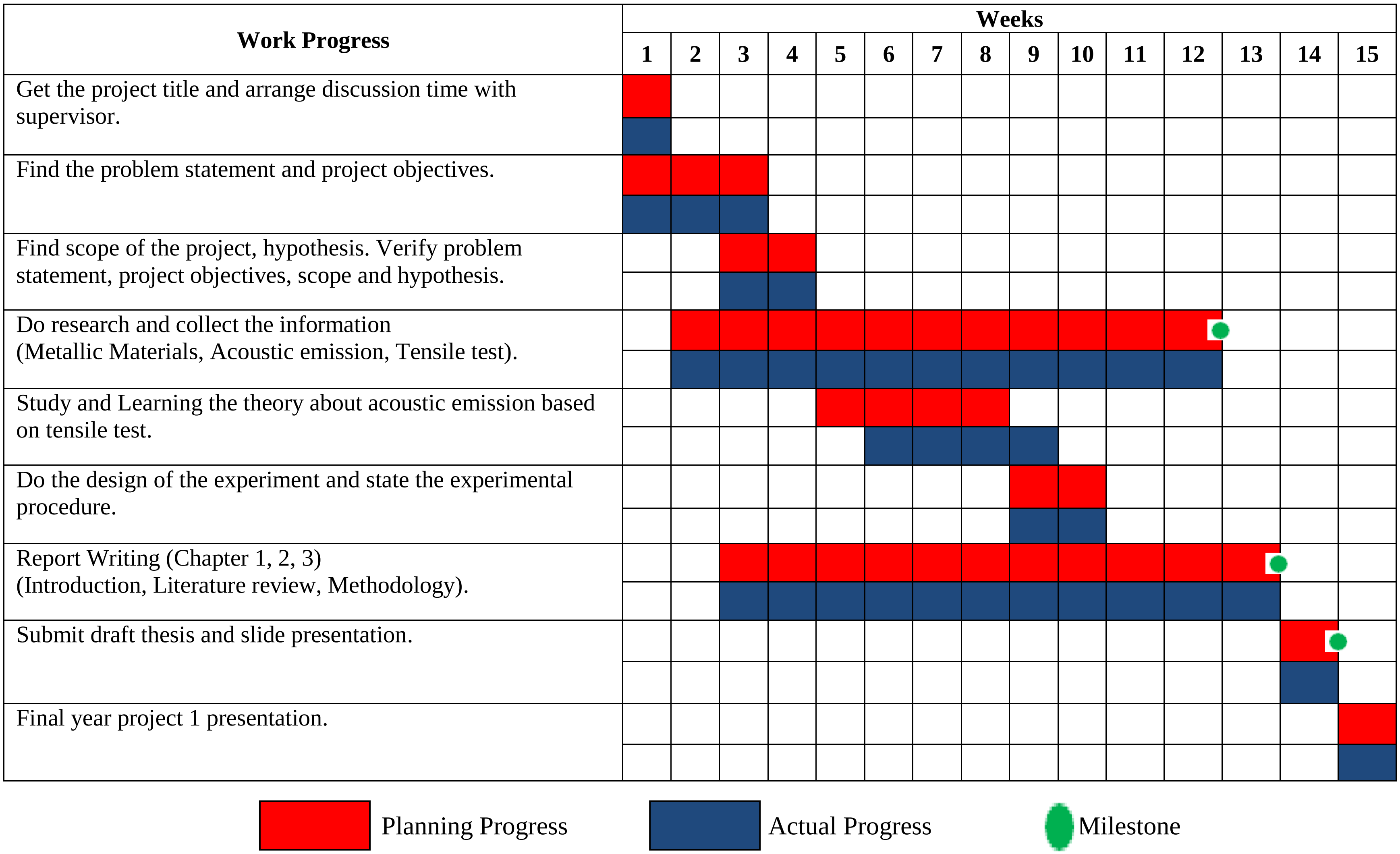
APPENDIX A

PROJECT PLANNING (GANTT CHART): FINAL YEAR PROJECT 1



PROJECT PLANNING (GANTT CHART): FINAL YEAR PROJECT 2

Work Progress	Weeks																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16-18	19	20
Material selection and Sample preparation.																		
Perform experiment for tensile test Data Acquisition and collection.																		
Analysis the experimental results.																		
State the possible error during the experiment.																		
Make a comparison each material based on event of acoustic emission parameter.																		
Report Writing (Chapter 4 and 5) (Results and Discussion, Conclusion and Recommendation).																		
Correction of the report writing Verify the Chapter (Chapter 4, 5).																		
Submit thesis report for Draft 1- Draft 2.																		
Final year project 2 presentation.																		
Submit final thesis report.																		

Planning Progress Actual Progress Milestone

APPENDIX B

SOLIDWORK DRAWING

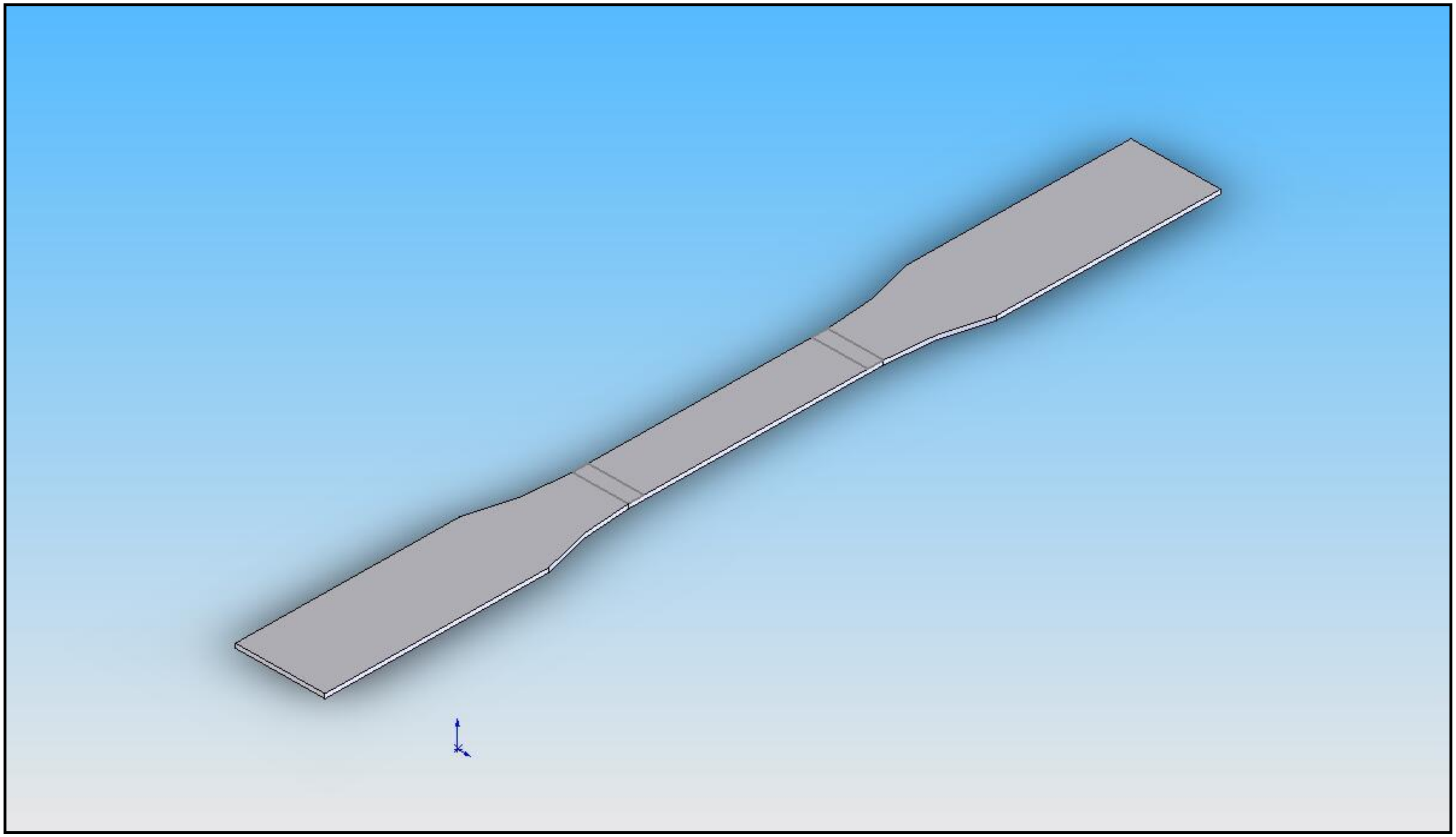


Figure 6.1: 3D drawing of rectangular tensile test specimen

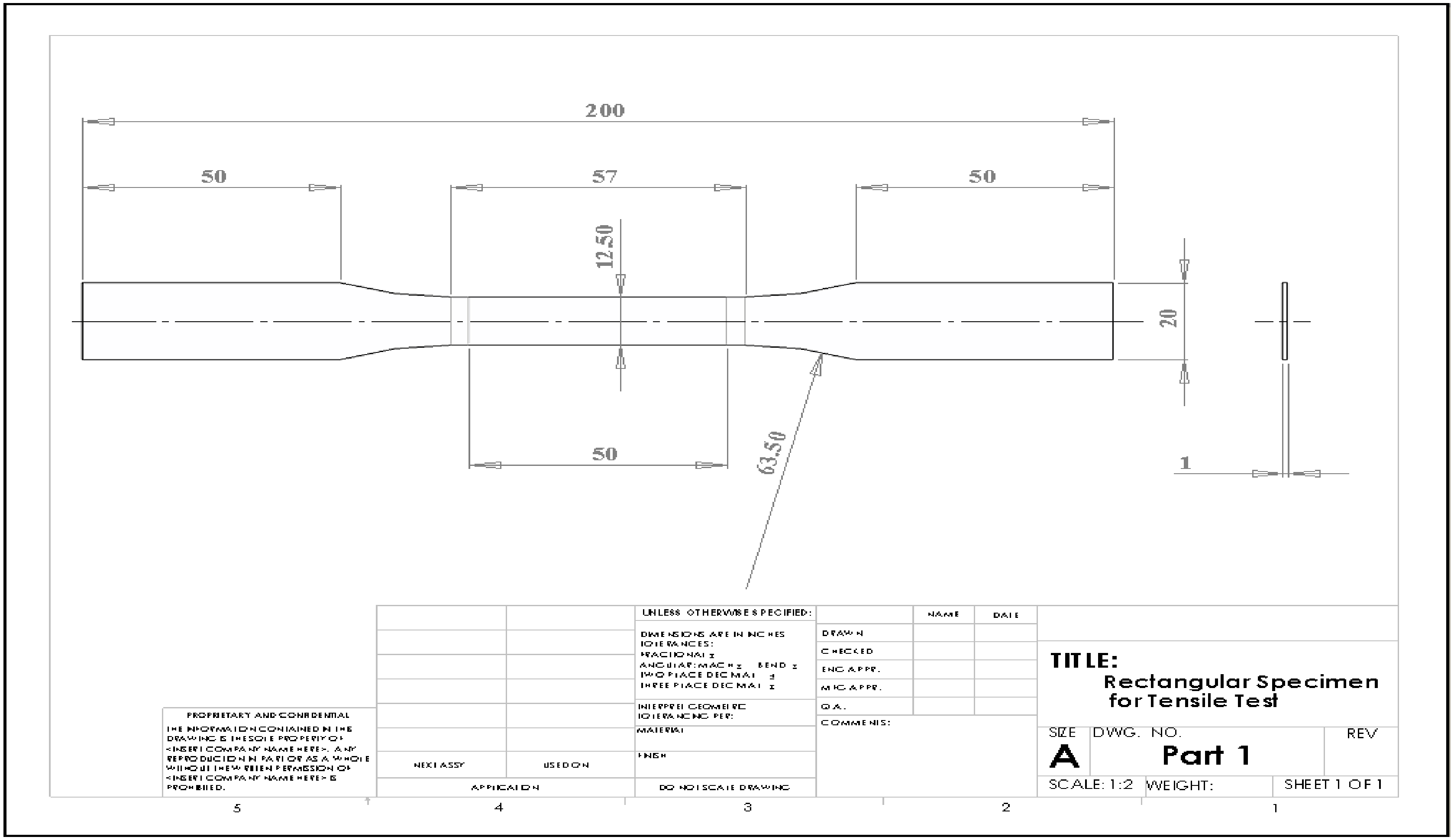


Figure 6.2: Sheet drawing of rectangular tensile test specimen

APPENDIX C

ACOUSTIC EMISSION AND TENSILE TEST DATA

Table 6.1: Acoustic emission data of Aluminum

Data Hit	Time (s)	Frequency (kHz)	Time Domain		
			RMS (V)	Energy (Vs)	Max. Amplitude (V)
1	0.00	4.88	0.00020	0.26980	0.01460
2	0.10	4.88	0.00031	0.50370	0.00310
3	0.22	156.30	0.00002	0.90840	0.00980
4	0.30	4.88	0.00019	0.39550	0.00310
5	0.46	151.40	0.00011	0.44920	0.00400
6	0.54	4.88	0.00061	0.64870	0.00180
7	0.57	4.88	0.00022	0.41200	0.00092
8	0.85	156.30	0.00003	0.55010	0.00520
9	0.96	156.30	0.00000	1.22420	0.01400
10	0.97	4.88	0.00041	0.58110	0.00270
11	0.98	156.30	0.00007	0.44040	0.00340
12	1.06	156.30	0.00018	0.70220	0.00790
13	1.25	4.88	0.00030	0.40220	0.00240
14	1.41	156.30	0.00014	0.52000	0.00490
15	2.00	156.30	0.00002	0.28460	0.00210
16	3.40	4.88	0.00100	1.02080	0.00000
17	3.64	4.88	0.00014	0.30330	0.00180
18	3.66	4.88	0.00093	0.95060	0.00000
19	6.44	9.77	0.00000	0.37630	0.00180
20	6.82	4.88	0.00031	0.54200	0.00520
21	8.01	4.88	0.00058	0.59830	0.00180
22	8.24	156.30	0.00016	0.69670	0.00700
23	9.68	156.30	0.00011	0.39430	0.00310
24	9.93	156.30	0.00004	0.45940	0.00430
25	10.23	4.88	0.00025	0.37610	0.00180
26	10.36	151.40	0.00008	0.50630	0.00310
27	11.34	156.30	0.00001	0.43730	0.00270
28	11.78	156.30	0.00003	0.44310	0.00340
29	12.20	151.40	0.00018	0.43700	0.00240
30	12.47	4.88	0.00081	0.95810	0.00270
31	13.43	190.40	0.00012	1.58080	0.00610
32	13.45	190.40	0.00015	0.82720	0.00310
33	13.76	4.88	0.00037	0.72750	0.00210
34	14.68	4.88	0.00050	0.51960	0.00180
35	14.84	9.77	0.00017	0.40340	0.00180
36	14.86	214.80	0.00012	0.50020	0.00180
37	14.89	4.88	0.00020	0.37030	0.00210
38	14.95	4.88	0.00046	0.58490	0.00120

39	15.06	4.88	0.00028	0.43880	0.00180
40	17.02	371.10	0.00000	0.53650	0.00400
41	17.05	351.60	0.00009	2.22580	0.01620
42	17.50	151.40	0.00006	0.48750	0.00370
43	18.21	4.88	0.00044	0.48580	0.00180
44	18.25	239.30	0.00020	1.33120	0.00700
45	18.55	4.88	0.00018	0.47490	0.00210
46	18.65	156.30	0.00004	0.71730	0.00490
47	18.88	4.88	0.00022	0.60560	0.00340
48	19.35	4.88	0.00065	0.67180	0.00180
49	19.57	4.88	0.00019	0.36190	0.00210
50	20.37	4.88	0.00035	0.50810	0.00120
51	20.65	151.40	0.00014	0.43460	0.00340
52	20.73	156.30	0.00011	0.39670	0.00340
53	22.59	151.40	0.00038	0.97020	0.00980
54	22.62	151.40	0.00014	0.34290	0.00240
55	22.78	4.88	0.00061	0.66800	0.00180
56	23.63	156.30	0.00016	0.44070	0.00210
57	25.36	4.88	0.00030	0.59770	0.00310
58	26.86	151.40	0.00010	0.40920	0.00340
59	28.20	156.30	0.00043	3.53110	0.05710
60	29.71	4.88	0.00069	1.71820	0.00031
61	29.93	4.88	0.00077	3.34100	0.00210
62	31.53	4.88	0.00072	1.57460	0.00180
63	33.08	151.40	0.00065	1.97110	0.00210
64	33.19	4.88	0.00065	1.49350	0.00240
65	34.09	4.88	0.00069	1.07120	0.00340
66	34.12	4.88	0.00103	3.46860	0.00310
67	37.67	156.30	0.00092	1.48810	0.00270
68	38.12	4.88	0.00083	1.41060	0.00210
69	40.77	4.88	0.00132	2.76800	0.00180
70	41.06	4.88	0.00121	0.97570	0.00310
71	45.49	4.88	0.00055	0.57650	0.00180
72	46.49	4.88	0.00063	0.68500	0.00092
73	47.74	4.88	0.00044	0.53240	0.00180
74	48.92	4.88	0.00042	0.49010	0.00180
75	50.87	156.30	0.00012	0.48980	0.00310
76	51.26	4.88	0.00081	0.83210	0.00000
77	56.17	4.88	0.00017	0.39990	0.00240
78	56.77	4.88	0.00059	0.61450	0.00061
79	57.02	151.40	0.00007	0.36000	0.00120
80	57.83	4.88	0.00095	0.97610	0.00000
81	57.88	4.88	0.00038	0.88560	0.00240
82	60.31	4.88	0.00076	0.77770	0.00180
83	63.67	4.88	0.00073	0.75640	0.00031
84	64.45	156.30	0.00024	0.88070	0.00890
85	68.17	4.88	0.00064	0.65220	0.00180
86	68.54	4.88	0.00027	0.39720	0.00180
87	68.81	4.88	0.00033	0.63370	0.00460
88	68.87	4.88	0.00038	0.48480	0.00061
89	68.88	4.88	0.00022	0.43630	0.00120
90	68.90	4.88	0.00065	0.70180	0.00092
91	68.92	156.30	0.00002	0.46830	0.00180
92	68.94	4.88	0.00067	0.70630	0.00061
93	68.95	4.88	0.00028	0.78050	0.00310

Table 6.2: Tensile test data of Aluminum

Data Point	Time (s)	Stress (MPa)
1	2.38	0
2	4.76	10
3	7.13	24
4	9.51	39
5	11.89	54
6	14.27	67
7	16.64	79
8	19.02	90
9	21.40	99
10	23.78	107
11	26.16	114
12	28.53	119
13	30.91	123
14	33.29	125
15	35.67	131
16	38.04	132
17	40.42	133
18	42.80	133
19	45.18	132
20	47.55	125
21	49.93	118
22	52.31	111
23	54.69	103
24	57.07	95
25	59.44	85
26	61.82	71
27	64.20	62
28	66.58	49
29	68.95	7

Table 6.3: Acoustic emission data of Copper

Data Hit	Time (s)	Frequency (kHz)	Time Domain RMS (V)	Time Domain Energy (Vs)	Time Domain Max. Amplitude (V)
1	1.07	4.88	0.00078	0.80400	0.00031
2	2.03	4.88	0.00047	0.50430	0.00180
3	6.92	4.88	0.00092	0.94480	0.00000
4	7.60	4.88	0.00070	0.71660	0.00180
5	7.61	4.88	0.00051	0.52630	0.00180
6	9.75	4.88	0.00048	0.57750	0.00061
7	10.11	4.88	0.00038	0.54520	0.00092
8	10.21	4.88	0.00033	0.38930	0.00180
9	11.03	210.00	0.00024	0.73300	0.00210
10	11.22	4.88	0.00056	0.57950	0.00180
11	11.25	4.88	0.00054	0.56980	0.00210
12	11.44	4.88	0.00065	0.73290	0.00092
13	11.58	151.40	0.00020	0.78800	0.00310
14	11.87	4.88	0.00040	0.69280	0.00240
15	11.87	4.88	0.00064	0.80600	0.00180
16	13.19	185.50	0.00000	0.74590	0.00370
17	13.64	4.88	0.00033	0.43670	0.00180
18	16.64	4.88	0.00069	0.73720	0.00061
19	19.79	4.88	0.00054	0.62850	0.00180
20	21.27	4.88	0.00072	0.77760	0.00061
21	22.12	4.88	0.00056	0.58500	0.00180
22	23.66	4.88	0.00043	0.46880	0.00180
23	24.11	4.88	0.00028	0.31860	0.00180
24	25.15	4.88	0.00045	0.51360	0.00180
25	28.08	4.88	0.00068	0.70940	0.00031
26	30.79	4.88	0.00040	0.44400	0.00180
27	30.94	4.88	0.00065	0.67000	0.00180
28	31.04	4.88	0.00056	0.59220	0.00180
29	31.25	4.88	0.00029	0.40540	0.00180
30	32.48	4.88	0.00049	0.51990	0.00180
31	36.04	4.88	0.00076	0.58880	0.00031
32	43.66	4.88	0.00085	0.55560	0.00210
33	45.52	4.88	0.00103	1.65260	0.00180
34	48.28	4.88	0.00192	1.88480	0.00180
35	48.61	4.88	0.00054	0.56520	0.00180
36	50.62	4.88	0.00090	0.92450	0.00000
37	55.58	4.88	0.00147	1.51420	0.00180
38	60.91	4.88	0.00070	0.72800	0.00031
39	63.81	4.88	0.00091	0.93640	0.00031
40	65.00	4.88	0.00057	0.66160	0.00180
41	65.35	4.88	0.00072	0.75490	0.00180
42	65.45	4.88	0.00063	0.65410	0.00180
43	66.08	4.88	0.00050	0.53540	0.00180
44	66.49	4.88	0.00087	0.52600	0.00180

45	67.87	4.88	0.00062	0.65700	0.00180
46	73.19	9.77	0.00100	0.87510	0.00180
47	77.80	4.88	0.00227	2.68880	0.00031
48	81.32	4.88	0.00099	1.01330	0.00000
49	84.16	4.88	0.00083	1.84980	0.00031
50	88.06	9.77	0.00015	1.33330	0.00180
51	88.31	4.88	0.00055	0.99400	0.00180
52	88.94	4.88	0.00050	0.56290	0.00180
53	91.76	4.88	0.00148	1.01440	0.00180
54	95.29	4.88	0.00078	0.79990	0.00180
55	96.73	4.88	0.00065	0.67320	0.00031
56	98.30	4.88	0.00092	0.94270	0.00000
57	98.42	4.88	0.00084	0.85750	0.00031
58	101.97	4.88	0.00088	0.98150	0.00180
59	102.13	4.88	0.00100	1.02620	0.00000
60	112.43	4.88	0.00072	0.74420	0.00180
61	116.48	4.88	0.00155	1.39590	0.00180
62	121.61	4.88	0.00102	1.04140	0.00031
63	121.74	4.88	0.00067	0.68050	0.00180
64	127.33	4.88	0.00094	0.46910	0.00180
65	127.36	4.88	0.00225	1.52540	0.00240
66	130.71	4.88	0.00094	1.98430	0.00180
67	134.85	4.88	0.00060	0.63370	0.00180
68	135.41	4.88	0.00068	0.69820	0.00031
69	139.45	4.88	0.00033	0.37430	0.00180
70	140.13	4.88	0.00050	0.52810	0.00180
71	143.21	4.88	0.00069	0.70400	0.00180
72	143.51	4.88	0.00063	0.65920	0.00180
73	147.48	151.40	0.00004	0.46100	0.00210
74	149.37	4.88	0.00079	1.52350	0.00061
75	151.16	4.88	0.00022	1.03928	0.00180
76	151.19	4.88	0.00072	0.75120	0.00180
77	152.53	4.88	0.00071	0.73180	0.00031
78	156.69	4.88	0.00089	0.92320	0.00031
79	157.09	4.88	0.00068	0.69900	0.00180
80	164.20	4.88	0.00058	0.61510	0.00180
81	167.02	4.88	0.00034	1.37900	0.00180
82	168.21	4.88	0.00039	1.21930	0.00180
83	168.26	4.88	0.00042	1.30980	0.00180
84	171.44	4.88	0.00048	1.43310	0.00180
85	181.17	4.88	0.00042	0.97320	0.00180
86	182.99	4.88	0.00024	0.89690	0.00180
87	191.18	4.88	0.00047	0.82780	0.00180
88	194.97	4.88	0.00070	0.72190	0.00180
89	197.27	4.88	0.00053	1.24250	0.00180
90	198.22	4.88	0.00051	1.15600	0.00180
91	198.46	151.40	0.00018	1.89330	0.00210
92	199.13	151.40	0.00016	0.91030	0.00180
93	199.26	4.88	0.00055	0.58090	0.00180
94	200.43	4.88	0.00075	0.49390	0.00180
95	201.76	9.77	0.00169	0.97260	0.00180
96	202.59	4.88	0.00066	0.67520	0.00180
97	204.62	146.50	0.00024	0.63420	0.00210
98	206.49	4.88	0.00037	0.46490	0.00180
99	207.96	4.88	0.00032	0.50130	0.00180
100	213.09	4.88	0.00032	0.39490	0.00180
101	213.56	4.88	0.00083	0.85600	0.00031
102	216.19	4.88	0.00056	0.62260	0.00180

103	218.10	4.88	0.00068	0.69960	0.00180
104	219.55	4.88	0.00061	0.63510	0.00031
105	220.97	4.88	0.00045	0.49650	0.00180
106	222.78	9.77	0.00021	0.52380	0.00180
107	223.54	4.88	0.00055	0.59520	0.00180
108	223.76	4.88	0.00078	0.79480	0.00180
109	226.70	4.88	0.00066	0.69050	0.00180
110	230.36	4.88	0.00075	0.76290	0.00000
111	233.67	4.88	0.00062	0.64180	0.00180
112	236.82	4.88	0.00043	0.44800	0.00180
113	237.40	4.88	0.00050	0.54090	0.00180
114	241.52	4.88	0.00035	0.43590	0.00180
115	242.62	4.88	0.00059	0.60230	0.00180
116	243.98	4.88	0.00051	0.54250	0.00180
117	244.15	9.77	0.00024	0.46890	0.00180
118	248.14	4.88	0.00038	0.50580	0.00180
119	253.95	4.88	0.00027	0.39020	0.00180
120	265.77	4.88	0.00071	0.72770	0.00180
121	269.66	4.88	0.00080	0.81830	0.00180
122	271.98	4.88	0.00067	0.68530	0.00180
123	274.22	4.88	0.00063	0.66930	0.00180
124	274.58	4.88	0.00031	0.50140	0.00180
125	274.94	4.88	0.00039	0.44070	0.00180
126	280.49	4.88	0.00085	1.58090	0.00180
127	280.99	4.88	0.00043	1.50060	0.00180
128	283.34	4.88	0.00059	0.65190	0.00180
129	284.40	4.88	0.00147	0.50610	0.00180
130	285.70	4.88	0.00125	1.35630	0.00180
131	286.26	4.88	0.00093	0.66410	0.00031

132	290.27	4.88	0.00089	1.38240	0.00180
133	290.83	4.88	0.00100	1.04060	0.00000
134	292.69	4.88	0.00058	0.59680	0.00180
135	295.53	4.88	0.00030	0.39150	0.00180
136	296.73	4.88	0.00070	0.71620	0.00180
137	297.52	4.88	0.00089	0.91750	0.00031
138	297.60	4.88	0.00035	0.47470	0.00180
139	301.84	4.88	0.00034	0.49870	0.00180
140	304.04	4.88	0.00060	0.62380	0.00180
141	309.14	4.88	0.00064	0.67060	0.00180
142	310.32	4.88	0.00057	0.62590	0.00180
143	311.45	4.88	0.00034	0.39750	0.00180
144	314.14	4.88	0.00021	0.39720	0.00180
145	317.89	4.88	0.00043	0.45010	0.00180
146	319.59	4.88	0.00040	0.42050	0.00180
147	319.97	4.88	0.00062	0.64210	0.00061
148	322.01	4.88	0.00043	0.47500	0.00180
149	322.26	4.88	0.00047	0.49790	0.00180
150	322.99	4.88	0.00063	0.65960	0.00061
151	325.45	4.88	0.00059	0.62270	0.00031
152	325.50	4.88	0.00071	0.73490	0.00061
153	326.86	4.88	0.00055	0.59590	0.00031
154	333.16	4.88	0.00095	0.97900	0.00031
155	337.64	4.88	0.00047	0.50250	0.00180
156	339.24	4.88	0.00050	0.53010	0.00180
157	339.85	4.88	0.00067	0.68790	0.00180
158	343.06	4.88	0.00085	0.87220	0.00031
159	344.73	4.88	0.00073	0.74430	0.00180
160	346.94	4.88	0.00052	0.56210	0.00180

161	347.81	4.88	0.00027	0.40210	0.00180
162	348.65	4.88	0.00025	0.30520	0.00180
163	350.48	4.88	0.00044	0.50090	0.00180
164	355.72	4.88	0.00051	0.53160	0.00180
165	357.12	4.88	0.00082	0.84350	0.00180
166	358.41	4.88	0.00088	0.90290	0.00031
167	359.53	4.88	0.00033	0.44910	0.00180
168	360.05	4.88	0.00066	0.68450	0.00180

Table 6.4: Tensile test data of Copper

Data Point	Time (s)	Stress (MPa)
1	2.61	0
2	5.22	15
3	7.83	35
4	10.44	58
5	13.05	82
6	15.65	103
7	18.26	123
8	20.87	141
9	23.48	156
10	26.09	169
11	28.70	178
12	31.31	185
13	33.92	190
14	36.53	193
15	39.14	196
16	41.75	198
17	44.35	199
18	46.96	200
19	49.57	201
20	52.18	201
21	54.79	202
22	57.40	202
23	60.01	203
24	62.62	203
25	65.23	203
26	67.84	204
27	70.45	204
28	73.05	204
29	75.66	204
30	78.27	205
31	80.88	205
32	83.49	205
33	86.10	205
34	88.71	206
35	91.32	206
36	93.93	206
37	96.54	206
38	99.15	206
39	101.75	206
40	104.36	207
41	106.97	207
42	109.58	207
43	112.19	207
44	114.80	207
45	117.41	207
46	120.02	208
47	122.63	208
48	125.24	208
49	127.84	208
50	130.45	208
51	133.06	208
52	135.67	208
53	138.28	208
54	140.89	209
55	143.50	209
56	146.11	209
57	148.72	209
58	151.33	209
59	153.94	209
60	156.54	209
61	159.15	209
62	161.76	209
63	164.37	209
64	166.98	209
65	169.59	209
66	172.20	209
67	174.81	209
68	177.42	209
69	180.03	209

70	182.64	209
71	185.24	209
72	187.85	209
73	190.46	209
74	193.07	209
75	195.68	209
76	198.29	209
77	200.90	209
78	203.51	209
79	206.12	209
80	208.73	209
81	211.34	210
82	213.94	210
83	216.55	210
84	219.16	211
85	221.77	212
86	224.38	212
87	226.99	213
88	229.60	213
89	232.21	214
90	234.82	214
91	237.43	215
92	240.04	215
93	242.64	215
94	245.25	215
95	247.86	215
96	250.47	215
97	253.08	215
98	255.69	215
99	258.30	214
100	260.91	214
101	263.52	214
102	266.13	214
103	268.74	213
104	271.34	213
105	273.95	213
106	276.56	213
107	279.17	214
108	281.78	214
109	284.39	214
110	287.00	215
111	289.61	215
112	292.22	215
113	294.83	216
114	297.44	216
115	300.04	216
116	302.65	216
117	305.26	217
118	307.87	216
119	310.48	216
120	313.09	216
121	315.70	216
122	318.31	215
123	320.92	214
124	323.53	214
125	326.13	213
126	328.74	200
127	331.35	186
128	333.96	167
129	336.57	154
130	339.18	140
131	341.79	128
132	344.40	116
133	347.01	103
134	349.62	89
135	352.23	76
136	354.83	63
137	357.44	52
138	360.05	38

Table 6.5: Acoustic emission data of Zinc

Data Hit	Time (s)	Frequency (kHz)	Time Domain		
			RMS (V)	**Energy (Vs)**	**Max. Amplitude (V)**
1	3.29	9.77	0.00014	0.44680	0.00340
2	38.21	4.88	0.00032	0.59170	0.00270
3	41.33	210.00	0.00013	1.79780	0.00700
4	45.53	258.80	0.00015	0.76170	0.00370
5	52.53	185.50	0.00004	2.48470	0.01160
6	59.04	146.50	0.00021	0.66470	0.00310
7	59.44	146.50	0.00028	0.78810	0.00240
8	167.95	146.50	0.00041	3.39070	0.01710
9	188.97	205.10	0.00006	11.11070	0.06290
10	200.62	151.40	0.00012	0.79800	0.00240

Table 6.6: Tensile test data of Zinc

Data Point	Time (s)	Stress (MPa)
1	1.10	0
2	2.20	23
3	3.31	53
4	4.41	81
5	5.51	106
6	6.61	128
7	7.72	143
8	8.82	152
9	9.92	159
10	11.02	162
11	12.13	165
12	13.23	167
13	14.33	169
14	15.43	170
15	16.53	171
16	17.64	172
17	18.74	173
18	19.84	174
19	20.94	175
20	22.05	175
21	23.15	176
22	24.25	177
23	25.35	178
24	26.46	178
25	27.56	179
26	28.66	180
27	29.76	180
28	30.86	181
29	31.97	182
30	33.07	182
31	34.17	183
32	35.27	183
33	36.38	184
34	37.48	184
35	38.58	185
36	39.68	186
37	40.78	186
38	41.89	187
39	42.99	187
40	44.09	188
41	45.19	188
42	46.30	189
43	47.40	190
44	48.50	190
45	49.60	191
46	50.71	191
47	51.81	192
48	52.91	192
49	54.01	193
50	55.11	193
51	56.22	194
52	57.32	194
53	58.42	195
54	59.52	195
55	60.63	196
56	61.73	196
57	62.83	197
58	63.93	197
59	65.04	198
60	66.14	198
61	67.24	199
62	68.34	199
63	69.44	200
64	70.55	200
65	71.65	201
66	72.75	201
67	73.85	202
68	74.96	202
69	76.06	203

70	77.16	203	99	109.13	215	128	141.09	236
71	78.26	204	100	110.23	216	129	142.20	236
72	79.37	204	101	111.33	218	130	143.30	235
73	80.47	205	102	112.43	218	131	144.40	235
74	81.57	205	103	113.54	219	132	145.50	235
75	82.67	206	104	114.64	220	133	146.61	235
76	83.77	206	105	115.74	221	134	147.71	235
77	84.88	207	106	116.84	221	135	148.81	236
78	85.98	207	107	117.95	222	136	149.91	236
79	87.08	208	108	119.05	223	137	151.01	236
80	88.18	208	109	120.15	223	138	152.12	237
81	89.29	208	110	121.25	224	139	153.22	237
82	90.39	209	111	122.35	225	140	154.32	238
83	91.49	209	112	123.46	225	141	155.42	238
84	92.59	210	113	124.56	226	142	156.53	239
85	93.70	210	114	125.66	227	143	157.63	239
86	94.80	210	115	126.76	228	144	158.73	240
87	95.90	211	116	127.87	229	145	159.83	240
88	97.00	211	117	128.97	231	146	160.94	240
89	98.10	212	118	130.07	231	147	162.04	240
90	99.21	212	119	131.17	232	148	163.14	240
91	100.31	212	120	132.28	233	149	164.24	240
92	101.41	213	121	133.38	234	150	165.34	240
93	102.51	213	122	134.48	234	151	166.45	240
94	103.62	213	123	135.58	235	152	167.55	240
95	104.72	214	124	136.68	235	153	168.65	239
96	105.82	214	125	137.79	236	154	169.75	239
97	106.92	214	126	138.89	236	155	170.86	238
98	108.03	214	127	139.99	236	156	171.96	238

157	173.06	237
158	174.16	237
159	175.27	236
160	176.37	236
161	177.47	236
162	178.57	236
163	179.67	236
164	180.78	236
165	181.88	235
166	182.98	235
167	184.08	235
168	185.19	234
169	186.29	233
170	187.39	232
171	188.49	230
172	189.60	227
173	190.70	224
174	191.80	219
175	192.90	213
176	194.00	201
177	195.11	187
178	196.21	151
179	197.31	129
180	198.41	106
181	199.52	76
182	200.62	22

Table 6.7: Acoustic emission data of Mild Steel

Data Hit	Time (s)	Frequency (kHz)	Time Domain		
			RMS (V)	Energy (Vs)	Max. Amplitude (V)
1	15.92	4.88	0.00022	0.52570	0.00340
2	17.11	180.70	0.00011	0.56240	0.00370
3	21.40	180.70	0.00011	0.42620	0.00310
4	28.44	4.88	0.00034	0.51730	0.00310
5	28.53	151.40	0.00002	0.63690	0.00400
6	40.27	190.40	0.00001	0.79650	0.00460
7	52.82	170.90	0.00015	0.86010	0.00430
8	63.50	205.10	0.00001	4.50000	0.02470
9	70.53	4.88	0.00041	0.88350	0.00610
10	75.07	4.88	0.00028	0.51570	0.00340
11	79.25	273.40	0.00030	3.71770	0.02750
12	134.15	210.00	0.00001	5.60290	0.02290
13	140.05	175.80	0.00012	1.94960	0.01500
14	150.46	146.50	0.00019	0.47780	0.00270
15	155.37	4.88	0.00041	0.61000	0.00310
16	165.87	146.50	0.00002	0.61230	0.00460
17	195.76	4.88	0.00037	0.77030	0.00400
18	223.27	4.88	0.00028	0.48770	0.00270
19	223.31	146.50	0.00012	3.48270	0.04550
20	223.34	146.50	0.00003	1.10380	0.01370
21	234.38	4.88	0.00029	0.65830	0.00340
22	317.92	146.50	0.00017	0.88320	0.00790
23	321.92	146.50	0.00011	0.77880	0.00700
24	353.16	146.50	0.00018	1.01640	0.00310
25	362.74	4.88	0.00048	0.67380	0.00180
26	432.76	4.88	0.00036	0.48570	0.00550

Table 6.8: Tensile test data of Mild Steel

Data Point	Time (s)	Stress (MPa)
1	2.22	0
2	4.44	17
3	6.66	44
4	8.88	77
5	11.10	112
6	13.32	145
7	15.54	173
8	17.75	193
9	19.97	206
10	22.19	213
11	24.41	214
12	26.63	212
13	28.85	212
14	31.07	212
15	33.29	212
16	35.51	213
17	37.73	213
18	39.95	213
19	42.17	214
20	44.39	214
21	46.61	215
22	48.82	215
23	51.04	216
24	53.26	216
25	55.48	217
26	57.70	217
27	59.92	217
28	62.14	218
29	64.36	219
30	66.58	220
31	68.80	220
32	71.02	221
33	73.24	221
34	75.46	221
35	77.68	222
36	79.89	223
37	82.11	223
38	84.33	224
39	86.55	224
40	88.77	224
41	90.99	224
42	93.21	224
43	95.43	225
44	97.65	226
45	99.87	226
46	102.09	226
47	104.31	227
48	106.53	228
49	108.75	228
50	110.96	229
51	113.18	230
52	115.40	231
53	117.62	231
54	119.84	232
55	122.06	233
56	124.28	234
57	126.50	234
58	128.72	235
59	130.94	236
60	133.16	237
61	135.38	237
62	137.60	238
63	139.82	239
64	142.03	240
65	144.25	240
66	146.47	241
67	148.69	242
68	150.91	243
69	153.13	243

70	155.35	244	99	219.71	260	128	284.07	287
71	157.57	245	100	221.93	261	129	286.29	288
72	159.79	245	101	224.15	261	130	288.51	288
73	162.01	246	102	226.37	262	131	290.73	289
74	164.23	246	103	228.59	262	132	292.95	289
75	166.45	247	104	230.81	263	133	295.17	289
76	168.67	248	105	233.03	263	134	297.39	289
77	170.89	248	106	235.25	263	135	299.60	289
78	173.11	249	107	237.46	265	136	301.82	289
79	175.32	250	108	239.68	267	137	304.04	289
80	177.54	250	109	241.90	268	138	306.26	289
81	179.76	251	110	244.12	269	139	308.48	289
82	181.98	252	111	246.34	270	140	310.70	289
83	184.20	252	112	248.56	271	141	312.92	289
84	186.42	253	113	250.78	272	142	315.14	289
85	188.64	253	114	253.00	273	143	317.36	289
86	190.86	254	115	255.22	273	144	319.58	290
87	193.08	254	116	257.44	274	145	321.80	290
88	195.30	255	117	259.66	275	146	324.02	291
89	197.52	256	118	261.88	276	147	326.24	291
90	199.74	256	119	264.10	277	148	328.46	292
91	201.96	257	120	266.32	278	149	330.67	293
92	204.18	257	121	268.53	279	150	332.89	293
93	206.39	258	122	270.75	280	151	335.11	294
94	208.61	258	123	272.97	281	152	337.33	294
95	210.83	259	124	275.19	283	153	339.55	294
96	213.05	259	125	277.41	284	154	341.77	295
97	215.27	260	126	279.63	285	155	343.99	295
98	217.49	260	127	281.85	286	156	346.21	295

157	348.43	295
158	350.65	294
159	352.87	294
160	355.09	293
161	357.31	293
162	359.53	292
163	361.75	292
164	363.96	291
165	366.18	291
166	368.40	291
167	370.62	290
168	372.84	290
169	375.06	290
170	377.28	290
171	379.50	290
172	381.72	290
173	383.94	291
174	386.16	290
175	388.38	290
176	390.60	290
177	392.82	289
178	395.03	287
179	397.25	286
180	399.47	284
181	401.69	281
182	403.91	277
183	406.13	273
184	408.35	268
185	410.57	262
186	412.79	255
187	415.01	244
188	417.23	224
189	419.45	194
190	421.67	159
191	423.89	136
192	426.10	114
193	428.32	92
194	430.54	63
195	432.76	21

Table 6.9: Acoustic emission data of Galvanized Iron

Data Hit	Time (s)	Frequency (kHz)	Time Domain		
			RMS (V)	Energy (Vs)	Max. Amplitude (V)
1	3.95	146.50	0.00040	2.96460	0.00980
2	3.96	151.40	0.00002	2.11030	0.01190
3	4.00	146.50	0.00005	2.82260	0.01190
4	4.20	205.10	0.00008	3.54600	0.01980
5	4.25	210.00	0.00009	2.98600	0.01220
6	4.27	180.70	0.00033	2.01200	0.01160
7	4.28	185.50	0.00011	3.99610	0.02870
8	4.34	151.00	0.00039	3.20470	0.01130
9	4.37	205.10	0.00007	2.47190	0.01160
10	4.38	185.50	0.00025	6.09730	0.02380
11	4.43	185.50	0.00009	2.18370	0.01190
12	4.43	180.70	0.00004	1.57620	0.01070
13	4.52	205.10	0.00006	2.31660	0.00950
14	4.53	200.20	0.00003	3.90060	0.01560
15	4.54	205.10	0.00039	2.31540	0.01010
16	4.70	205.10	0.00027	2.74170	0.01310
17	4.74	205.10	0.00014	6.70110	0.02990
18	4.79	205.10	0.00018	3.41900	0.01460
19	4.81	151.40	0.00012	1.72240	0.01070
20	4.85	185.50	0.00004	2.48080	0.01400
21	4.87	200.20	0.00004	2.41580	0.01220
22	4.90	205.10	0.00039	1.67920	0.00760
23	5.00	185.50	0.00022	3.27820	0.01220
24	5.06	185.50	0.00038	3.82100	0.01950
25	5.12	205.10	0.00002	2.55750	0.01220
26	5.23	185.50	0.00038	3.18180	0.01920
27	5.23	234.40	0.00001	4.20790	0.02780
28	5.27	180.70	0.00035	1.92990	0.01100
29	5.30	175.80	0.00040	5.03600	0.01890
30	5.34	185.50	0.00013	2.73380	0.01340
31	5.35	210.00	0.00010	1.84540	0.00850
32	5.37	210.00	0.00036	2.47250	0.01100
33	5.39	205.10	0.00016	2.12080	0.01220
34	5.49	185.50	0.00034	2.37410	0.01340
35	5.52	210.00	0.00042	1.99540	0.00820
36	5.54	205.10	0.00040	1.59450	0.01100
37	5.63	185.50	0.00059	2.83050	0.02170
38	5.64	210.00	0.00018	2.14280	0.01100
39	5.70	180.70	0.00010	1.90890	0.01070
40	5.71	210.00	0.00033	2.44310	0.01430
41	5.75	205.10	0.00016	2.63670	0.01130
42	5.77	141.60	0.00018	2.22180	0.01400
43	5.79	205.10	0.00006	3.93260	0.01340
44	5.80	210.00	0.00015	2.83910	0.01560

45	5.86	205.10	0.00009	2.49710	0.01070
46	5.88	210.00	0.00019	1.44740	0.00610
47	5.90	205.10	0.00028	2.68600	0.01460
48	5.92	175.80	0.00020	2.85220	0.01070
49	5.93	205.10	0.00018	2.13210	0.00920
50	5.98	151.40	0.00026	2.95500	0.01190
51	6.00	205.10	0.00033	1.67080	0.01010
52	6.03	205.10	0.00025	2.03140	0.01070
53	6.06	205.10	0.00009	3.77700	0.01400
54	6.07	205.10	0.00019	1.85670	0.00950
55	6.10	210.00	0.00053	2.20840	0.01190
56	6.11	283.20	0.00025	2.84520	0.01890
57	6.13	210.00	0.00023	2.06330	0.01040
58	6.14	210.00	0.00032	2.60820	0.01010
59	6.16	180.70	0.00028	2.78690	0.01070
60	6.32	205.10	0.00038	2.44170	0.01280
61	6.36	185.50	0.00010	6.01880	0.03480
62	6.37	185.50	0.00005	5.65440	0.02320
63	6.40	151.40	0.00038	3.27390	0.01220
64	6.40	185.50	0.00001	1.89250	0.01430
65	6.48	185.50	0.00002	22.10430	0.15750
66	6.58	200.20	0.00028	1.64890	0.00980
67	6.59	185.50	0.00019	1.79780	0.01340
68	6.66	151.40	0.00013	2.92600	0.01100
69	6.69	205.10	0.00032	2.48150	0.01340
70	6.78	185.50	0.00037	1.92980	0.01250
71	6.83	185.50	0.00004	2.88800	0.01370
72	6.86	195.30	0.00049	1.81170	0.01100
73	6.89	205.10	0.00002	2.75890	0.01130
74	6.91	146.50	0.00012	2.92680	0.01040
75	6.92	185.50	0.00014	1.94090	0.01010
76	6.95	185.50	0.00007	2.94270	0.01740
77	6.95	185.50	0.00040	2.31050	0.00920
78	7.03	205.10	0.00019	2.00530	0.01370
79	7.08	273.40	0.00019	2.73070	0.01160
80	7.16	190.40	0.00020	2.16250	0.01040
81	7.26	156.30	0.00002	2.10340	0.01770
82	7.29	185.50	0.00011	2.97160	0.01130
83	7.42	210.00	0.00038	1.59840	0.01220
84	7.47	185.50	0.00025	2.41230	0.01040
85	7.48	205.10	0.00010	2.26380	0.01010
86	7.54	185.50	0.00010	2.16340	0.01430
87	7.55	185.50	0.00002	2.19770	0.00980
88	7.67	210.00	0.00004	2.37440	0.01830
89	7.69	210.00	0.00023	1.91130	0.01010
90	7.71	180.70	0.00003	3.37420	0.01590
91	7.75	185.50	0.00003	1.62110	0.01010
92	7.83	205.10	0.00011	2.29460	0.01280
93	7.86	151.40	0.00020	3.04310	0.01250
94	7.89	210.00	0.00026	1.86780	0.01430
95	7.97	180.70	0.00009	2.20760	0.01310
96	7.97	185.50	0.00000	1.78530	0.01220
97	8.03	185.50	0.00011	2.61600	0.01680
98	8.04	205.10	0.00011	2.41970	0.01430
99	8.07	205.10	0.00010	1.62410	0.01100
100	8.11	180.70	0.00016	3.73490	0.01400
101	8.18	185.50	0.00061	2.08660	0.01430
102	8.21	200.20	0.00010	1.99690	0.01280

103	8.24	185.50	0.00007	1.66210	0.01040
104	8.29	210.00	0.00017	1.64960	0.01040
105	8.34	180.70	0.00015	4.44350	0.02620
106	8.63	234.40	0.00020	2.63980	0.01500
107	8.64	180.70	0.00046	8.70130	0.03850
108	8.68	151.40	0.00027	3.20560	0.01920
109	8.70	156.30	0.00046	3.63250	0.01530
110	8.74	180.70	0.00019	2.28490	0.01100
111	8.80	224.60	0.00016	2.06760	0.01400
112	8.83	210.00	0.00021	1.84940	0.00890
113	8.89	210.00	0.00009	2.46020	0.00950
114	8.90	210.00	0.00039	2.37380	0.01310
115	8.92	210.00	0.00003	2.51650	0.01280
116	8.98	210.00	0.00011	1.47490	0.01010
117	8.99	200.20	0.00046	2.13360	0.01370
118	9.04	151.40	0.00012	5.52640	0.02380
119	9.05	210.00	0.00039	1.96790	0.00950
120	9.06	234.40	0.00013	2.34500	0.00920
121	9.09	210.00	0.00008	2.40260	0.01160
122	9.13	210.00	0.00009	2.96110	0.01250
123	9.16	151.40	0.00006	2.24900	0.01100
124	9.18	210.00	0.00017	2.49660	0.01100
125	9.55	210.00	0.00002	2.11840	0.01310
126	9.68	185.50	0.00014	3.13430	0.01920
127	9.75	190.40	0.00021	3.86610	0.01740
128	9.79	258.80	0.00014	2.06770	0.01710
129	9.83	180.70	0.00022	2.28870	0.01100
130	9.85	200.20	0.00015	2.42740	0.01430
131	9.88	185.50	0.00010	3.52890	0.01370

132	9.94	180.70	0.00021	4.87290	0.03140
133	9.98	268.60	0.00021	1.41560	0.00820
134	10.06	234.40	0.00010	2.37960	0.01100
135	10.18	224.60	0.00010	1.64690	0.00950
136	10.21	185.50	0.00016	3.77910	0.01530
137	10.25	268.60	0.00016	2.50020	0.01680
138	10.31	151.40	0.00028	1.78450	0.00950
139	10.46	185.50	0.00014	3.37830	0.01590
140	10.55	185.50	0.00046	4.49840	0.01920
141	10.57	185.50	0.00006	4.57520	0.02620
142	10.58	234.40	0.00013	2.60640	0.01370
143	10.61	190.40	0.00005	3.47440	0.01710
144	10.64	185.50	0.00032	3.30700	0.01460
145	10.66	210.00	0.00008	2.43240	0.01500
146	10.69	210.00	0.00019	3.65880	0.03170
147	10.77	195.30	0.00003	2.42080	0.01070
148	10.82	185.50	0.00048	1.78680	0.00890
149	10.87	146.50	0.00034	1.62000	0.01400
150	10.94	234.40	0.00034	2.55720	0.00850
151	10.98	151.40	0.00033	2.89670	0.01620
152	11.22	210.00	0.00030	1.77050	0.01100
153	11.34	210.00	0.00004	2.69870	0.01710
154	11.40	190.40	0.00033	2.56100	0.01220
155	11.54	210.00	0.00039	2.51050	0.01310
156	11.54	146.50	0.00011	3.34610	0.01530
157	11.62	234.40	0.00013	4.32040	0.02040
158	11.68	210.00	0.00012	1.86720	0.01160
159	11.73	268.60	0.00017	1.55820	0.00920
160	11.82	151.40	0.00006	2.29890	0.01160

161	11.83	146.50	0.00017	2.64300	0.01250	190	13.73	156.30	0.00034	3.61680	0.02110
162	11.90	278.30	0.00014	3.20360	0.01920	191	13.76	180.70	0.00008	10.47870	0.04640
163	11.96	210.00	0.00002	3.65840	0.01500	192	13.87	180.70	0.00023	2.44980	0.01160
164	12.00	210.00	0.00023	3.00060	0.01430	193	14.05	210.00	0.00018	2.90370	0.01190
165	12.05	190.40	0.00026	4.00570	0.01830	194	14.11	239.30	0.00002	3.05310	0.01310
166	12.10	185.50	0.00041	2.32360	0.01830	195	14.22	210.00	0.00034	1.57030	0.01100
167	12.12	234.40	0.00027	2.78380	0.01650	196	14.24	205.10	0.00028	2.26910	0.00850
168	12.21	205.10	0.00056	2.03090	0.01710	197	14.27	185.50	0.00016	2.79860	0.01830
169	12.22	210.00	0.00025	1.60830	0.01100	198	14.45	205.10	0.00056	2.16750	0.01160
170	12.41	151.40	0.00000	2.60150	0.01100	199	14.57	210.00	0.00019	4.89870	0.02110
171	12.51	210.00	0.00027	2.31380	0.01250	200	15.24	195.30	0.00009	2.06280	0.01160
172	12.52	210.00	0.00013	2.91180	0.01460	201	15.27	210.00	0.00021	2.25100	0.00980
173	12.55	151.40	0.00021	2.16460	0.01310	202	15.34	210.00	0.00012	2.04800	0.01160
174	12.58	210.00	0.00012	1.56690	0.01160	203	15.47	185.50	0.00016	1.44100	0.00980
175	12.59	185.50	0.00003	4.64580	0.02320	204	15.55	185.50	0.00016	1.44100	0.00980
176	12.61	185.50	0.00005	4.01700	0.02010	205	15.62	210.00	0.00017	2.36570	0.01530
177	12.72	210.00	0.00035	3.37200	0.01710	206	15.78	210.00	0.00018	2.62390	0.01460
178	12.85	190.40	0.00002	4.13990	0.01590	207	15.82	146.50	0.00030	3.89390	0.01860
179	12.92	234.40	0.00018	4.94090	0.02350	208	15.83	151.40	0.00010	2.43040	0.01310
180	13.00	185.50	0.00018	3.64150	0.01310	209	15.91	283.20	0.00006	2.26040	0.01160
181	13.02	151.40	0.00000	2.23920	0.01070	210	15.94	151.40	0.00013	2.78500	0.01430
182	13.07	151.40	0.00046	3.89830	0.01740	211	16.08	190.40	0.00025	2.29060	0.01160
183	13.16	205.10	0.00003	2.34210	0.01340	212	16.16	156.30	0.00031	1.97490	0.01160
184	13.23	210.00	0.00003	2.70710	0.00920	213	16.18	210.00	0.00031	2.02580	0.01280
185	13.25	239.30	0.00005	2.55000	0.01070	214	16.21	146.50	0.00021	2.89340	0.02380
186	13.27	180.70	0.00012	2.59140	0.01460	215	16.35	268.60	0.00026	1.88140	0.01070
187	13.34	195.30	0.00006	2.98460	0.01100	216	16.50	210.00	0.00004	4.44760	0.02350
188	13.63	234.40	0.00049	4.67180	0.02040	217	16.70	268.60	0.00000	1.86340	0.01340
189	13.71	210.00	0.00032	1.88280	1.88280	218	16.76	200.20	0.00026	1.98410	0.01370

219	16.83	268.60	0.00016	1.67010	0.01070
220	17.04	210.00	0.00015	1.25600	0.00890
221	17.14	210.00	0.00032	1.25790	0.00950
222	17.30	146.50	0.00032	1.88690	0.00790
223	17.41	210.00	0.00022	1.98900	0.00950
224	17.55	185.50	0.00003	4.12950	0.01830
225	17.58	185.50	0.00013	1.79890	0.01430
226	17.73	146.50	0.00034	14.29180	0.07480
227	17.85	146.50	0.00009	1.20670	0.01130
228	17.88	234.40	0.00020	3.07910	0.01680
229	17.95	180.70	0.00024	3.33830	0.01070
230	17.99	185.50	0.00013	3.02060	0.01280
231	18.09	210.00	0.00038	2.73850	0.01560
232	18.12	185.50	0.00001	1.84230	0.00980
233	18.14	210.00	0.00026	2.46400	0.01460
234	18.25	210.00	0.00021	2.42610	0.01250
235	18.29	234.40	0.00016	1.57260	0.00980
236	18.46	146.50	0.00033	2.11240	0.01100
237	18.55	210.00	0.00003	1.48620	0.01040
238	18.60	210.00	0.00004	1.60130	0.01280
239	18.64	146.50	0.00034	6.09530	0.03050
240	18.68	210.00	0.00006	2.20920	0.01500
241	19.27	185.50	0.00023	2.16450	0.01010
242	19.44	185.50	0.00015	5.22050	0.02350
243	19.59	205.10	0.00034	2.13500	0.01280
244	19.79	185.50	0.00038	3.78690	0.01400
245	19.84	185.50	0.00011	5.61020	0.02040
246	19.84	210.00	0.00001	1.23180	0.01010
247	19.98	268.60	0.00035	1.62230	0.01220
248	20.32	210.00	0.00050	1.74270	0.01370
249	20.37	205.10	0.00041	1.86770	0.01100
250	20.66	210.00	0.00025	1.29240	0.01160
251	20.82	180.70	0.00042	1.66850	0.00890
252	20.85	146.50	0.00000	2.13130	0.01100
253	20.90	210.00	0.00002	1.84300	0.00980
254	20.98	210.00	0.00001	2.01640	0.01770
255	21.00	185.50	0.00017	2.73640	0.01340
256	21.20	185.50	0.00041	2.81220	0.02200
257	21.59	146.50	0.00014	3.18830	0.01650
258	21.59	146.50	0.00017	1.81080	0.01040
259	21.62	190.40	0.00022	2.42080	0.01100
260	21.65	205.10	0.00015	2.95580	0.01560
261	21.82	180.70	0.00013	2.45670	0.01100
262	21.97	151.40	0.00028	4.91490	0.01860
263	22.01	146.50	0.00017	2.45130	0.01400
264	22.64	146.50	0.00002	2.05470	0.01190
265	22.65	210.00	0.00018	1.51540	0.01310
266	22.68	185.50	0.00000	1.82530	0.01340
267	22.69	146.50	0.00011	2.66910	0.01740
268	22.98	288.10	0.00002	1.73720	0.01070
269	23.08	210.00	0.00020	2.09350	0.01160
270	23.26	180.70	0.00006	3.10880	0.01710
271	23.44	190.40	0.00066	3.07750	0.01160
272	23.53	146.50	0.00023	2.13000	0.01370
273	23.54	210.00	0.00002	1.89510	0.01070
274	23.69	190.40	0.00026	4.00970	0.01830
275	23.71	185.50	0.00001	1.56390	0.01130
276	23.84	180.70	0.00071	2.95070	0.01500

277	24.04	185.50	0.00003	1.81880	0.00890	306	26.55	146.50	0.00006	2.57660	0.01190
278	24.11	146.50	0.00007	2.48410	0.01370	307	27.05	156.30	0.00005	1.75690	0.01070
279	24.23	210.00	0.00023	1.54750	0.01220	308	27.11	156.30	0.00017	2.28880	0.01370
280	24.29	146.50	0.00027	2.52910	0.01340	309	27.15	185.50	0.00013	1.87610	0.00790
281	24.61	151.40	0.00018	2.80560	0.01070	310	27.23	156.30	0.00009	1.84710	0.01160
282	24.93	210.00	0.00003	1.48650	0.00850	311	27.28	185.50	0.00011	2.61900	0.01190
283	25.10	180.70	0.00053	2.09920	0.01040	312	27.60	210.00	0.00015	1.96930	0.00950
284	25.27	210.00	0.00022	1.87410	0.01500	313	27.76	185.50	0.00003	2.09260	0.00920
285	25.28	151.40	0.00006	3.44940	0.01370	314	27.77	185.50	0.00048	1.97160	0.00820
286	25.46	185.50	0.00008	2.00700	0.00850	315	27.88	156.30	0.00023	2.53720	0.01500
287	25.52	239.30	0.00004	1.91480	0.01010	316	27.89	185.50	0.00012	2.98030	0.01500
288	25.53	185.50	0.00043	2.17470	0.00950	317	27.98	180.70	0.00031	2.13460	0.01010
289	25.58	190.40	0.00053	2.11470	0.01130	318	28.06	180.70	0.00013	1.90230	0.00980
290	25.60	180.70	0.00046	5.92270	0.02350	319	28.11	156.30	0.00001	1.64780	0.00700
291	25.77	283.20	0.00037	3.03730	0.01400	320	28.68	180.70	0.00029	2.45880	0.01310
292	25.84	210.00	0.00026	1.59740	0.01070	321	28.85	210.00	0.00017	1.47430	0.01160
293	25.95	146.50	0.00020	1.31790	0.01070	322	29.02	180.70	0.00013	2.07630	0.00980
294	25.97	210.00	0.00027	2.07920	0.00820	323	29.44	205.10	0.00028	2.19880	0.01220
295	26.04	190.40	0.00016	2.38100	0.01130	324	29.81	185.50	0.00035	2.10560	0.00890
296	26.15	156.30	0.00004	1.92690	0.01100	325	29.89	151.40	0.00015	1.61820	0.01040
297	26.26	239.30	0.00014	1.61390	0.01310	326	30.95	278.30	0.00028	1.45370	0.00980
298	26.34	185.50	0.00011	2.61110	0.01100	327	31.43	278.30	0.00026	1.69630	0.01040
299	26.36	185.50	0.00019	1.77810	0.00760	328	32.93	278.30	0.00028	1.90550	0.01190
300	26.39	185.50	0.00012	2.58830	0.01040	329	33.31	190.40	0.00048	2.53510	0.01530
301	26.39	185.50	0.00019	3.14930	0.01310	330	34.39	185.50	0.00014	1.45740	0.00980
302	26.42	190.40	0.00001	1.80080	0.01130	331	34.92	185.50	0.00045	1.63010	0.01040
303	26.46	185.50	0.00010	3.09140	0.01310	332	35.92	210.00	0.00015	1.82100	0.00820
304	26.46	185.50	0.00007	3.17180	0.01040	333	36.27	190.40	0.00024	2.51630	0.01220
305	26.52	190.40	0.00016	1.99340	0.00950	334	36.42	151.40	0.00002	2.73990	0.01190

335	37.50	210.00	0.00017	1.82100	0.01250
336	37.82	210.00	0.00024	3.12730	0.01770
337	39.07	185.50	0.00050	1.78380	0.00950
338	39.09	146.50	0.00010	3.54020	0.02380
339	41.75	210.00	0.00014	3.73250	0.01740
340	41.90	170.90	0.00031	8.01470	0.03660
341	47.24	185.50	0.00002	2.63570	0.01280
342	47.28	185.50	0.00002	2.13350	0.01010
343	48.32	185.50	0.00005	2.25020	0.01130
344	52.66	210.00	0.00008	1.49220	0.01070
345	53.68	185.50	0.00010	6.84460	0.04880
346	54.40	185.50	0.00001	1.49480	0.01070
347	57.85	185.50	0.00021	7.59770	0.06010
348	58.60	146.50	0.00027	1.98720	0.01070
349	61.89	180.70	0.00024	3.36040	0.01800
350	61.93	185.50	0.00065	4.57490	0.02530
351	61.94	205.10	0.00052	3.49520	0.01860
352	61.98	185.50	0.00007	8.92330	0.01590
353	62.16	180.70	0.00023	6.78180	0.00760
354	62.19	205.10	0.00048	9.14970	0.01250
355	62.24	180.70	0.00013	1.32670	0.01220
356	62.37	185.50	0.00008	5.84930	0.01430
357	62.44	185.50	0.00025	5.99620	0.01560
358	62.47	185.50	0.00025	5.99620	0.01560
359	62.58	185.50	0.00086	6.80620	0.01400
360	62.65	180.70	0.00079	6.56270	0.01340
361	62.94	190.40	0.00064	2.21920	0.01280
362	63.10	195.30	0.00029	3.78970	0.01070
363	63.44	185.50	0.00036	1.76860	0.00790
364	64.67	210.00	0.00027	2.76210	0.00820
365	65.32	185.50	0.00058	2.57890	0.01040
366	66.03	185.50	0.00045	2.70980	0.01250
367	67.42	190.40	0.00093	2.20890	0.01070
368	68.16	185.50	0.00121	3.85590	0.01190
369	68.47	185.50	0.00137	3.17230	0.01710
370	68.48	185.50	0.00120	4.55350	0.01160
371	68.52	185.50	0.00108	1.87290	0.01310
372	69.44	185.50	0.00191	8.81230	0.01280
373	69.53	185.50	0.00047	2.67450	0.01190
374	69.65	185.50	0.00082	1.47080	0.01070
375	70.10	185.50	0.00076	2.79460	0.01500
376	70.21	185.50	0.00111	3.20280	0.01770
377	70.83	185.50	0.00130	1.67850	0.01070
378	71.75	185.50	0.00070	6.73670	0.01220
379	72.10	185.50	0.00006	2.12720	0.01070
380	72.25	185.50	0.00001	4.84110	0.00950
381	72.83	185.50	0.00001	2.09960	0.01100
382	79.25	190.40	0.00020	9.28420	0.01190
383	81.40	190.40	0.00044	2.47890	0.01220
384	86.69	180.70	0.00006	2.08560	0.01190
385	86.71	180.70	0.00020	2.08570	0.01130
386	86.72	180.70	0.00011	2.16030	0.01190
387	86.80	180.70	0.00002	1.88830	0.01100
388	86.85	180.70	0.00027	2.37630	0.01280
389	87.08	180.70	0.00008	3.31770	0.01890
390	87.39	180.70	0.00000	2.05810	0.01130
391	90.84	180.70	0.00034	2.81940	0.01430
392	114.39	151.40	0.00049	2.15300	0.01130

393	115.36	185.50	0.00004	2.03220	0.01130
394	120.26	185.50	0.00017	2.22140	0.01250
395	123.51	185.50	0.00050	2.55370	0.00920
396	125.42	185.50	0.00024	1.80020	0.00980
397	133.58	185.50	0.00004	1.87710	0.01190
398	134.65	151.40	0.00015	3.09280	0.01370
399	135.03	210.00	0.00009	2.27490	0.01650
400	142.21	185.50	0.00006	3.12040	0.01680
401	145.51	185.50	0.00018	2.29580	0.01650
402	146.00	205.10	0.00015	2.94280	0.01100
403	153.61	205.10	0.00015	2.94280	0.01100
404	154.59	210.00	0.00014	3.57680	0.02350
405	157.71	210.00	0.00009	1.20860	0.01070
406	163.46	210.00	0.00020	3.77910	0.03270
407	170.25	151.40	0.00025	2.99670	0.00980
408	174.33	151.40	0.00037	1.47230	0.01100
409	174.51	210.00	0.00040	2.77160	0.02320
410	176.78	185.50	0.00000	3.44070	0.01280
411	179.82	185.50	0.00011	2.87430	0.01500
412	180.81	151.40	0.00014	6.81500	0.06500
413	181.40	190.40	0.00028	1.95800	0.01100
414	187.00	234.40	0.00047	2.12520	0.01530
415	188.27	146.50	0.00017	2.27110	0.01010
416	190.26	185.50	0.00022	3.17580	0.02470
417	193.60	151.40	0.00018	2.74800	0.01100
418	193.97	210.00	0.00021	1.39130	0.01160
419	202.24	210.00	0.00013	5.41700	0.03170
420	243.78	273.40	0.00046	2.03200	0.01280
421	248.80	239.30	0.00011	1.87650	0.01070

422	275.24	151.40	0.00006	6.57320	0.02010
423	331.07	185.50	0.00005	1.98520	0.01160
424	342.97	180.70	0.00021	2.12250	0.01190
425	346.27	180.70	0.00038	2.06770	0.01100
426	358.91	180.70	0.00010	2.06240	0.01340
427	358.94	190.40	0.00003	1.72040	0.01220
428	359.21	180.70	0.00047	1.63350	0.00820
429	362.66	190.40	0.00044	3.39900	0.02380
430	365.86	190.40	0.00008	1.44850	0.01040
431	367.19	185.50	0.00022	2.74190	0.01830
432	369.64	190.40	0.00007	2.49730	0.01680
433	370.23	185.50	0.00064	1.72390	0.01040
434	370.91	151.40	0.00014	1.89530	0.01160
435	372.39	190.40	0.00018	3.12240	0.02170
436	375.26	151.40	0.00020	4.26570	0.02530
437	375.55	156.30	0.00017	2.75340	0.01590
438	376.03	175.80	0.00012	2.01780	0.01190
439	378.05	146.50	0.00011	1.68110	0.00950
440	378.08	210.00	0.00004	2.63170	0.01430
441	378.93	190.40	0.00030	11.30540	0.06900
442	379.54	210.00	0.00005	9.07330	0.04090
443	379.64	205.10	0.00026	2.50090	0.01710
444	379.74	444.30	0.00002	6.60970	0.03570
445	380.02	200.20	0.00017	1.53080	0.01160
446	380.21	210.00	0.00020	1.42290	0.01250
447	380.25	210.00	0.00002	1.27670	0.01100
448	380.46	185.50	0.00019	8.14450	0.05860
449	380.84	210.00	0.00010	2.42920	0.01590
450	380.98	151.40	0.00028	9.38280	0.05430

451	381.21	156.30	0.00009	7.14080	0.04520
452	381.29	185.50	0.00036	1.51780	0.01190
453	381.31	180.70	0.00000	2.83520	0.01560
454	381.40	185.50	0.00009	2.00180	0.01280
455	381.46	146.50	0.00008	2.16130	0.01310
456	381.52	205.10	0.00029	1.89360	0.01400
457	381.61	210.00	0.00017	1.68030	0.01130
458	381.91	151.40	0.00006	2.35630	0.01280
459	381.92	205.10	0.00003	2.52150	0.01250
460	381.94	185.50	0.00001	2.03170	0.01100
461	382.00	185.50	0.00008	9.48610	0.06010
462	382.07	151.40	0.00007	2.02010	0.01220
463	382.33	146.50	0.00014	12.14280	0.07350
464	382.72	210.00	0.00013	1.52860	0.00890
465	382.81	151.40	0.00030	10.55370	0.04730
466	382.82	151.40	0.00010	2.16420	0.01250
467	382.99	210.00	0.00002	2.98100	0.01370
468	383.02	151.40	0.00001	3.10550	0.01740
469	383.03	156.30	0.00027	3.08580	0.01950
470	383.17	146.50	0.00008	20.74420	0.09740
471	383.32	205.10	0.00007	4.02360	0.02380
472	383.33	205.10	0.00036	4.29050	0.02320
473	383.43	146.50	0.00021	2.59120	0.01190
474	383.56	200.20	0.00000	2.99210	0.01370
475	383.57	185.50	0.00034	1.58940	0.01070
476	383.64	151.40	0.00062	1.97080	0.00950
477	383.67	185.50	0.00008	2.37670	0.01650
478	383.68	205.10	0.00023	2.14310	0.01040
479	383.69	210.00	0.00013	3.97250	0.01890
480	383.72	156.30	0.00028	3.89220	0.02230
481	383.77	175.80	0.00029	1.90730	0.00980
482	383.81	146.50	0.00001	2.65210	0.01530
483	383.87	210.00	0.00014	1.46680	0.00890
484	383.98	185.50	0.00072	2.58670	0.01800
485	383.99	210.00	0.00003	2.00290	0.01400
486	384.05	146.50	0.00020	4.12450	0.02350
487	384.07	151.40	0.00002	3.95460	0.02140

Table 6.10: Tensile test data of Galvanized Iron

Data Point	Time (s)	Stress (MPa)
1	2.72	0
2	5.45	34
3	8.17	69
4	10.90	99
5	13.62	121
6	16.34	140
7	19.07	157
8	21.79	173
9	24.51	187
10	27.24	201
11	29.96	213
12	32.69	226
13	35.41	239
14	38.13	252
15	40.86	265
16	43.58	278
17	46.31	291
18	49.03	304
19	51.75	317
20	54.48	331
21	57.20	344
22	59.93	357
23	62.65	368
24	65.37	353
25	68.10	354
26	70.82	355
27	73.54	356
28	76.27	358
29	78.99	360
30	81.72	362
31	84.44	363
32	87.16	362
33	89.89	362
34	92.61	361
35	95.34	360
36	98.06	360
37	100.78	360
38	103.51	361
39	106.23	360
40	108.96	360
41	111.68	355
42	114.40	352
43	117.13	351
44	119.85	350
45	122.57	348
46	125.30	351
47	128.02	351
48	130.75	350
49	133.47	346
50	136.19	344
51	138.92	343
52	141.64	344
53	144.37	343
54	147.09	340
55	149.81	338
56	152.54	338
57	155.26	339
58	157.98	341
59	160.71	342
60	163.43	343
61	166.16	343
62	168.88	346
63	171.60	348
64	174.33	350
65	177.05	349
66	179.78	345
67	182.50	343
68	185.22	343
69	187.95	344

70	190.67	344
71	193.40	345
72	196.12	346
73	198.84	346
74	201.57	347
75	204.29	345
76	207.01	345
77	209.74	344
78	212.46	346
79	215.19	347
80	217.91	350
81	220.63	346
82	223.36	342
83	226.08	343
84	228.81	351
85	231.53	356
86	234.25	360
87	236.98	361
88	239.70	363
89	242.42	364
90	245.15	365
91	247.87	366
92	250.60	367
93	253.32	367
94	256.04	368
95	258.77	368
96	261.49	369
97	264.22	370
98	266.94	371
99	269.66	371
100	272.39	373
101	275.11	373
102	277.84	375
103	280.56	376
104	283.28	377
105	286.01	378
106	288.73	378
107	291.45	379
108	294.18	379
109	296.90	379
110	299.63	380
111	302.35	379
112	305.07	379
113	307.80	379
114	310.52	378
115	313.25	377
116	315.97	377
117	318.69	376
118	321.42	376
119	324.14	375
120	326.87	374
121	329.59	374
122	332.31	374
123	335.04	373
124	337.76	373
125	340.48	373
126	343.21	373
127	345.93	373
128	348.66	373
129	351.38	372
130	354.10	371
131	356.83	369
132	359.55	367
133	362.28	365
134	365.00	361
135	367.72	357
136	370.45	352
137	373.17	345
138	375.89	329
139	378.62	308
140	381.34	280
141	384.07	12