DEVELOPMENT OF A CRACK MOUTH DISPLACEMENT GAUGE FOR FRACTURE MECHANICS SPECIMENS

By:

SITI NURAIMI BT ABDUL HAMID

(Matrix no.: 120416)

Supervisor:

Dr. Feizal bin Yusof

June 2017

This dissertation submitted to
Universiti Sains Malaysia
As partial fulfilment of the requirements to graduate with honours degree in
BACHELOR OF ENGINEERING (MECHANICAL ENGINEERING)

School of Mechanical Engineering
Engineering Campus
Universiti Sains Malaysia

DECLARATION

I hereby declare that the word reported in this thesis is the result of my own investigation and that no part of the thesis has been plagiarized from external sources. Materials taken from other sources are duly acknowledgement by giving explicit references.

Name of student : Siti Nuraimi bt Abdul Hamid Signature:

Date :

ACKNOWLEDGEMENT

Alhamdulillah, I express all my gratitude and all praise to Allah SWT for giving me the chance to have a healthier life during completing this project and writing the thesis.

Firstly, I would love to express my deepest gratitude and thankfulness to my supervisor, Dr. Feizal bin Yusof for the valuable guidance and help in completing my final year project.

My utmost appreciations to all academic and technical staff especially Mr. Fakhrurazi, Mr. Baharom, Mr. Zul, Mr. Fariz, Mr. Kamarul and Mr. Abdul Halim for their assistance and guide through the workshop work during my project.

I would like to take this opportunity to thank my fellow colleagues who always been there giving me advice, guidance and supported me in my research work and my thesis writing

A special thanks to my parents whose encourage me all the time to finish this final year project, I would love to thank my loving mother and father for theirs pray, love and encouragements during my academic journey. Lastly, to those who contributed directly or indirectly in this research, I appreciate your kindness.

TABLE OF CONTENTS

Contents **Page**

LIST OF TABLES

Contents **Page**

LIST OF FIGURES

Contents **Page**

LIST OF ABBREVIATION

CT Specimen	Compact specimen
CMOD	Crack mouth opening displacement
BFS	Back face strain
COD	Crack opening displacement
ASTM	American Society for Testing and Materials
Al	Aluminium
Cu	Copper
Si	Silicon
Mg	Magnesium
Zn	Zinc
HDPE	High density Polyethylene
LDPE	Low density polyethylene
CTOD	Crack tip opening displacement
CTOA	Crack tip opening angle
LEFM	Linear elastic fracture mechanic
EDM	Electro discharge machining

LIST OF SYMBOLS

V	Crack opening displacement
K_Q	Fracture toughness
K_{IC}	Fracture toughness of metallic materials
J_{IC}	Elastic-plastic fracture toughness
K_I	Intensity factor
K	Stress intensity factor
V_m	Crack mouth displacement
E	Young modulus
E'	Effective young’s modulus
υ	Poisson’s ratio
kN	Kilo-Newton
mm	millimetre
MPa	mega Pascal
σ_{YS}	yield strength
σ_{UTS}	ultimate tensile strength
ε	strain
δ	deflection
δ_{max}	maximum deflection
RM	ringgit Malaysia
ft	feet
B	specimen thickness
W	width

PEMBUATAN TOLOK ANJAKAN PERMULAAN RETAK UNTUK SPECIMEN FRAKTUR MEKANIK

ABSTRAK

Tolok anjakan permulaan retak dibina untuk ujian fraktur mekanik pada sampel fraktur mekanik. Melalui projek ini, tolok anjakan permulaan retak dibina untuk digunakan untuk ujian fraktur mekanik. Ukuran tolok anjakan permulaan retak yang dibina mengikut ketetapan dari ASTM E399-09. Langkah pemilihan bahan dilakukan untuk memilih bahan yang sesuai untuk digunakan. Spesimen padat digunakan untuk ujian mekanik fraktur. Anjakan permulaan retak diperolehi adalah 0.07574 mm dan nilai tersebut dibandingkan dengan nilai analitikal. Jumlah ralat yang diperolehi adalah 1.3%. Keputusan ini membuktikan tolok anjakan permulaan retak yang dibina dapat digunakan untuk ujian fraktur mekanik dengan ralat kurang daripada 5% Penyebaran keretakan dikira untuk setiap 50 saat menggunakan nilai terikan. Pertumbuhan keretakan dikira menggunakan nilai terikan yang diambil. Nilai kos akhir tolok anjakan permulaan retak yang dibina adalah RM 364.19 di mana nilai tersebut adalah jauh lebih murah dari nilai pasaran tolok anjakan permulaan retak. Pembinaan tolok anjakan permulan retak menunjukkan keberkesanan kos dan boleh digunakan untuk ujian mekanik fraktur.

DEVELOPMENT OF CRACK MOUTH DISPLACEMENT GAUGE FOR FRACTURE MECHANIC SPECIMENS

ABSTRACT

Crack mouth opening displacement (CMOD) gauge was designed to perform fracture mechanic testing on fracture mechanic specimen. In this project, a CMOD gauge was developed to be used in fracture mechanic testing. The designed CMOD gauge follows the standard by ASTM E399-09. Selection of materials was taken to select suitable materials used to develop the CMOD gauge. Compact (CT) specimen was used as the fracture mechanic specimen for the test using fabricated CMOD gauge. From the test, crack mouth opening displacement, V_m was calculated with 0.075974 mm and compared with the theoretical value with error obtained was 1.3%. This result conclude that the designed CMOD gauge can be used to performed the fracture toughness test with error less than 5% which was considered low. Crack length propagation was calculated using strain for every 50 seconds. The crack length growth was calculated by using the strain value. The final cost calculated to fabricate the CMOD gauge was RM 364.19. The costs obtained was extremely cheaper than the current market price for CMOD gauge. The development of CMOD gauge proved to be cost effective and the developed CMOD gauge are able to performed fracture mechanic testing.

CHAPTER 1

INTRODUCTION

1.1 RESEARCH BACKGROUND

Fatigue and fracture are common cause of service failure of engineering components and structures. It is very important to study about fatigue and fracture related problem of any kind of machine parts, components and engineering structure that is related to various type of loading condition during their operation. Fracture mechanics is based on the inherent assumption that there already exists a crack in a work-component or engineering structure. The crack may be man-made as a key-hole, grooves, a notch, a re-entrant corner, or a slot, etc. The crack may exist within a component due to manufacturing defects like slag or impurities inclusion, cracks in a weldment or heat affected zones due to irregular cooling and existence of foreign particles. A serious crack may be nucleated and start growth during their service of the machine elements or structure. Thus, Compact (CT) specimens are the most widely used test specimens to measure fatigue-crack-growth rates in metallic materials. There are two methods that have been used to monitor crack length in these specimens as a function of compliance. These methods are the crack-mouth opening-displacement (CMOD) gage and the back-face strain (BFS) gage, as shown in Figure 1.1. However, cost for commercially available CMOD gauge is expensive and not suitable for modification.

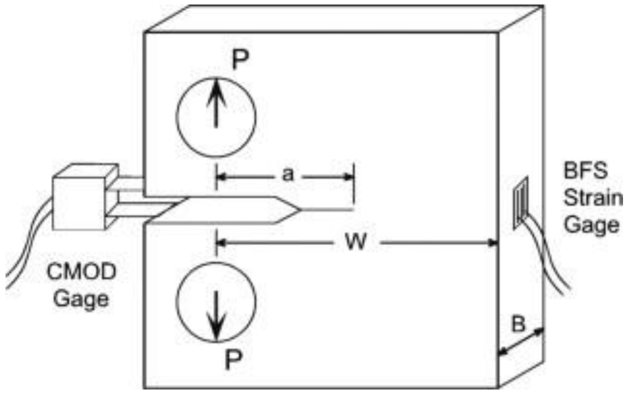


Figure 1.1: Compact specimen with CMOD and BFS gages (Newman, Yamada et al. 2011)

1.2 PROBLEM STATEMENT

Cracks and fracture can occur on any shapes and form of material such as straight, circle and bended. In fact, fracture is one of the reasons for the failure of technological invention in today's modern world. CT specimen can be used as a test specimen to measure fracture related problems in materials. The measurement of the crack opening displacement, V at the mouth of a CT specimen as a function of crack length, a have been measured experimentally (Sullivan and Crooker 1977). The suitable method to monitor crack length in CT specimen is by using a CMOD gauge. However, a commercially developed CMOD gauge in the market can be highly expensive and hence reduce the flexibility for modifications to suit changing needs in measurement of several of cracked specimens. To overcome this problem, CMOD gauge is fabricated with a lower cost compared to commercially developed CMOD gauge. Moreover, a fabricated CMOD gauge is expected to serve the same function as a commercially CMOD gauge available in the market.

1.3 OBJECTIVES

The objectives of this project are as follow:

i. To fabricate a crack mouth opening displacement gauge for fracture mechanics specimen.
ii. To measure crack opening displacement of compact tension specimen during fracture toughness testing.

1.4 SCOPE OF WORK

This project focused on the development of CMOD gauge. The scope of work includes the conceptual design of CMOD gauge using basic CAD software such as Solidworks. This is followed by a fabrication of a prototype CMOD gauge and the assembly of an electrical strain gauge on the cantilever beams which are then link to a data acquisition instrument for fracture mechanics crack characterisation. Aluminium plate with the thickness of 2.0 mm was used for the cantilever beams. The tensile strength testing was investigated using the Instron Universal Testing machine at a constant head-speed of 1.0 mm/min, up to the final failure of the joint. Three test pieces for each of the sample were tested and an average value was taken so that the accuracy of testing is much precise. For the determination of maximum deflection of the cantilever beam, three-point bend testing were conducted using Instron Universal Testing machine at a constant head-speed of 1.0 mm/min. The fabricated CMOD gauge was mounted in the machined crack mouth of the CT specimen for the measurement of crack opening displacement (COD), crack size and fracture toughness, K_Q of the CT specimen.

CHAPTER 2

LITERATURE REVIEW

2.1 CMOD GAUGE

CMOD gauge are designed to sense crack openings and meet the ASTM E399 standard which are suitable for fracture toughness, K_{Ic}, elastic-plastic fracture toughness, J_{Ic}, and crack growth rates. Crack mouth opening is typically used to monitor crack growth in a specimen during fracture mechanics testing. A specific design on CMOD gauge is given in ASTM E399-09.

2.1.1 Principle operation of CMOD gauge

According to ASTM E399, CMOD gauge consists of two cantilever beams and a spacer block clamped together with a single end nut. Electrical-resistance strain gauges are adhesively bonded to the tension and compression surfaces of each cantilever beam. The deflection of the beams will result in a change of voltage across the strain gauges which vary linearly with a different displacement. CMOD gauge will be attached to sharp knife edges in order to ensure the end of the beam is free to rotate. The knife edges can either be machined into the specimen or attached to the specimen at the crack mouth.

2.1.2 Application of CMOD gauge

CMOD gauge commonly referred to as clip-on gauge are primarily used for fracture mechanics testing. It is also used for ASTM E399 or ASTM E1820 for fracture toughness measurement. Besides that, CMOD gauge can be used with a wide variety of specimens including compact tension, round compact tension, C-shaped, bend, and other common specimens.

2.2 CMOD GAUGE COMPONENT

There are four main components of CMOD gauge which are consist of cantilever beams, spacer block, body cover and strain gauges. These components are important for assembly process of CMOD gauge. Cantilever beam produces fiber strain proportional to end deflection while the spacer block provide distance between the cantilever beam (Bubsey, Fisher et al. 1966). The body cover will provide a protection for the inside component from a mechanical damage. Thus, the choices of materials for each component playing an important role to produce a high quality CMOD gauge.

2.2.1 Strain gauge

The strain gauge is one of the most widely used strain measurement. Strain gauge is a device that converts force, pressure, tension and weight into a change in electrical resistance to measure strain. When such material is stretched, the length increases and the cross-section decreases. Thus, there is an increase in electrical resistance where this change in resistance is a measure of its mechanical motion. Measurement of strain near a crack tip with electrical strain gauges has been developed to determine stress intensity factor, K_I (Dally and Sanford 1987). Irwin was first person who suggested the use of strain gages to determine the stress-intensity factor near the crack tip (Irwin,1957). An approached has been extended for making use of multi-element of strain gauges to improves the accuracy in K_I measurement (Dally and Sanford 2013).

2.2.2 Aluminium Alloy (6061)

Aluminium is the third most abundant element in the earth's crust, and the most abundant metallic element. For the last 50 years, it has been second only to iron in its industrial use. The mechanical strength of pure aluminium is relatively weak. This is the reason that aluminium is rarely used for constructional purposes. Some alloy elements are added to increase the mechanical strength of pure aluminium which is mainly silicon, magnesium, copper and zinc. There are two forms of aluminium alloys which are wrought and casting alloys (Ambroziak and Korzeniowski 2010). Wrought alloys are identified with four-digit number indicating the alloying elements. Designation of wrought alloys, the main alloying elements, production forms and application are presented in Table 2.1.

Table 2.1: Typical forms and uses of aluminium alloys (Mathers 2002)

Aluminium wrought alloy designation	Product form	Application
Pure aluminium	Foil, rolled plate, extrusions	Packaging and foil, roofing, cladding, low-strength corrosion resistant vessels and tanks
2XXX (Al-Cu)	Rolled plate and sheet, extrusions, forgings	Highly stressed parts, aerospace, structural items, heavy duty forgings, heavy goods vehicle wheels, cylinder heads, pistons
3XXX (Al-Mn)	Rolled plate and sheet extrusions, forgings	Packaging, roofing and cladding, chemical drums and tanks, process and food handling equipment, vehicles
4000 series (Al-Si)	Wire, castings	Filler metals, cylinder heads, engine blocks, valve bodies, architectural purposes
5000 series (Al-Mg)	Rolled plate and sheet, extrusions, forgings, tubing, piping	Cladding, vessel hulls and superstructures, structural members, vessels and

		tanks, vehicles, automotive body sheet
6000 series (Al-Si-Mg)	Rolled plate and sheet, extrusions, forgings, tubing, piping	High-strength structural members, vehicles, rolling stock, marine applications, architectural applications, automotive body sheet
7000 series (Al-Zn)	Rolled plate and sheet, extrusions, forgings	High-strength structural members, heavy section aircraft forgings, military bridging, heavy goods vehicle

According to ASTM E399-09, the material for the cantilever beams should have a high ratio of yield strength to elastic modulus where aluminium alloy 6061 is found to be suitable material. Commercially aluminium alloy 6061 which is available in sheet, plate and extrusions, offers medium to high strength. It is a heat treatable alloy with medium fatigue strength and very good corrosion resistance.

2.2.3 High density polyethylene (HDPE)

Polyethylene is one of the world's most popular plastics. It is an enormously versatile polymer which is suited to a wide range of applications from heavy-duty damp proof membrane for new buildings to light, flexible bags and films. HDPE plastic has several properties that make it ideal to be used as a packaging and manufacturing product. It is stronger than standard polyethylene, acts as an effective barrier against moisture and remains solid at room temperature. It resists insects, rot and other chemicals. HDPE creates no harmful emissions during its production or during its use by the consumer. HDPE is known for its large strength-to-density ratio. HDPE has little branching which gives it is stronger intermolecular forces and tensile strength than compared to Low density polyethylene (LDPE). Besides, HDPE is a good electrical resistance, light in weight and high tensile strength.

2.3 SIMPLE BEAM THEORY

According to Fleck (1983), design of a strain gauge was based on the sensitivity, the useful measurement range, the difference in slopes of the ends of the two beams when attached to a specimen, and the attached force of the gauge. Figure 2.1 shows a twin cantilever gauge. It is commonly used forms of clip gauge or a CMOD gauge.

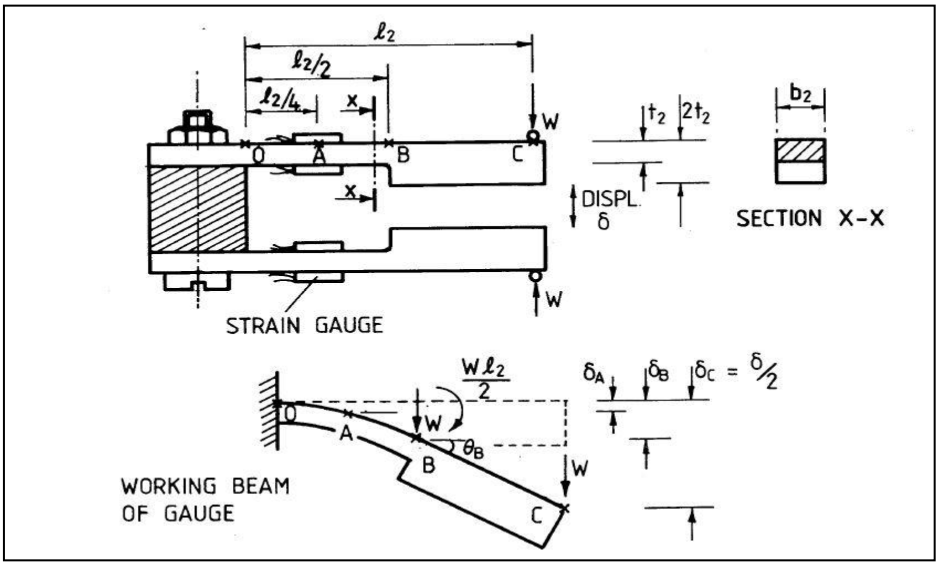


Figure 2.1: Idealisation of a twin cantilever beam for CMOD gauge (Fleck 1983)

From Figure 2.1, the sensitivity and stiffness of a twin cantilever beam gauge were determined by modelling one arm of the beam. It is assumed that the strain gauges experienced the same strain as experienced at point A which located at a distance $\frac{l_2}{4}$ from the end of the gauge. The curvature of portion BC of the arms is assumed to be negligible in comparison with that of portion OB. The end deflection δ_c, of the beam OC is given by:

$$\delta_C = \delta_B + (\frac{l_2}{2})\,\theta_B \quad (1)$$

where δ_B is the deflection of point B and θ_B is the slope at point B.

$$\delta_B = \frac{W(\frac{l_2}{2})^3}{3E_{2l_2}} + \frac{\left(\frac{Wl_2}{2}\right)(\frac{l_2}{2})^2}{2E_{2l_2}} \quad (2)$$

$$\theta_B = \frac{W(\frac{l_2}{2})^2}{2E_{2l_2}} + \frac{\left(\frac{Wl_2}{2}\right)(\frac{l_2}{2})}{E_{2l_2}} \quad (3)$$

using equation (2) and (11) into equation (1).

Equation (1) can now be simplified as:

$$\delta_C = \frac{7}{24} \cdot \frac{Wl_2^3}{E_{2I_2}} \quad (4)$$

The stiffness of the cantilever beam can be expressed as:

$$stiffness = \frac{W}{2\delta_C} = \frac{1}{7} \cdot \frac{E_2 b_2 t_2^3}{I_2^3} \quad (5)$$

The sensitivity of the gauge can be derived which is defined as the ratio of the strain ε_A experienced by the outer fiber of the beam at location A to the end displacement, $2\delta_C$. The bending moment at displacement A is given by $\frac{3Wl_2}{4}$ where force,W times the distance from point A. Thus, equation of sensitivity is given as:

$$\varepsilon_A = \frac{\left(\frac{3Wl_2}{4}\right)(\frac{t_2}{2})}{E_{2I_2}} \quad (6)$$

$$sensitivity = \frac{\varepsilon_A}{2\delta_C} = \frac{9}{14} \cdot \frac{t_2}{l_2^2} \quad (7)$$

2.4 FRACTURE TOUGHNESS

Fracture toughness is a property which indicates the ability of a material containing a crack to resist fracture, and measures in terms of resistance to crack extension. For any material for most design and working applications, fracture toughness is one of the most desired properties. A material that has higher fracture toughness will slightly experience a ductile fracture while brittle fracture will likely experience for a materials with less fracture toughness (Hertzberg 1989). The stress intensity factor K, the J-integral, CTOD (δ), and the crack-tip opening angle (CTOA) are the key parameters mostly used in fracture mechanics. The stress intensity factor K has been introduced by Irwin in 1957 to deal with the intensity of elastic crack-tip fields and represent the LEFM. The J-integral was proposed by J. Rice in 1968 to describe the intensity of elastic plastic crack-tip fields and represents the EPFM (Rice 1968). The CTOD concept was introduced in 1963 by Wells to be used as an engineering fracture parameter which it can be equivalently used as K or J in practical applications (Wells 1963).

2.5 TYPES OF FRACTURE TOUGHNESS TESTING

According to ASTM E399-09, there are four types of fracture toughness testing which includes Testing of Compact Specimens, Testing of Disk- Shaped Specimen, Testing of The Arc-Shaped Tension Specimen and Testing of Bend Specimen.

2.5.1 Testing of Compact Specimens

Testing of Compact Specimens involves the standard compact specimen which is a single edge-notched and fatigue cracked plate loaded in tension. There are two holes at both sides of the notch which will be used for clevis and also to be loaded through pins ac shown in Figure 2.2. The size of these holes depends on the critical tolerances and suggested proportions.

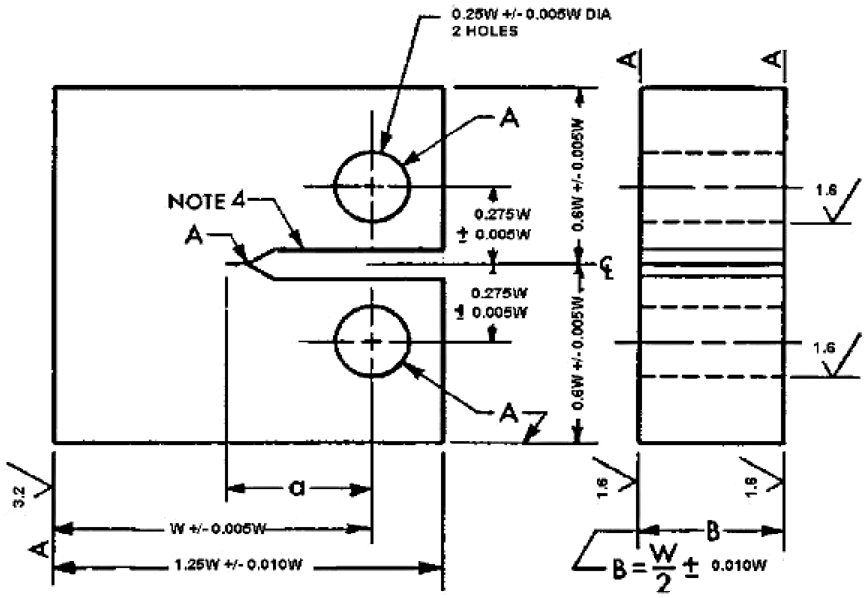


Figure 2.2: Compact CT specimen standard proportions and tolerances after ASTM E399 (2009)

2.6 TERMINOLOGY

There are several terms that are used in ASTM E399-09 to determine the fracture toughness of CT specimens. Those important terms are fracture toughness K_Q, compact specimen crack mouth opening compliance, $\frac{V_m}{P}$ and crack size, $\frac{a}{W}$.

2.6.1 Fracture Toughness, K_Q

From the crack driving stress intensity factor (K) at which a small thin crack in the material starts to grow, the linear elastic fracture toughness of a material is evaluated. It is represented by the term K_{Ic} (critical stress intensity factor value at Mode-I loading condition). According to the theory of Linear Elastic Fracture Mechanics (or LEFM),

K_I is called the stress intensity factor and is dependent on loading conditions and the flaw size in the material, and K_{Ic} is a material property known as the plane strain fracture toughness. The stress intensity factor is usually expressed as where Q is a geometry correction factor depending on the geometry of the structural component and the crack geometry. Several test specimen configurations are available for obtaining plane-strain fracture toughness. The ASTM standards provide the specimen configuration and size, test setup, loading requirement and data interpretation techniques (Materials 2016). From ASTM E399-09, K_Q can be obtained as:

$$K_Q = \frac{P_Q}{\sqrt{BB_N\sqrt{W}}} \cdot f(\frac{a}{W}) \tag{8}$$

where:

$$f(\frac{a}{W}) =$$

$$\frac{\left(2+\frac{a}{W}\right)[0.886 + 4.64\frac{a}{W} - 13.32(\frac{a}{W})^2 + 14.72(\frac{a}{W})^3 - 5.6(\frac{a}{W})^4]}{(1-\frac{a}{W})^{\frac{3}{2}}}$$

P_Q = Force

B = Specimen thickness

B_N = Specimen thickness between the roots of the side grooves

W = Specimen width (depth)

a = crack size

2.6.2 Compact specimen crack mouth opening compliance, $\frac{V_m}{P}$

Calculation of crack mouth opening compliance, $\frac{V_m}{P}$ can be calculated by using crack size measurements where V_m is a crack mouth displacement and P is an applied load as shown in Figure 2.3.

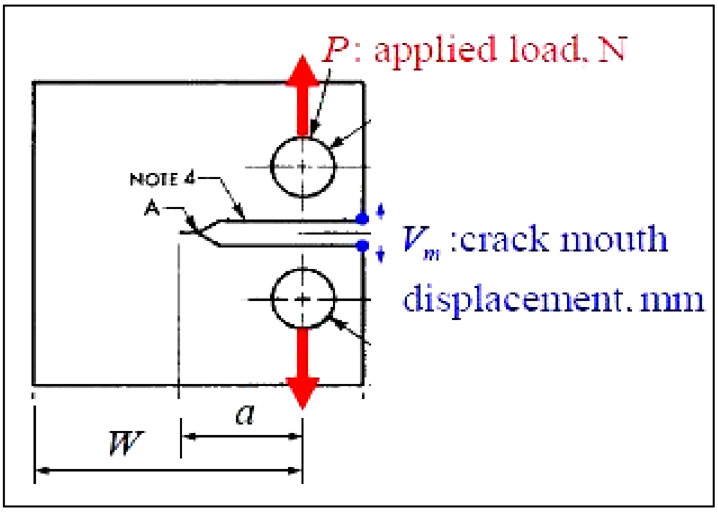


Figure 2.3: Testing compact specimen

Compact specimen crack mouth opening compliance, $\frac{V_m}{P}$ can be obtained as follow:

$$\frac{V_m}{P} = \frac{1}{E' B_e} \cdot q\left(\frac{a}{W}\right) \tag{9}$$

where:

$$q\left(\frac{a}{W}\right) = \frac{19.75}{\left(1-\frac{a}{W}\right)^2}\left[0.5+0.192\left(\frac{a}{W}\right) + 1.385\left(\frac{a}{W}\right)^2 - 2.919\left(\frac{a}{W}\right)^3 + 1.842\left(\frac{a}{W}\right)^4\right]$$

E' = Effective Young's Modulus

v = Poisson's ratio

B_e = $B-(B-B_N)^2/B$

2.6.3 Crack size, $\frac{a}{W}$

Crack size can be calculated by using crack mouth opening compliance measurement, $\frac{V_m}{P}$. Thus, compact specimen normalized crack size is calculated as follows:

$$\frac{a}{W} = 1.000 - 4.500.U + 13.157.U^2 + 879.944.U^4 - 1514.671.U^5 \qquad (10)$$

where:

$$U = \frac{1}{1 + \sqrt{\frac{E' B_e V_m}{P}}}$$

V_m = crack mouth opening displacement, m

P = Applied force, N (lbf)

$B_e = B-(B-B_N)^2/B$

CHAPTER 3

DESIGN AND EXPERIMENTAL PROCEDURE

3.1 INTRODUCTION

This chapter presents the procedure taken to design and fabricate the crack mouth opening displacement gauge (CMOD). The method to fabricate the CMOD gauge including the first step of the fabrication which is design by using Solidwork 2014. Then, the materials selection for the CMOD gauge is taken and the mechanical testing is performed on the material used for the cantilever beam. The mechanical testing included the tensile testing and the three-point bending test to determine the mechanical properties of 6061 aluminium alloy that been used for the cantilever beam. There are three types of materials used for the CMOD gauge which are 6061 aluminium alloy for the cantilever beam, high density polyethylene for the cover of the CMOD gauge and 6082 aluminium alloy for the spacer block between the cantilever beam. Fracture toughness testing is performed after the assembly of the fabricated CMOD gauge to a specimen to make sure the fabricated CMOD gauge function and to determine the fracture toughness of the prepared specimen which is made from 316 stainless steel.

3.2 CMOD GAUGE DESIGN AND MATERIALS SELECTION

The first step on the fabrication of the CMOD gauge was the design of the components of the CMOD gauge. There were five components need to be considered to fabricate a CMOD gauge. The main components were the cantilever beam, the spacer block, the body cover, the strain gauge and the fastener used for the assembly. The materials selection of each of the component are important to make sure the fabricated CMOD gauge can function well.

3.2.1 Cantilever Beam

The cantilever beam of the CMOD gauge is one of the most important component on CMOD gauge. During the fracture toughness test, cantilever beam was placed between the mouth of the crack. The structure of the cantilever beam is important to make sure it is suitable for a specific size of CMOD gauge. Figure 3.1 shows the 3-D design of the cantilever beam.

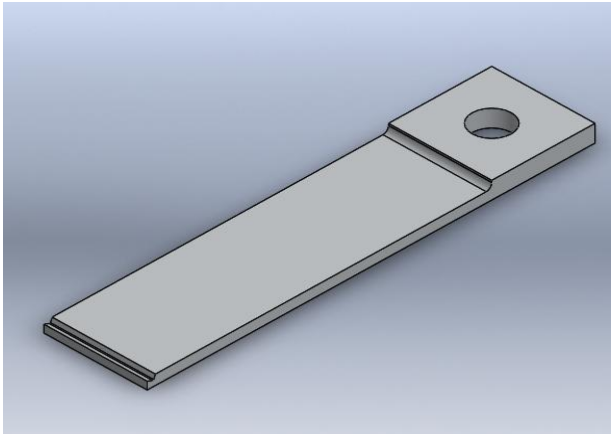


Figure 3.1: Cantilever Beam Solidwork Design

The 6061 aluminium alloy was cut into the dimension of the cantilever beam by the electro discharge (EDM) machining wire cut method. The materials used for the cantilever beam was also important to make sure the cantilever beam will not break during its service or during the fracture toughness test performed using the fabricated CMOD gauge. Proper selection of materials was taken to make sure the cantilever beam is strong enough. In this project, 6061 aluminium alloy was selected as the material for the cantilever beam. 6061 aluminium alloy selected because of its lightweight and corrosion resistance. The corrosion resistance properties of aluminium alloy is desired to make sure the cantilever beam is not corroded when exposed to surrounding. Stainless steel was not selected as the material for cantilever beam because of the stainless steel will give extra weight on the cantilever beam and increase the weight of the CMOD gauge. The cantilever beam was fabricated by Precision Wire-Cut EDM Sodick-AG400L machine.

3.2.2 Spacer Block

The spacer block was located between the cantilever beam to create a distance between them. The dimension of the spacer block is compliance with the dimension of the cantilever beam. Figure 3.2 shows the 3-D design of the spacer block.

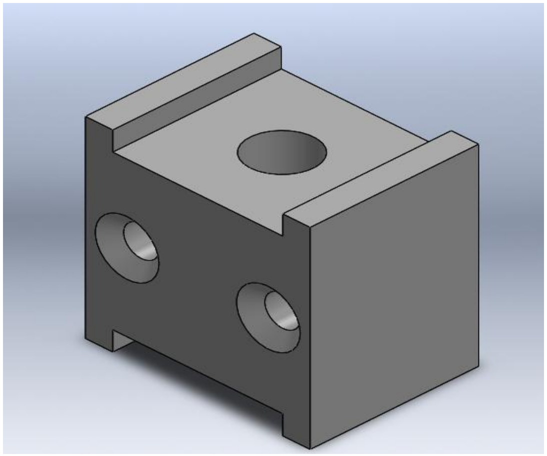


Figure 3.2: Spacer Block Solidwork Design

The materials used for the spacer block is 6082 aluminium alloy block. The 6082 aluminium alloy is chosen to minimize the CMOD gauge weight. CNC 5-axis DMU 40 Monoblock to shape the 6082 aluminium block into it dimension.

3.2.3 Body Cover

Body cover is the external component of the CMOD gauge. Its function as the protection the internal part of the CMOD gauge from mechanical damage. The size and dimension of the body cover was also compliance with the cantilever beam and the spacer block dimensions. The design of the body cover was designed using Solidwork 2014 software. Figure 3.3 shows the 3-D design of the body cover.

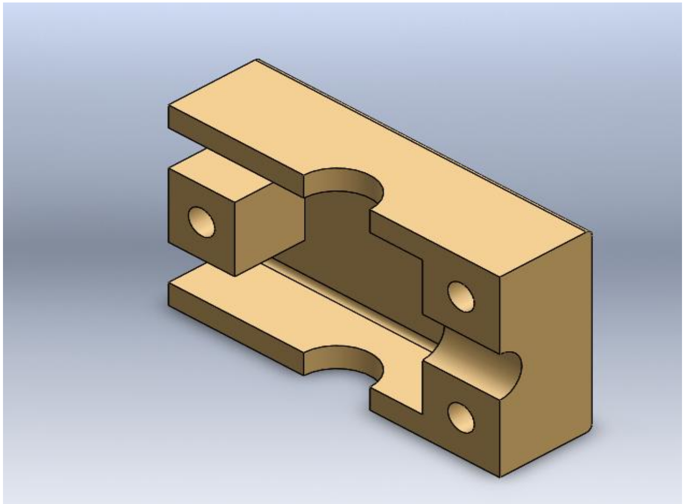
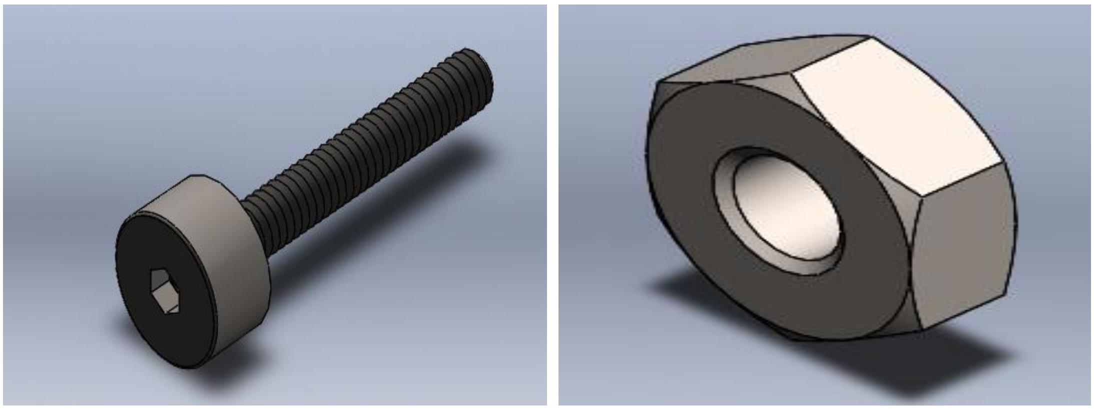


Figure 3.3: Body Cover Solidwork Design

The selection of material for the body cover was an important step to make sure the body cover can protect the internal component of the CMOD gauge from mechanical damage. In this project, high density polyethylene (HDPE) block was used as the material for the body cover. The HDPE block is shaped using CNC 5-axis DMU 40 Monoblock.

3.2.4 Fastener

The components of the CMOD gauge were assembled by using hexagon socket cap screws and nuts. The size of the hexagon socket cap screws was M3x0.1. There were four screws and four nuts used during the final assembly of the CMOD gauge. Figure 3.4 shows the 3-D design of the hexagon socket cap screw and the nut.



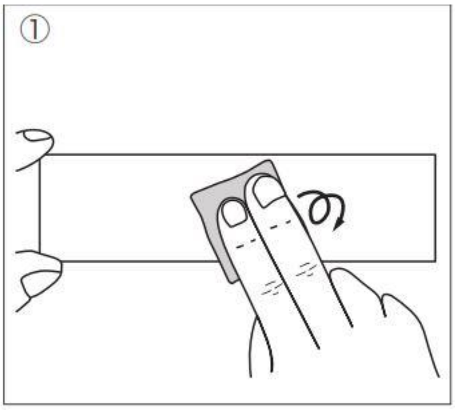
(a) (b)

Figure 3.4: (a) Hexagon socket cap screws (b) Hexagon nut

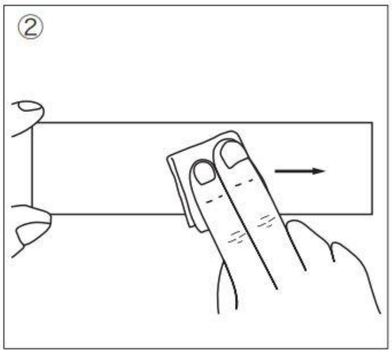
3.2.5 Strain Gauge

Four strains gauge used for the CMOD gauge. KYOWA strain gauge used were KFG 5-120-C1 type with gauge factor 2.08 ± 1.0% and the gauge length is 5 mm. Correct procedure need to be follow to attached the strain gauge to the cantilever beam of the CMOD gauge. The steps details on bonding the strain gauge are as below:

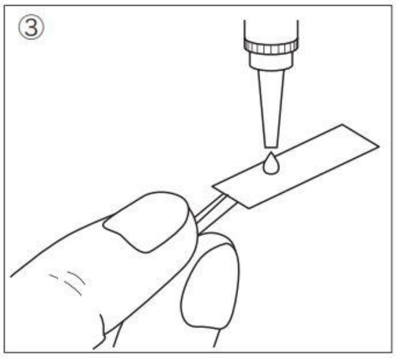
i. Sandpaper (300 grits) used to polish the strain gauge bonding area. The polished area must be wider than the strain gauge size.



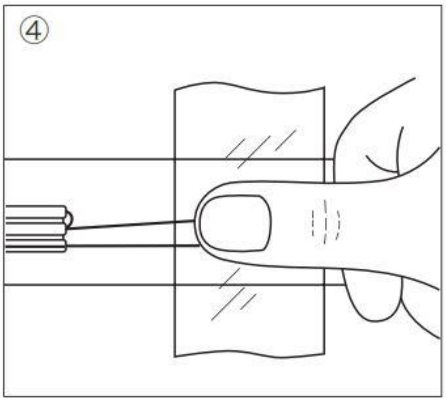
ii. Using cloth which dipped in acetone the bonding area was wiped in single direction to remove any contaminants left from the polishing step.



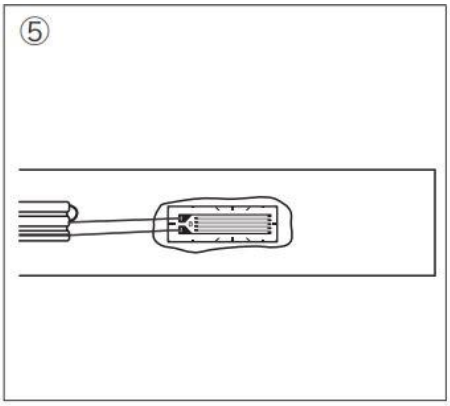
iii. Apply a drop of the adhesive to the rear surface of the strain gauge and attached the strain gauge on the bonding site.

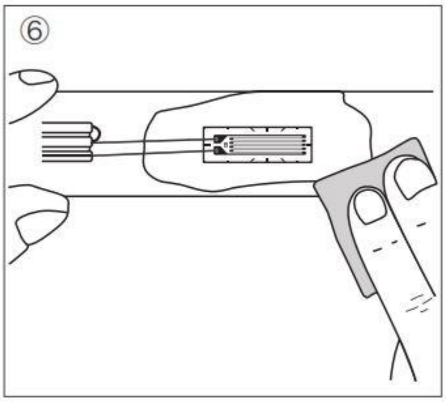


iv. The strain gauge then is covered with the accessory polyethylene sheet and pressed (for 1 minute) until the adhesive is cured.

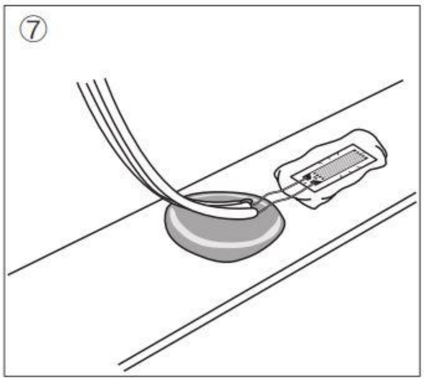


v. The polyethylene sheet is removed once the adhesive is cured.

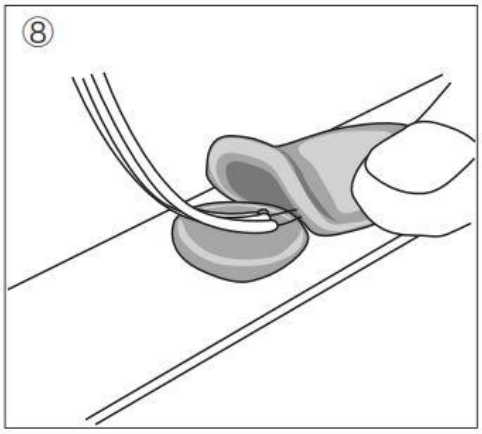




vi. For the wire part, put up the lead wire before the area where the adhesive applied. A block of coating agent was placed below the lead wire with gauge leads lightly slackened.



vii. Completely cover the strain gauge and the lead wire with another block of coating agent.



3.3 CMOD GAUGE ASSEMBLY

The final step of fabricating CMOD gauge was the assembly of all the designed components. There were five components in CMOD gauge which are cantilever beam, spacer block, body cover, strain gauge and the screws and nuts. The assembled of the CMOD gauge components using manual method. Figure 3.5 shows the exploded view of CMOD gauge.

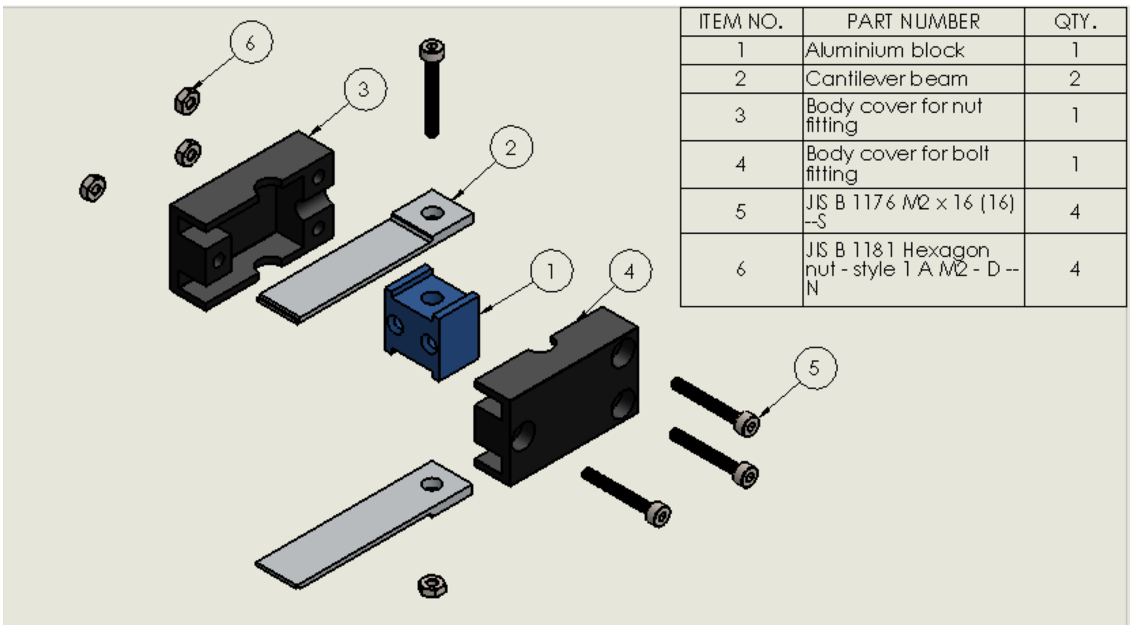


Figure 3.5: Exploded view of CMOD gauge

The 3-D exploded view clearly shows the position of the cantilever beam, the spacer block, body cover, screws and nuts. All of the components were assembled manually. The CMOD gauge is ready to use after assembly process

3.4 MECHANICAL TESTING

Mechanical testing such as tensile test and three-point bend test were performed to get the tensile strength and the maximum deflection of the material used for the cantilever beam which in this project is 6061 aluminium alloy sheet.

3.4.1 Tensile Test

Tensile test is one of the common testing to determine the behaviour of the sample while an axial stretching load is applied. The test was performed in a controlled condition or under ambient to determine the tensile properties of the material. This test was performed on aluminium alloy 6061 sheet which was used for the cantilever beam. The tensile strength of the 6061 aluminium alloy is important to make sure it will not break while performing the fracture toughness test using the CMOD gauge. The tests were conducted following the ASTM standard E8-M (E8-M 2009). The dimensions of the tensile specimens are shown in Figure 3.6. The tensile test was performed using 3367 Instron Universal Testing Machine as shown in Figure 3.8 connected with computer with a software Bluehill. The test was carried out at a displacement rate 1 mm/min. The tensile test generated data after test were investigated to estimate the various mechanical properties of the material.

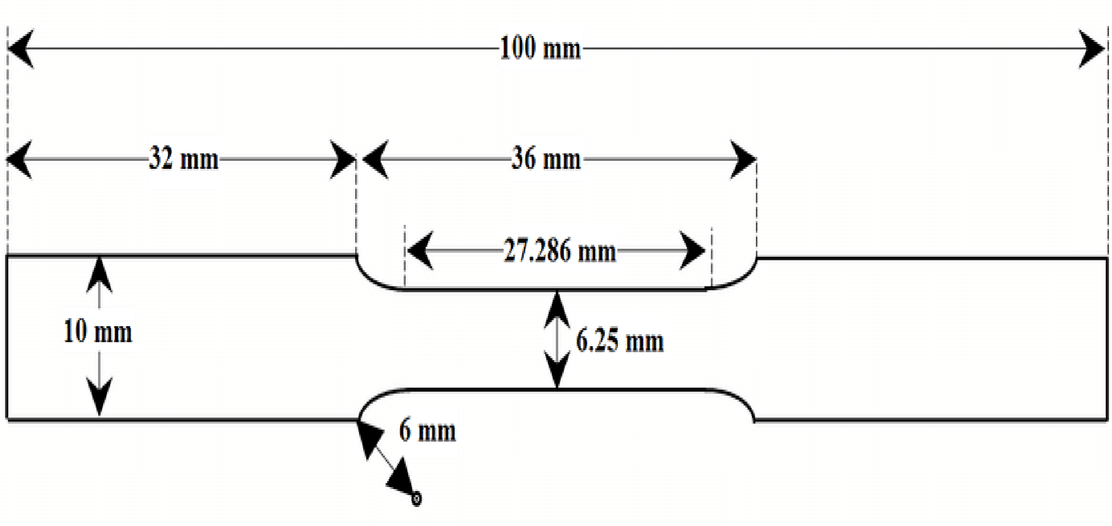


Figure 3.6: Sub-size tensile test specimen following the ASTM E8-M (E8-M 2009)

Figure 3.7: Five samples of aluminium alloy 6061