MEASUREMENT OF STRESS AND STRAIN OF AN AUTOMOTIVE COMPONENT SUBJECTED TO STATIC LOADING

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DECLARATION

"I hereby declare that I have read this project and my opinion this project is sufficient in terms of scope and quality for the award of the degree of Bachelor Mechanical Engineering (Sturcture and Materials)"

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This report is submitted as partial fulfilment of the requirement for the degree of Bachelor of Mechanical Engineering (Structure and Materials)

Faculty of Mechanical Engineering

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DECLARATION

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

Signature	:	....
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Date	:	....

To my beloved family

ACKNOWLEDGEMENT

In the name of Allah s.w.t, The Most Gracious, The Most Merciful. First of all, I would like to share my grateful and thank you Allah for giving me the opportunity to study in this field. Without His permission there is no way I can complete this project successfully. It is such grateful that I can finally fulfil the requirements of Bachelor of Mechanical Engineering (Structure & Materials).

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ABSTRACT

One of the important parts of the passenger vehicle is its braking system or specifically the brake pedal. This has been taken as the main research subject of this Final Year Projek (PSM). The measurement of stress and strain conditions of the brake pedal was determined by conducting a compression test to the brake pedal by controlling the travel distance of brake pedal. The study was done by designing and fabricating a special test fixture to hold the brake pedal while conducting the compression test by applying to static loading through the Instron universal testing machine. The compression load was applied to the brake pedal at three different areas and with three different travelling distance of 2 mm, 3mm and 4 mm respectively. And the areas of applying force is at the centre, left and right side of the brake pedal and is known as F1, F2 and F3 locations respectively. The strain gauges are installed at the critical part of the brake pedal and connected to the strain meter for the determination of strain readings at the specified locations. The load of every position of applying force and travelling distance of braking system has been recorded together with the strain gauge readings. Based on this study, the main achievement of determining the value of maximum stresses or strains at the critical locations of the brake pedal has been done though some influential factors have significantly affected the final results. Other than that, the determination of maximum load that the brake pedal can withstand at three different areas of applied force and three different travelling distance of brake pedal has also been carried out successfully.

ABSTRAK

Salah satu komponen yang penting di dalam kenderaan yang membawa penumpang adalah sistem brek atau lebih spesifik ialah pedal brek. Kajian ini telah diambil sebagai kajian subjek utama untuk Projek Sarjana Muda (PSM). Pengukuran tekanan dan tegangan di pedal brek dapat ditentukan dengan menjalankan uji kaji penekanan kepada pedal brek tersebut dengan menggunakan pedlbagai jarak sistem brek.Kajian ini telah dijalankan dengan mengfabrikasi 'jig' yang digunakan untuk memegang pedal brek tersebut semasa uji kaji dijalankan tertakluk kepada daya statik.Daya static dirujuk sebegai daya yang dikenakan dengan daya yang statik dengan struktur yang static tanpa mengubah posisi daya yang dikenakan. Uji kajii ini dijalankan dengan menggunakan tiga posisi keatas daya yang akan dikenakan di brek pad dan tiga jenis jarak sistem brek. Jarak sistem brek yang dikenakan ialah 2mm, 3mm dan 4 mm dan permukaan daya yang dikenakan di brek pad adalah di bahagian tengah, kiri dan kanan yang dikenali sebagai F1, F2 dan F3. . "Strain gauges" telah dipasang di tempat yang kritikal pedal brek dan telah disambungkan pada "strain meter" untuk mendapatkan bacaan nilai pemanjangan. Daya yang dikenakan pada setiap posisi daya dikenakan dan jarak sistem brek telah dicatat. Daripada pembelajaran ini, dapatlah dianalisis nilai pemanjangan pada pedal brek tersebut daripada sesetengah faktor berpengaruh yang menyebabkan kesan kepada bacaan akhir uji kaji. Selain itu, dapat mengenal pasti daya maksimum yang boleh brek pedal terbut bertahan dengan tiga jaak sistem brek dan tiga permukaan yang berbeza. Akhir sekali, daripada uji kaji ini dapatlah dikenal pasti bahagian yang kritikal yang terdapat pada pedal brek tersebut setelah daya penekanan diaplikasikan.

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ABBREVIATIONS

UTM	Universal Tensile Machine
AISI	American Iron and Steel Institute
ASTM	American Society for Testing and Materials

CHAPTER 1

INTRODUCTION

1.1Background

Brake pedal is an important automotive part for the vehicle that required high strength material in order to produce it. Typically mild or medium carbon steel is used for this part that meet the standard of AISI 1018. Carbon steels of various grades have very high value of tensile strength that involved a lot of heat treatment process in producing it such as normalizing, forging, tempering, annealing, stress relieving, case hardening, core refining and carburizing. With the presence of notches and areas of potential crack to initiate, it is necessary to know and determine the stress fields in the brake pedal completely to avoid its failure while under working condition. The failure process of such automotive component is not only controlled by the local stress amplitude, but also by the stress gradient.[26] (A. Nyoungue., 2016). The use of strain gauges for fracture studies was first suggested by Irwin in 1957. However, at that time researchers were hesitant in using strain gages because of large averaging errors produced due to finite size of these gages.

With the availability of extremely small gauges, it is now possible to effectively use them for fracture studies. Static fracture studies have been conducted recently using strain gauges.

In structural engineering, understanding the behavior of steel under extreme loading conditions is essential for accurate prediction of material response when subjected to combination of severe load scenarios. The overall stress-strain relationship, as well as the mechanical properties of pre-damaged steel is investigated previously at various temperatures and under static loading [2](Mirmomeni et al., 2015). In addition, application of high static load induces irreparable plastic deformation to the material which cannot be neglected when assessing the resistance of the material at room and elevated temperatures.

In order to investigate the mechanical behavior of the pedal brake that will cause the failures, the mechanical test must be conducted with the brake pedal is subjected to various loading conditions.

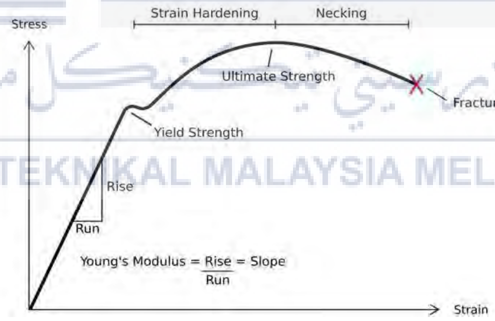


Figure 1.1 Stress-strain curve

For this study, it is crucial that the stress-strain curve of a material as shown in Figure 1.1 is known since it is one of the most important results that need to be determined and further investigated.The curve is normally used to measure a material's mechanical properties such as the yield and ultimate strengths, Young's modulus and ductility of the material. However, they are not without some subtlety, where in the case of ductile materials that can undergo substantial geometrical change during testing[4](Carlsson et al., 2006).

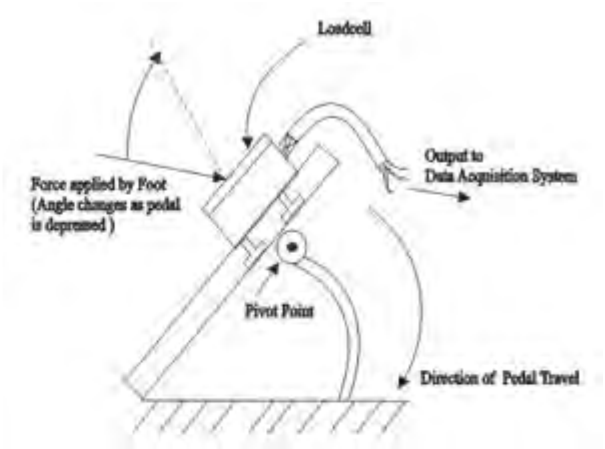


Figure 1.2 Brake Pedal

Figure 1.2 shows the brake pedal where the force is applied by foot of the driver with the angle varied. The maximum stress on the pedal brake is to be found under the various angle of applying load. There is a pivot point which can withstand the applied force or load.

1.2Problem Statement

The mechanical problems of the brake pedal will cause a brake failure such as poor braking performance which will cause it harder or difficult to control and stop the vehicle. Other than that, squealing or grinding noises will occur during braking. Excessive drag during acceleration can also happen if there is a failure on the brake pedal. The brake pedal will typically crack on its critical zone which caused by the excessive loading on the brake pedal or caused by the overloaded pressure subjected to the brake pedal. The present study is conducted to investigate the stress-strain distribution on the brake pedal when subjected to static and dynamic loadings in such a way the location and magnitude of critical stress may be determined and identified experimentally.For the brake pedal, the magnitude of the applied load will depends on the travelling distance of braking system of the respective vehicle. Different size of vehicle will have different design and size of the brake pedal and also its travelling distance to apply load to stop or control the vehicle. For the purpose of this study, a locally manufactured brake pedal for a passenger car has been chosen. It is a brake pedal ofPeroduaKancilwill be taken as the research object of the current study.

1.3Objectives

For the current study, a few objectives will be investigated to complete the scope of this project successfully. The main objective is to investigate the stress-strain behavior occurred on the brake pedal when applying the static and dynamic loadings. This is followed with the objective to investigate the maximum value of stress and applied force for a certain travelling distance of braking system and compare the experimental result with its theoretical value.

1.4 Scope of Project

The scopes of the current project are listed below;

1. To investigate the stress-strain behaviour or distribution on the brake pedal subjected to static and dynamic loadings.
2. To determine the maximum value of applied force for a certain distance of braking system and compare the experimental value with the theoretical result.
3. Lastly, to investigate the effect of dynamic loading on the brake pedal when the force is applied at high rate or speed.

Furthermore, this project will be conducted with some limitations. The aerodynamic aspect of the car will not be included. In addition, the project will not be involved with test of other automotive part of the car.

In addition, this project will be focused only on the vehicles that are locally manufactured for passenger. The brake pedal that have been chosen for this study is one used for Perodua Kancil. Lastly, the specific weight of the driver that will push the brake pedal will not be included in this study because the research found that it is depends on the weight and type of person that apply the force on the brake pedal. It is also stated that the brake failure efficiency is at range of 60 to 85 percent of breaking efficiency[6](Segel, Dugoff, & Campbell, 1971).

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter will explain the stress strain measurement of an automotive part which is brake pedal of a car subjected to static and dynamic loadings. In order to measure the value of stress and strain, the experiment needs to be conducted by installing strain gauges on the brake pedal at a number of locations. The strain gauges will measure the value of strain that will be generated on the brake pedal while compressing the brake pedal with a certain load. The applications and review of strain gauges in measuring strains will be discussed in this chapter. The stress and strain analyses will also be covered in order to get a better understanding on this project.

2.2 Brake Pedal

Brake pedal is one of the automotive part of a car that used to stop or slower down the vehicle or car from accelerating. The brake pedal is also the most important active safety means of a vehicle. Now a day, the braking system of many vehicles has been upgraded and supplemented with electronic system that are helpful to users and will be much safe to use the vehicle with the latest design of braking system [7]. The cracking problems on a brake pedal was typically occurred due to the manufacturing defects of the brake pedal. The cracking also related to the higher stress-strain that exists on the critical section of the brake pedal [3].

The braking system in a car is normally made of mechanical, electronic and hydraulically activated components that used friction on the braking system as shown in Figure 2.1, either to stop the car or slower down the speed of the car. When the force is applied on the brake pedal as shown in Figure 2.2, it will produce a pressure that will moves a piston in the master cylinder. Next, the brake fluid from the master cylinder will force through the brake lines and flexible hoses to the calipers and wheel cylinders. As the driver push the brake pedal thus, the force will be applied. The applied force on the brake pedal is proportional on each of the pistons.

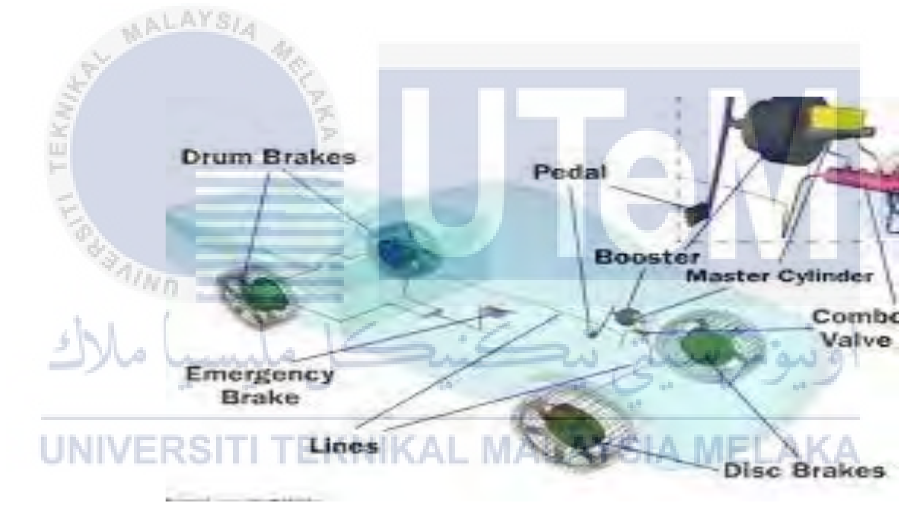


Figure 2.1 Braking system

According to Todorovic, Dubokaetat in 1995 and Park in 2005, the vehicle deceleration or stopping the car will produce the braking effectiveness. The driver will control itself the force that need to apply on the brake pedal by sensing the pedal force and the pedal travel. The brake effectiveness of a car is important as it has the relationship between stopping distance and perceived quality. The braking effectiveness can be determined by the types of the braking system and the system parameters which include the brake pedal travel, brake pedal force and the relationship for the car to stop and certain distances with times. Thus, by improving the parameters of the braking system will improve the effectiveness of the brake pedal.

2.3 Material of Brake Pedal

The actual material of brake pedal used in this study initially was not known except it appears as steel without details information from the manufacturer or supplier. Thus it is necessary to determine the actual type of steel being used to produce the Perodua brake pedal. This may be done through a number of methods such as conducting the tensile test, metallurgical study as well as the hardness test. The first two options will involve the destruction of the brake pedal, thus is it decided that conducting hardness test is the most viable method for the current study. By conducting the Rockwell hardness test, the material of the brake pedal was determined. The Rockwell hardness results gave the information of tensile strength based on the conversion table. From the literatures, it is found that the brake pedal was made from the carbon steel which met the standards of AISI 1018 of mild or low carbon steel. This material has good weldability which considered as the best steel that can be case-hardened. With the great balance of toughness, strength and ductility, brake pedalsare most suitable be made from carbon mild steel. To deform a brake pedal during its production, the carbon steel need to have specific manufacturing controls such as chemical composition, rolling and heating process. To ensure the brake pedal has strong structure, the fabrication process will include the welding, forging, drilling, machining, cold drawing and heat treating process [15]. The properties of the low carbon steel are shown in Table 2.3.1[16]

Table 2.3.1 properties of low carbon steel

Property	Value
Density (kg/cm^3)	7870
Poisson's Ratio	0.29
Young's Modulus (GPa)	205
Thermal Conductivity (W/m^{o}C)	51.9
Specific Heat (J/kg/^{o}C)	486

Table 2.3.2 shows the chemical composition of the low carbon steel, AISI 1018:

Table 2.3.2 Chemical composition of carbon steel

Material	AISI 1018 steel
A(MPa)	520
B(MPa)	269
N	0.282
C	0.0476
M	0.053
T_{melt}(^{o}C)	1520

On the other hand, the mechanical properties of the low carbon steel is depicted in Table 2.3.3

Table 2.3.3 Mechanical propertiesof low carbon steel

Mechanical Properties	Metric
Hardness Rockwell	71
Tensile strength, Yield	370 MPa
Tensile strength, Ultimate	440 MPa
Modulus of Elasticity	205 GPa

2.4 Stress-Strain behaviour of a material

By using the well- known Bridgman equation, the correction of true stress can be determined [8]. The definition and correlation between stress-strain is derivedwhen there is changes of shape and size of the specimen as the external force is applied. On the other hand, strain is derivedwhen the external force is applied thus change the shape or size of the specimen while stress is defined as the internal force per unit area that associated with strain. From this definition, it refers to the Hooke's Law which is stress isdirectly proportional to strain for the linear part of the graph/curveshown in Figure 2.3. The stress-strain curve is virtually independent of specimen dimensions. Based on the Hooke's law,

$$Stress \propto Strain$$

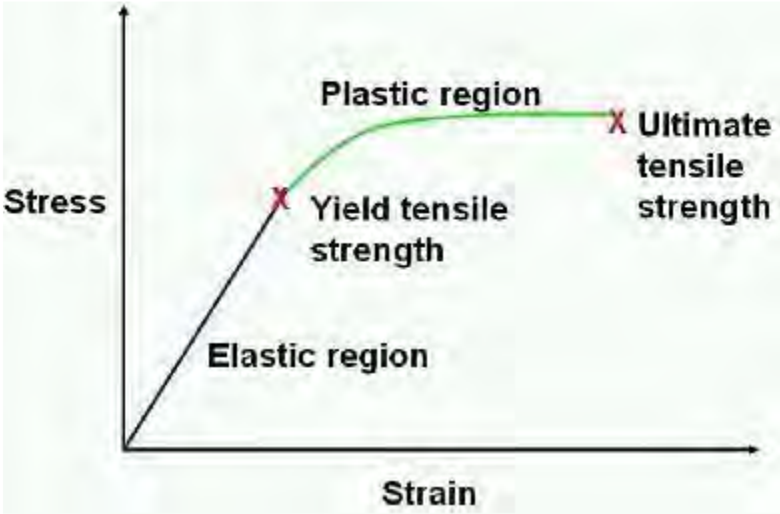


Figure 2.3 Hooke's Law

2.4.1 Bending Stress

For this project, the brake pedal was being compressed for a certain distanceof braking system. The compression of the brake pedal will cause bending stresses alongthe brake pedal. Bending stress is a specific type of normal stressgenerated longitudinally in the brake pedal material except on the neutral axis of the structure. The brake pedal will be subjected to compressive bending stress on the top side of itsneutral axis. While, the bottom side of the brake pedal experienced tensile bending stress. Generally, the bending stress vary linearly with distance from the neutral axis of the brake pedal. Equation (2.1) below shows that bending stress's equation that vary with the distance from the neutral axis.

$$\sigma_b = \frac{Mc}{I} \tag{2.1}$$

where,

σ_b= Bending stress

M = Bending moment

c= Vertical distance from neutral axis

I= Moment of inertia for the brake pedal cross-sectional area

The moment $M$is calculated by using the equation 2.2 below:

$$M = F \times d$$
(2.2)

where,

F = Applied Force to the brake pedal

d = Distance of the applied force F from centroid of the pedal cross-section.

2.4.2 Strain

When the compressive force is applied on the brake pedal with certain load, the brake pedal will experience the deformation of the structure. The deformation will change the length of the materials [17]. This explained well about the definition of strain that related to the change of dimensions and shape of a material. Strain also can be explained as change in length per original length,

$$strain, \varepsilon = \frac{change\ in\ length}{original\ length} = \frac{\Delta L}{L_o}$$
(2.3)

From the Hooke's Law, the relation of stress and strain is,

$$\frac{stress}{strain} = constant$$

The constant is known as modulus of elasticity, E. So, the value of strain can be calculated as:

$$\varepsilon = \frac{\sigma}{E}$$
(2.4)

where,

ε= strain

σ= stress

E= Young's Modulus

The typical value of E is in the range of 190 GPa to 210 GPa depends on the percentage of carbon in steel.

2.4 Static Loading

Static load is defined as the mechanical force that applied to a structure slowly. By using static load, it can determine the maximum allowable loads on the engineering structures. For this study, the structure is the brake pedal that fixed on the fixture. Static load are often applied on the engineering structure because static load can determined the maximum force that the structure can withstand before the structure can collapsed. Any force that applied on a structure steadily without changing the positions considered as static load. Figure 2.3 below shows the graph of static loading that is constant with time.

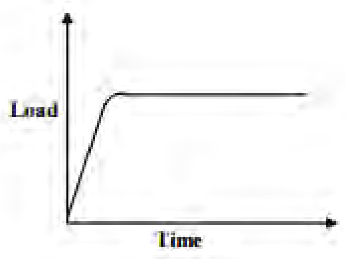


Figure 2.3 Graph of static loading

2.5 Strain Gauges

Strain gauges are used in this project in order to determine or measure the value of normal strain at the location where it was installed. The strain measurement is a very sensitive process to the monitor with the performance of the structure while local property of the structure or material may deteriorated, changed or deformed. [17,18]. There are various types of strain gauges available in the market which can be used for various applications or purposes from measuring the stresses or strains, deformation or loads through its sensing elements. The working principle of strain gauge can be studied by knowing that the installation of the strain gauges on the brake pedal is to sense the changes in dimensions of the brake pedal which may elongate or increase or decrease [16] while supporting the applied loads.

The strain gauge carried out the strain measurement through the concept of resistance change, ΔR. Generally the zig-zag element that formed the strain gages will experience deformation (i.e elongation or contraction) and this is translated in term of electrical signal or changes or resistance. The working principle of strain gauge is governed by:

$$\frac{\Delta R}{R} = K.\varepsilon \qquad (2.5)$$

where,

R = Original resistance of strain gauge, Ω (ohm)

ΔR= Change of Resistance, Ω (ohm)

K= Proportional constant (also known as Gauge Factor as determined by its manufacturer)

ε=Strain

For this project, the strain gauges that has been selected is suitable for steel structure which is metallic materials. The strain gauge have specific Gauge factor which is, K = 2.5.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter will explain about how to measure the stress and strain on the brake pedal subjected to static and dynamic loadings by focusing on how to conduct the experiment. The equipment and apparatus used will be explained including the procedure of the experiment. In addition, this chapter will explain about the test conducted on the actual brake pedal to determine the tensile strength. The hardness tester by using the Rockwell Hardness Testing Machine was conducted in the Material Science Laboratory. The hardness test required the conversion table of the Rockwell Hardness to determine the tensile strength of the tested material. Furthermore, this chapter will briefly explain the designation of fixtures or jig to hold the brake pedal on the Universal Testing Machine INSTRON. This chapter also will explain about the machine used in order to complete this final year project. The flow chart in Figure 3.1shows all the steps in conducting this project. The most important step in this project is conducting the compressive test of the brake pedal by using the specially designed jig, collecting the test data or results and lastly analyze the results by comparing with the theoretical prediction.

Hardness Test

Rockwell

↓

Design of jig by using the correct dimensions specification of INSTRON machine

↓

Fabrication of jig

- Cutting the materials
- Surface finishing
- Drilling
- Welding

↓

Surface finishing of the brake pedal

- Grinding

↓

Installation of the strain gauges

- Critical areas of the brake pedal

↓

Test

Figure 3.1 Procedure Flowchart

3.2 Rockwell Hardness Test

To determine the tensile strength of the brake pedal, the hardness test was conducted in order to determine the behaviour of the brake pedal. The test was conducted on the selected areas of the brake pedal by repeating the experiment up to three times in one area. First, the penetrator and test block was selected by using a diamond penetrator and a 150kg Major Load of Rockwell C Scale. After that, the tester was set up by checking the position of the indicator hand. After that, the barrel dial was set up by rotating the top of the barrel dial toward the observer. Next, the major load was applied. The hand wheel was turned until the dial pointer rests on major pressure load indicated by the chat. The hand wheel was turned back to bring the indicator hand back to 'SET' and the reading was taken on the barrel dial through the Lucite magnifier. Lastly, the reading was taken by observing the read of the column C on the barrel dial with the black numbers. The table of the column C was attached in the Appendix. Figure 3.2 shows the Rockwell Hardness Tester that has been used for the brake pedal.

Figure 3.2 Rockwell Hardness Machine

3.3 Designation of Jig and Brake Pedal

To conduct the test, fabrication of jig needs to be done to hold the brake pedal while conducting the test. Before the fabrication of jig, the design of the jig must also follow the specifications of the INSTRON machine needed. The dimensions had been taken so that the jig can fit and fix into the machine. The jig was drawn by using the software of SolidWork in order to get better designation of jig. Figure 3.3.1 below shows the design of the jig.

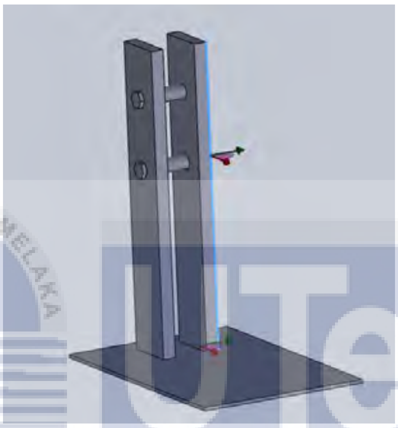


Figure 3.3.1 Jig design

The jig was attached with the spring so that after the load is applied, the brake pedal will return back to the normal position. Figures 3.3.2, 3.3.3 and 3.3.4 show the drawing of the brake pedal drawn by using SolidWork.

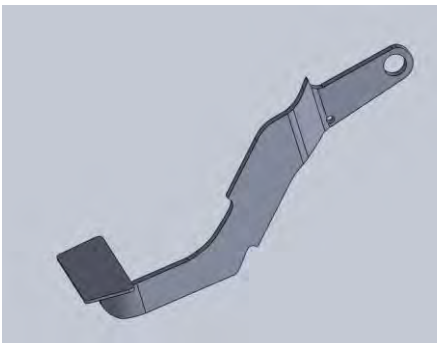


Figure 3.3.2 3D view of brake pedal

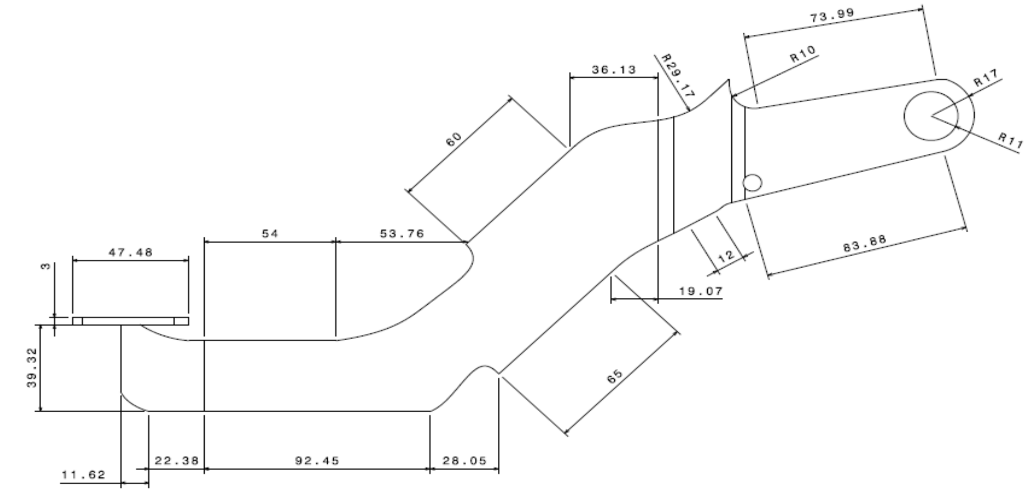


Figure 3.3.3 Side view of brake pedal

Figure 3.3.4 Top view of brake pedal

3.4 Strain gauge

One of the main objective of the project is to measure the stress-strain value of the brake pedal at a number of chosen locations. Thus, the strain gauges have been installed at the outer surfaces of the brake pedal. Altogether, there are six strain gauges were used and fixed to the brake pedal for this study. A certain strain gauge was installed on the critical part of the brake pedal as predicted theoretically where high stress concentration was expected. Before installing the strain gauges, a few steps need to be taken as described below.

First of all, the surface of the brake pedal where the strain gauge will be installed need to be cleaned. Grinding machine was used for this purpose in order to get smooth surfaces. The function of grinding is to remove all of the coating or metal plating on the surface of the brake pedal. After cleaning the surface all the left-over oils or grease were removed by using degreaser. Next, an axis or line marking was drawn where the strain gauges will be aligned properly and installed. Then, a little bit of hot glue was rubbed at the center of the axis drawn earlier. After that, the strain gauge was placed at the center of the axis where glue has been placed earlier on. The strain gauge then need to be connected with the connecting wire part on the upside of the axis. After the strain gauge is considered dried with the glue, the strain gauge is covered with the coating agent to ensure the wire will not bed is connected from the strain gauge. After that, the wire of the strain gauge need to be connected with the other wire before joining it to the multi meter or strain meter. Figure 3.3.5 shows two locations where the strain gauges were fixed to the brake pedal.

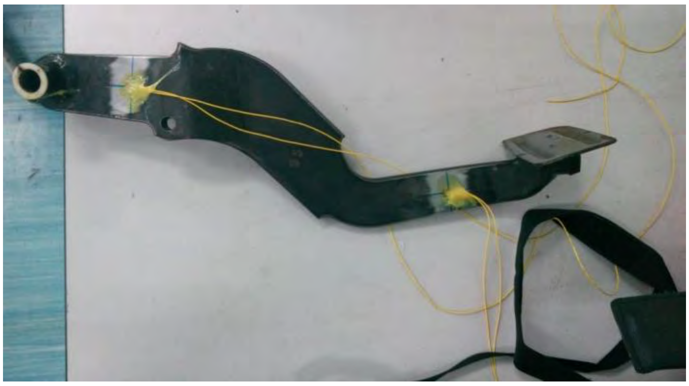


Figure 3.3.5 Strain gauges installed to the brake pedal

3.5 Compression test on the brake pedal

For this project, the actual brake pedal of Perodua Kancil was used in order to measure the stress-strain condition on the critical area of brake pedal under a compression test. The compression test was conducted by controlling the distance of the applied force pressing on the surface of the brake pedal. The force was applied on three different areas or locations on the brake pad. The areas are shown in the Figure 3.3.6 labelled as F1, F2 and F3:

Figure 3.5 Force applied on brake pedal at three different locations

As stated earlier, the test was conducted by controlling the distance of the force applied on the brake pedal. The distance was determined by using the real pressing of the brake pedal in a car. The maximum of a person can press the brake pedal in reality is 40 mm and the minimum is 20mm. The test was conducted by using these methods of pressing the brake pedal in reality. Table 3.5 shows the example of how the strain measurement data / results will be recorded during the test period.

Table3.5 Tabulated Results of strain measurement

CENTRE (F2) - The braking load is applied at the centre of the brake - pad

Braking Distance (mm)	Load (N)	Area 1			Area 2		
		ε1	ε2	ε3	ε1	ε2	ε3
20							
30							
40							

LEFT (F1) - The braking load is applied at the left side of the brake-pad

Braking Distance (mm)	Load (N)	Area 1			Area 2		
		ε1	ε2	ε3	ε1	ε2	ε3
20							
30							
40							

RIGHT(F3)- The braking load is applied at the right of the brake-pad

Braking Distance (mm)	Load (N)	Area 1			Area 2		
		ε1	ε2	ε3	ε1	ε2	ε3
20							
30							
40							

CHAPTER 4

RESULTS AND ANALYSIS

4.0 EXPERIMENTAL RESULTS

4.1 Experimental Data

The experiment has been conducted in order to measure the strain on the actual brake pedal. The experiment was set up by connecting the strain gauge to the strain indicator using the correct directions of wire connector. Figure 4.1.1 and 4.1.2 show the areas that has been installed with the strain gauges.

Figure 4.1.1 Strain gauges area 1

Figure4.1.2 Strain gauges area 2

Based on Figures 4.1.1 1nd 4.1.2 the strain gauges installed at two different locationsthat may have critical value. Three strain gauges were installed at each area or location. The values of the strains have been recorded in Table 4.1

Table 4.1Experimental results of strain measurement.

CENTRE							
		Area 1			Area 2		
Travelling Distance (mm)	Load (N)	ε1	ε2	ε3	ε1	ε2	ε3
20	18	13	10	-4	-7	-3	3
30	23.7	2	13	-1	-1	3	10
40	32	-11	15	1	7	4	15

LEFT							
		Area 1			Area 2		
Travelling Distance (mm)	Load (N)	ε1	ε2	ε3	ε1	ε2	ε3
20	15.15	-4	4	4	-6	-4	8
30	23.3	-6	26	5	-8	-5	12
40	36.1	-10	51	3	-15	-4	8

RIGHT							
		Area 1			Area 2		
Travelling Distance (mm)	Load (N)	ε1	ε2	ε3	ε1	ε2	ε3
20	19.5	-6	8	4	-6	13	12
30	27.26	-14	19	0	0	12	9
40	35.1	-12	33	-1	-10	19	23

The value of ε_1 referred to the strain gauge that installed at the centreof compression axis which is on the bottom of the brake pedal. The value of ε2 referred to the strain gauge that installed on the neural axis of the brake pedal and ε3 referred to the strain gauge that installed at the compression axis of the brake pedal which is on the top of the brake pedal.

ε1 : Compression (bottom)

ε2 : Neutral (centre)

ε3 : Tension (top)

4.2 Experimental Graphs

From the strain results obtained from the experiment work, it is has been converted to graphical form as shown in Figure 4.2.1 for the 20mm pressing distance to apply the compression load to the brake pedal:

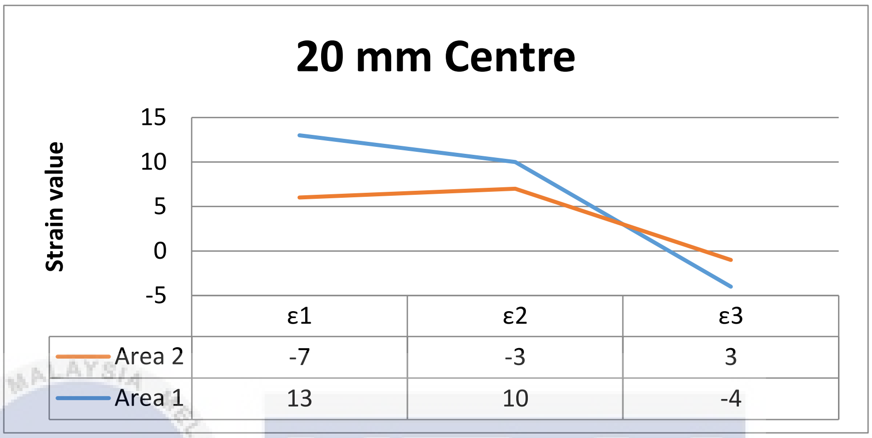


Figure 4.2.1 20 mm Centre

From Figure 4.2.1, it shows that area 1 has higher value of strain compared with the area 2. It is shown that area 1 is considered as critical part of the brake pedal. At area 1 the value of strain at the neutral axis (ε2) is not acceptable as it is higher than value of strain on the compression side (ε1). The load applied on the brake pedal in this case is 18 N at the centre(F2) of the brake pad.

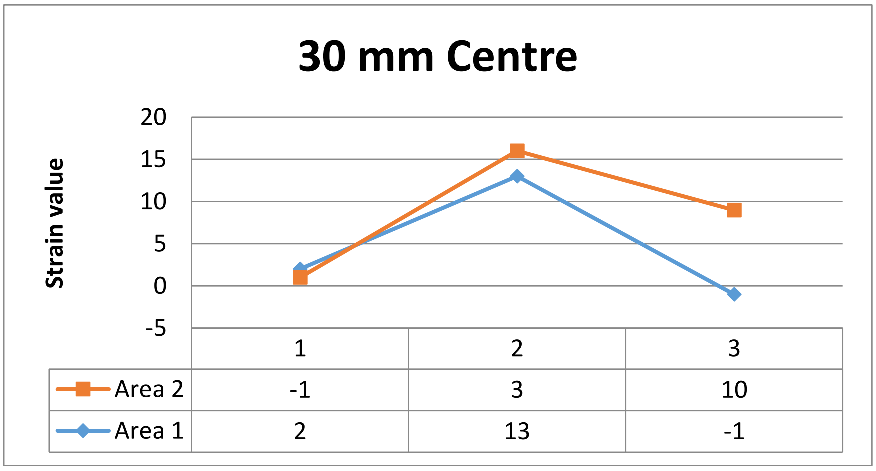


Figure 4.2.2 30 mm Centre

Figure 4.2.2 shows result for the 30 mm travelling distance of braking system. It shows thatthe area 2 has higher value of strain compared to area 1. These results are not accurate because area 1 supposed to have higher results of strain compared to area 2. In addition, the strain value at area 1 seems not quite accurate as the value of strain gauge 1 is higher compared with strain 3 and the value at neutral axis is far away from the value of zero. The applied load is 23.3N of the braking system on the centre of the brake pad.

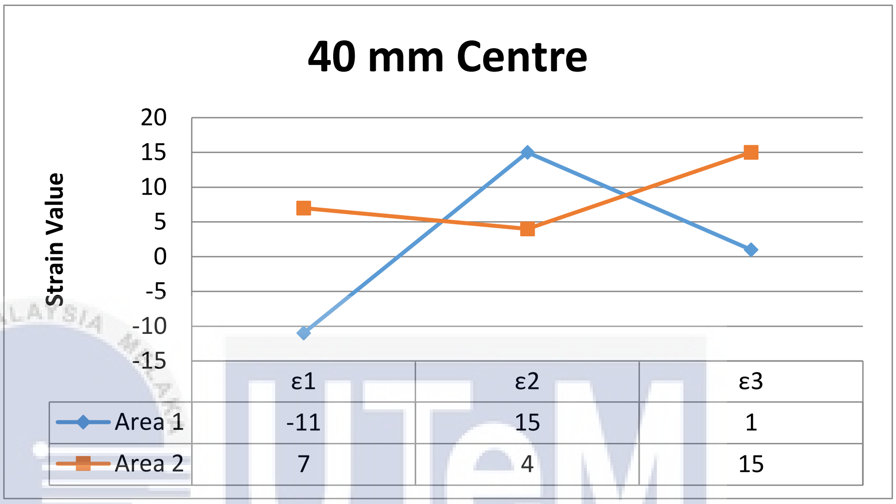


Figure 4.2.3 40mm Centre

At the 40 mm travelling distance of the braking system, the graph of Figure 4.2.3 is obtained. It shows that the value of data is notincreasing linearlydue to some errors while conducting the experiment. The value of strain 2 at the area 2 is higher than strain 3 which is not acceptable. Whereas at the area 2, the value of strain 1 should be negative as it is compression. The value of load applied at the centre of the brake pad (F2) is 32N for this case.

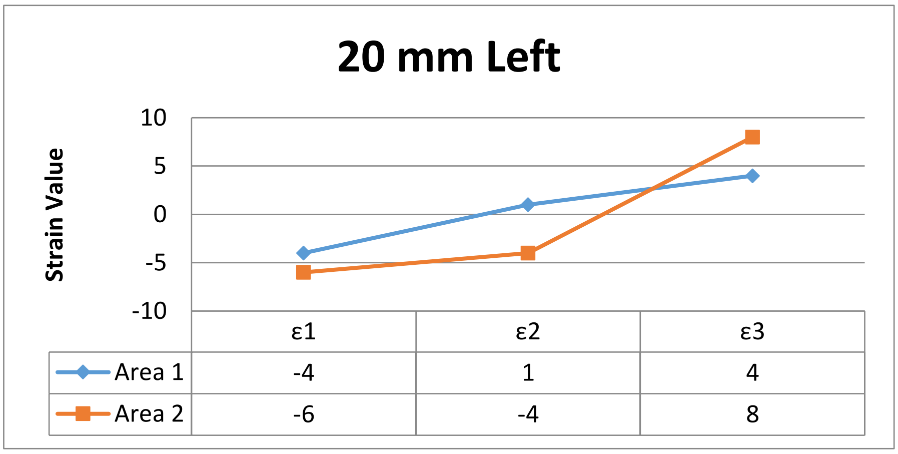


Figure 4.2.4 20 mm Left

From Figure 4.2.4 of 20mm travelling distance of the braking system, the value of strains obtained for area 1 and area 2 is generally constant at the tension, neutral axis and compression sides. The applied load is 15.15 N on the left part (F1) of the brake pad.

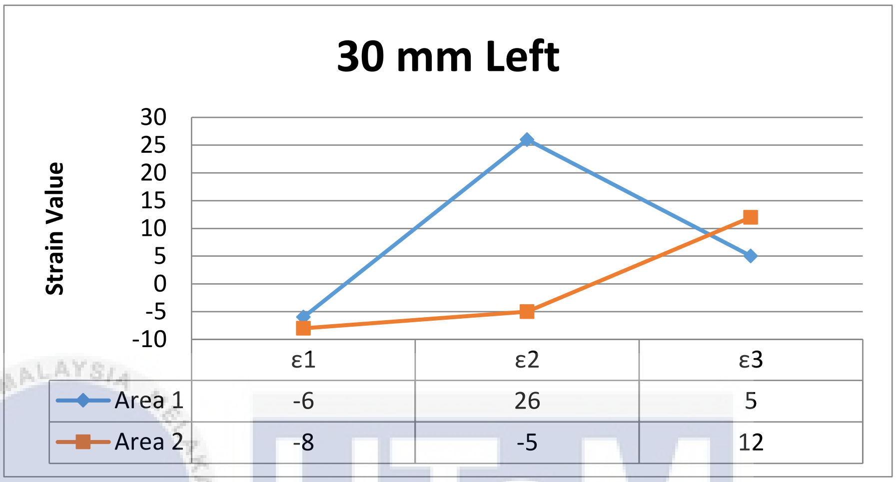


Figure 4.2.5 30mm Left

As for the 30mm travelling distance of the braking system, the results are shown in Figure 4.2.5. The value is quiet acceptable as the critical part of area 1 has higher value of strain compared to area 2. But, for this case the value of strain 2 is higher on the neutral axis compared to the strain 3.The applied load is 23.33 N on the left side of the brake pad.

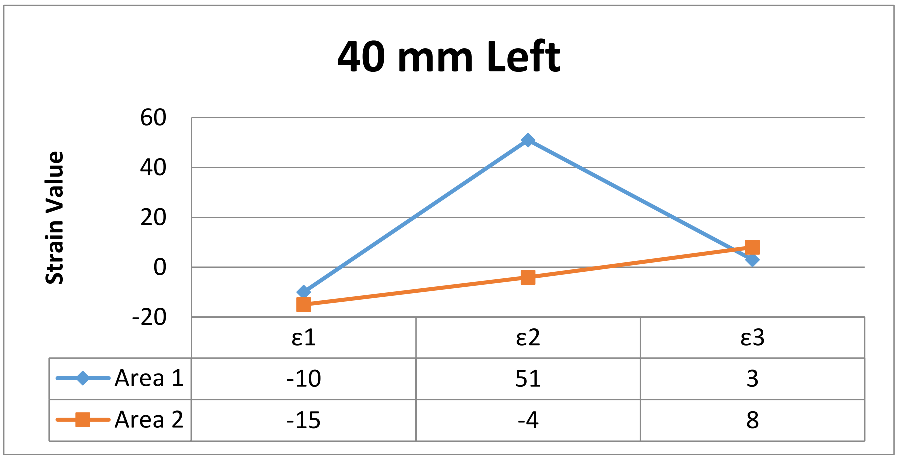


Figure 4.2.6 40 mm Left

For the 40mmtravelling distance, the results are shown in Figure 4.2.6 above. The value of strain 2 at area 1 is not acceptable as the value is higher that strain 3. Strain 2 should be nearly to 0 as it is at neutral axis. The strain on neutral axisis given by strain 2, where is not acceptable since it is higher than the strain on the tension side represented by strain 3 and the value is not equal to zero. At area 2, the value of strain is considered reasonable. The value of applied load is 36.1 N at the left side of brake pad.

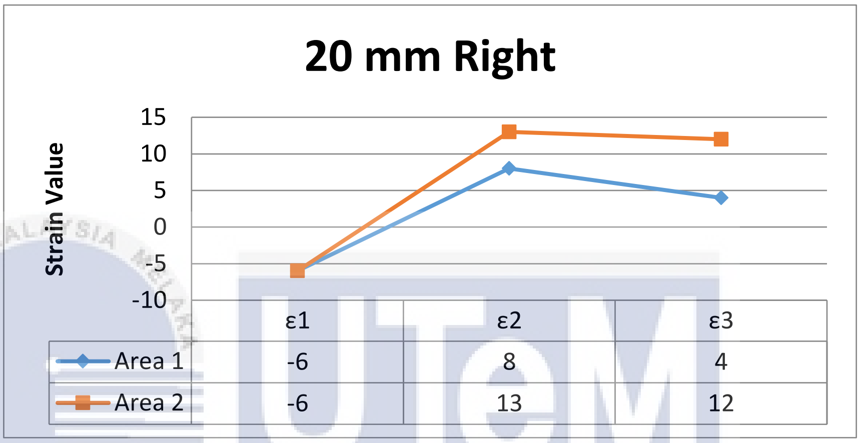


Figure 4.2.7 20 mm Right

From the graph shown in Figure 4.2.7, both areas 1 and 2 have an unacceptable results. At strain gauge 2, the value is higher than the strain 3 and is not closeto zero. The graph shows that area 2 has higher deformation compared to the area 1 and area 3. The applied force of the braking system at 20 mm on the right side of the brake pedal is 19.5 N.

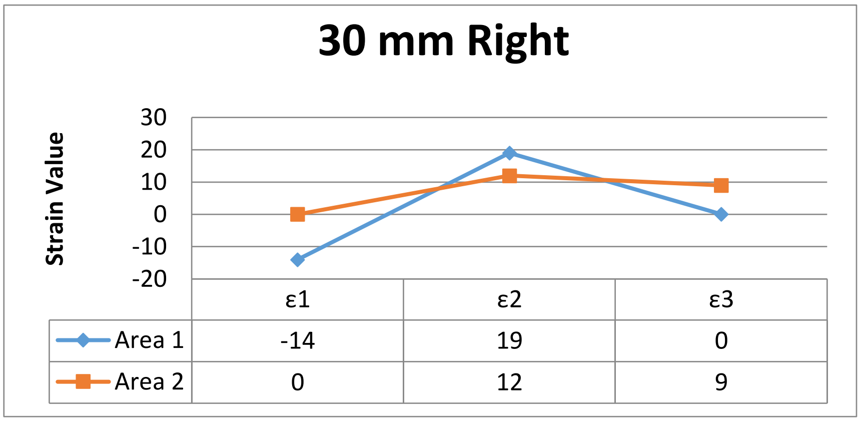


Figure 4.2.8 30 mm Right

At 30 mm travelling distance of the brake pedal, the results are shown in Figure 4.2.8. The data has higher error because the value of strain 1 should be negative which is acceptable for area1 but not for area 2. The value of strain 2 and strain 3 are not acceptable for both areas as the neutral axis have higher value than at the tension axis. The applied force for the 20 mm of braking system at the right side of the brake pedal is 27.26 N.

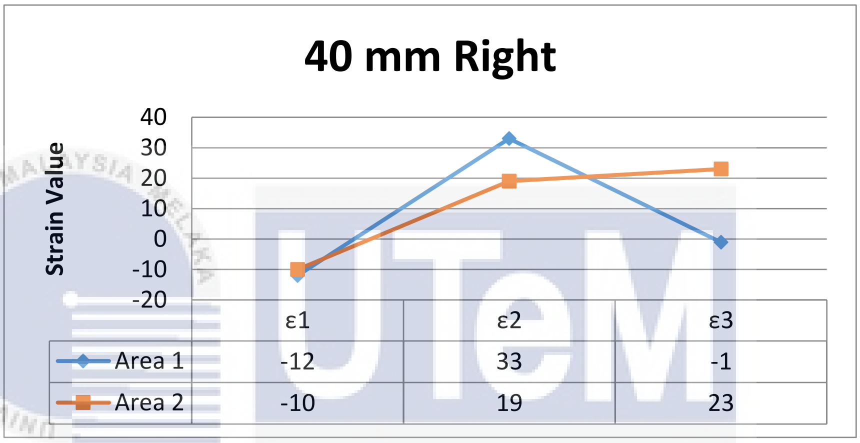


Figure 4.2.9 40 mm Right

For the last graph shown in Figure 4.2.9is for the 40mm travelling distance. It can be seen that the value of strain 1 for both areas has acceptable results as the value is negative as it is on the compression side. The value of strain 2 at area 1 is not acceptable as it is higher than strain 3. The applied load at the right side of the brake pad is 35.1 N.

4.3 Experimental Calculations

From the experiment that has been conducted, it is found that there arebending moment and torsional or twisting moment (torque) effects that occurred on the brake pedal. The bending moment and torqueare calculated by using the method shown below and the final results are shown in the Table. 4.3.1 and Table 4.3.2 respectively. The moment (*M*) and torque (*T*) of the brake pedal at the area 1 and area 2 are calculated by using equations (4.1) and (4.2) with the relevant moment arms (L) are shown in Figures 4.3.1 and 4.3.2:

$M = F \times L_1$............(4.1)

$T = F \times L_2$.............(4.2)

AREA 1

Figure 4.3.1 Area 1 of brake pedal

AREA 2

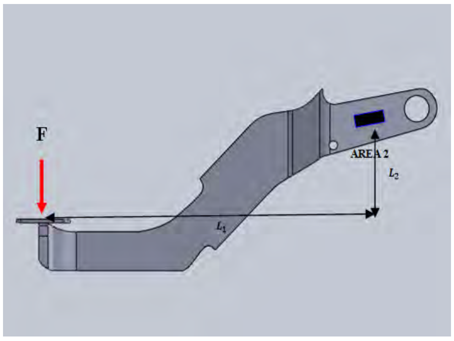


Figure 4.3.2 Area 2 of brake pedal

From the equations 4.1 and 4.2 and figures above, it shows that the moment and torque can be obtained by the length of the brake pedal. The lengthL_1 on figure area 1 and area 2 totally has different length which measured horizontally from the force applied to the installed strain gauge. Same as lengthL_2 that has different length for both areas measured perpendicularly from the applied force to the installed strain gauges.

Sample of calculations of moment and torque for 20 mm travelling distance of the braking system with the applied force at the centre of the brake pad are shown below.

<u>Area 1</u>

Force applied, $F = 18\ N$

Horizontal length from applied force, $L_1 = 0.0392\ m$

Perpendicular length from applied force, $L_2 = 0.08005\ m$

Moment, $M = 18\ N \times 0.0392\ m = 0.70776\ Nm$

Torque, $T = 18\ N \times 0.08005\ m = 1.4409\ Nm$

<u>Area 2</u>

Force applied, $F = 18\ N$

Horizontal length from applied force, $L_1 = 0.275\ m$

Perpendicular length from applied force, $L_2 = 0.055\ m$

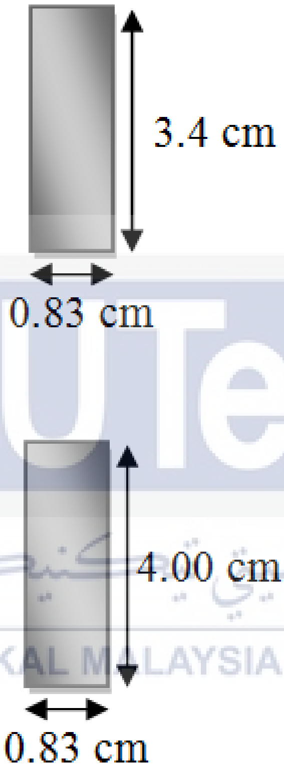
Moment, $M = 18\ N \times 0.275\ m = 4.95\ Nm$

Torque, $T = 18\,N \times 0.055\,m = 0.99\,Nm$

The value of experimental stress can be also calculated by knowing the value of moment of inertia. Both areas of moment of inertia has different dimensions that shown below;

Area 1

Area 2



The value of moment inertia is calculated as below:

$$I = \frac{BH^3}{12} \text{........}(4.3)$$

While, the value of bending stress is computed as follows

$$\sigma = \frac{Mc}{I} \dots \dots \dots (4.4)$$

Sample of calculations for the moment of inertia and stress are shown below for both areas at 20 mm of braking system with the applied force at the centre of the brake pad:

Area 1

Height, $H = 3.4\ cm = 0.034\ m$

Base, $B = 0.83\ cm = 0.0083\ m$

Moment of inertia, $I = \frac{(0.0083)(0.034)^3}{12} = 2.7 \times 10^{-8}\ m^4$

Centre from the tension, $c = 0.0085\ m$

Stress, $\sigma = \frac{(0.70776\ Nm)(0.0085\ m)}{2.7\times10^{-8} kg.m^2} = 0.2213\ MPa$

Area 2

Height, $H = 4.00\ cm = 0.04\ m$

Base, $B = 0.83\ cm = 0.0083\ m$

Moment of inertia, $I = \frac{(0.0083)(0.04)^3}{12} = 4.42667 \times 10^{-8}\ m^4$

Centre from the tension, $c = 0.01\ m$

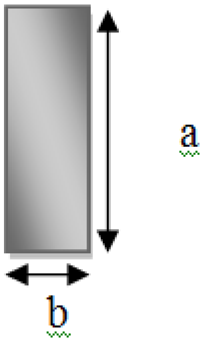
Stress, $\sigma = \frac{(4.95\ Nm)(0.01\ m)}{4.42667\times10^{-8}\ m^4} = 1.1182\ MPa$

As torque occurred on the brake pedal while the load is applied on the brake pad, torsional stress or shearing stress has been assumed to exist on the brake pedal and calculated as shown below:

$$\tau = \frac{T}{c_1 ab^2} \dots\dots\dots (4.4)$$

The value of c_1 is obtained by dividing value of a and b.

Area 1



Cross-section of the brake pedal

a=	3.4	cm	=	0.034	m
b=	0.83	cm	=	0.0083	m
a/b=	4.096386	≈	4		
c1=	0.282				
c2=	0.281				

The value of c is obtained from the table of coefficients for rectangular bars in torsion

Shearing stress, $\tau = \frac{1.4409\ Nm}{(0.282)(0.034m)(0.034m)^2} = 2.1815\ MPa$

Area 2

a=	4.00	cm	=	0.04	m
b=	0.83	cm	=	0.0083	m
a/b=	4.8193	≈	5		
c1=	0.291				
c2=	0.291				

The value of c is obtained from the table of coefficients for rectangular bars in torsion

Shearing stress, $\tau = \frac{0.99\ Nm}{(0.291)(0.04m)(0.034m)^2} = 1.2346\ MPa$

The overall results of calculated stresses are shown in Tables 4.3.1 and 4.3.2 for area1 and area2 respectively.

Experimental calculation for area 1 of the brake pedal

Table 4.3.1 Experimental calculation for area 1

Distance (mm)	Load (N)	ε1	ε2	ε3	Average	Moment (Nm)	Torque (Nm)	(Nm^2)	(Mpa)	t	(MPa)
CENTRE											
20	18	13	10	-4	2	0.70776	1.4409	221294.8681	0.2213	2181471.941	2.1815
30	23.7	2	13	-1	4.666667	0.931884	1.897185	291371.5763	0.2914	2872271.389	2.8723
40	32	-11	15	1	1.666667	1.25824	2.5616	393413.0988	0.3934	3878172.339	3.8782
LEFT											
20	15.15	-4	4	4	1.333333	0.595698	1.2127575	186256.5139	0.1863	1836072.217	1.8361
30	23.3	-6	26	5	8.333333	0.916156	1.865165	286453.9125	0.2865	2823794.234	2.824
40	36.1	-10	51	3	14.66667	1.419452	2.889805	443819.152	0.4438	4375063.17	4.3751
RIGHT											
20	19.5	-6	8	4	2	0.76674	1.560975	239736.1071	0.2397	2363261.269	2.3633
30	27.26	-14	19	0	1.666667	1.0718632	2.182163	335138.7835	0.33514	3303718.061	3.3037
40	35.1	-12	33	-1	6.666667	1.380132	2.809755	431524.9927	0.43152	4253870.285	4.2539

Experimental calculation for area 2 of the brake pedal

Table 4.3.2 Experimental calculation for area 2

CENTRE											
Distance (mm)	Load (N)	Experimental Strain				Moment (Nm)	Torque (Nm)	σ (Nm^2)	σ (Mpa)	τ	τ (MPa)
		ε1	ε2	ε3	Average						
20	18	-7	-3	3	-2.333333	4.95	0.99	1118222.892	1.1182	1234599.309	1.2346
30	23.7	-1	3	10	4	6.5175	1.3035	1472326.807	1.4723	1625555.757	1.6256
40	32	7	4	15	8.666667	8.8	1.76	1987951.807	1.9880	2194843.216	2.1948

LEFT											
Distance (mm)	Load (N)	Experimental Strain				Moment (Nm)	Torque (Nm)	σ (Nm^2)	σ (Mpa)	τ	τ (MPa)
		ε1	ε2	ε3	Average						
20	15.15	-6	-4	8	-0.666667	4.16625	0.83325	941170.9337	0.9412	1039121.085	1.0391
30	23.3	-8	-5	12	-0.333333	6.4075	1.2815	1447477.41	1.4475	1598120.217	1.5981
40	36.1	-15	-4	8	-3.666667	9.9275	1.9855	2242658.133	2.2427	2476057.503	2.4761

RIGHT											
Distance (mm)	Load (N)	Experimental Strain				Moment (Nm)	Torque (Nm)	σ (Nm^2)	σ (Mpa)	τ	τ (MPa)
		ε1	ε2	ε3	Average						
20	19.5	-6	13	12	6.333333	5.3625	1.0725	1211408.133	1.2114	1337482.585	1.3375
30	27.26	0	12	9	7	7.4965	1.4993	1693486.446	1.6935	1869732.065	1.8697
40	35.1	-10	19	23	10.66667	9.6525	1.9305	2180534.639	2.1805	2407468.652	2.4075

4.4 Theoretical Calculations of strain

The experiment was conducted by fixing the value of travel distance of braking system at 20mm, 30mm and 40mm. By doing this, the value of load applied on the brake pad will be varied accordingly. The value of load is considered as fixed value. Thus, the value of bending moment, torque and stresses that have been shown in Tables 4.3.1 and 4.3.2is the considered as equal to the theoretical value. The total length of L_1 and L_2 is the same from the method of calculation for the experimental value of stress.

To calculate the theoretical value of strain, the value of stress that has been calculated earlier is used as for the equation (4.6) below:

$$\varepsilon = \frac{\sigma}{E} \dots \dots \dots \dots (4.6)$$

Sample calculation of theoretical strain at the 20 mm of travelling distance of brake pedalwith the applied force at the centre of the brake pad is demonstrated below:

Area 1

Experimental stress, $\sigma = 0.2213\ MPa$

Assuming modulus of elasticity, $E = 210\ GPa$

Theoretical strain, $\varepsilon = \frac{0.2213\ MPa}{210\ GPa} = 1.05379\ \times 10^{-6} = 1.05379\mu\varepsilon$

Area 2

Experimental stress, $\sigma = 1.1182\ MPa$

Modulus elasticity, $E = 210\ GPa$

Theoretical strain, $\varepsilon = \frac{1.1182\ MPa}{210\ GPa} = 5.3287\ \times 10^{-6} = 5.3287\mu$

The overall calculations of strains are shown in the Table pf 4.4.1 and 4.4.2 respectively

Results of theoretical calculation of strain for area 1:

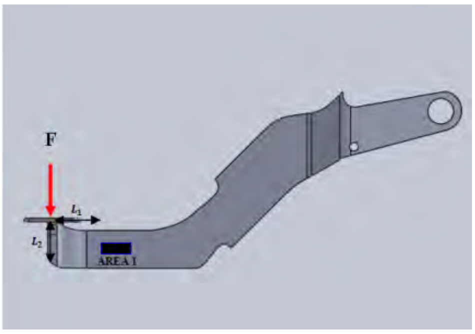


Table 4.4.1 Theoretical calculation for area 1

CENTRE	
Theoretical Strain	
ε	με
1.05379E-06	1.05
1.38748E-06	1.39
1.8734E-06	1.87

LEFT	
Theoretical Strain	
ε	με
8.86936E-07	0.89
1.36407E-06	1.36
2.11342E-06	2.11

RIGHT	
Theoretical Strain	
ε	με
1.1416E-06	1.14
1.5959E-06	1.6
2.05488E-06	2.05

Results of theoretical calculation of strain for area 2:

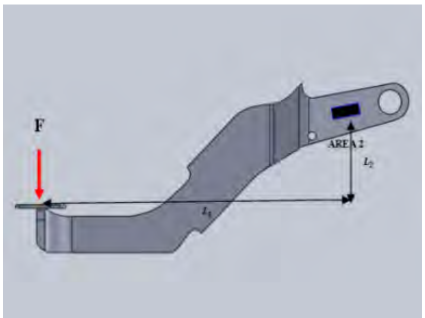


Table 4.4.2 Theoretical calculation for area 2

CENTRE	
Theoretical Strain	
ε	με
5.32487E-06	5.32
7.01108E-06	7.011
9.46644E-06	9.47
LEFT	
Theoretical Strain	
ε	με
4.48177E-06	4.82
6.89275E-06	6.89
1.06793E-05	10.68
RIGHT	
Theoretical Strain	
ε	με
5.76861E-06	5.77
8.06422E-06	8.06
1.03835E-05	10.38

4.5 Comparison of Theoretical and Experimental Results

The experiment was conducted to get the value of strain on the brake pedal and the theoretical value of strain was calculated by fixing the value of the brake pedal traveling distance and force applied. The theoretical value of strain was calculated by taking the value of centre from the tension side of the brake pedal. Thus, the theoretical value of strain will give a positive value. The tension value of strain on the brake pedal is at strain three, $\varepsilon 3$.

Table 4.5.1 below shows the comparison results between the theoretical and experimental value of strain for area 1:

Table 4.5.1 Comparison of strain results for area 1

CENTRE				
Distance (mm)	Force Applied (N)	Experimental value of strain three, ε3 (με)	Theoretical value of strain (με)	Percentage Error (%)
20	18	-4	1.05	126.25
30	23.7	-1	1.39	239.00
40	32	1	1.87	46.52

LEFT				
Distance (mm)	Force Applied (N)	Experimental value of strain three, ε3 (με)	Theoretical value of strain (με)	Percentage Error (%)
20	15.15	4	0.89	77.75
30	23.3	5	1.36	72.80
40	36.1	3	2.11	29.67

RIGHT				
Distance (mm)	Force Applied (N)	Experimental value of strain three, ε3 (με)	Theoretical value of strain (με)	Percentage Error (%)
20	19.5	4	1.14	71.50
30	27.26	0	1.6	100.00
40	35.1	-1	2.05	148.78

Table 4.5.1 shows the comparison between the experimental and theoretical results for strains at area1. It is found that the experimental results have different values than the theoretical results. The results of strain for the applied force at the CENTRE of the brake pedal shows thatthe percentage error is higher for the 20 mm and 30 mm of brake travelling distance. This could be due to a number of reasons while conducting the experiment.

For the strain results due to the force applied at the LEFT side of the brake pedal, the strains are considered acceptable since the difference between the theoretical and experimental results are not too high. The most acceptable results of the experiment is at 40 mm of brake travelling distance because it shows the lowest percentage of error among other distances. The percentage of error for the 40 mm brake distance is 29.67 % as may be seen in Table 4.5.1

For the RIGHTside of the applying force on the brake pedal, the results show that all the braking distances exhibited higher percentage of errors. The lowest percentage of error is obtained at 20 mm of braking distance which is at 71.50 %. Both 30mm and 40 mm braking distances demonstrated much higher percentage of error with 100% and 148.78% respectively.

For the area 2, the comparison of theoretical and experimental results are shown in Table 4.5.2.

Table 4.5.2 Comparison of strain results for area 2

CENTRE				
Distance (mm)	Force Applied (N)	Experimental value of strain three, ε3 (με)	Theoretical value of strain (με)	Percentage Error
20	18	3	5.32	43.61
30	23.7	10	7.011	42.63
40	32	15	9.47	58.39

LEFT				
Distance (mm)	Force Applied (N)	Experimental value of strain three, ε3 (με)	Theoretical value of strain (με)	Percentage error
20	15.15	8	4.82	65.98
30	23.3	12	6.89	74.17
40	36.1	8	10.68	25.09

RIGHT				
Distance (mm)	Force Applied (N)	Experimental value of strain three, ε3 (με)	Theoretical value of strain (με)	Percentage Error
20	19.5	12	5.77	107.97
30	27.26	9	8.06	11.66
40	35.1	23	10.38	121.58

From the results shown in Table 4.5.2, with braking load is applied at the CENTRE of the brake pad, its shows that the percentage error is considered as acceptable since the experimental and theoretical results are not differ so much. The lowest value of percentage error is found at 30 mm braking distance which is 42.63% with the value of strain of 10$\mu\varepsilon$for theexperimental value and 7.011 $\mu\varepsilon$for thetheoretical value.

At the LEFT side for the applied load on the brake pad, the value of percentage error is lowest at 40 mm braking distance which is acceptable as both experimental and theoretical valuesof strain is only at 8 $\mu\varepsilon$ and 10.68 $\mu\varepsilon$respectively. The percentage error for the 40 mm braking distance is 25.09 %.

At the RIGHTside of applied force on the brake pad it is found that both distance of braking system at 20 mm and 40 mm has higher percentage of error which is more that 100%. On the other hand, at30 mm braking distance has the low percentage of error at 11.66 % which only has 9 $\mu\varepsilon$ of experimental result and 8.06$\mu\varepsilon$ of theoretical result.

The results for both areas may have unacceptable results and higher percentage of error. The percentage of errors may be caused by a number of factors either while conducting the experiment and/or before the experiment was carried out. Among the factors that may influenced the experimental results are;

(a) The installation of the strain gauges may not accurate at the centre of the axis as required. This could be largely due to the lack of skills in installing the strain gauges by the operator or technician of the FKM laboratory.
(b) The wire of the strain gauge is very sensitive to any disturbances or vibration from the surrounding areas. Any external disturbances need to be avoided in order to minimize the strain reading errors.
(c) The surfacesof the brake pedal where the strain gauges were installed may have not been properly clean before the installation of the strain gauges. Thus it affects the sensitivity of the gauge reading.

When conducting the experiment, the error may occurred because the readingof strain on every channels does not being reset correctly. This may caused the error of the reading of the strain gauges.

Last not least, the applied force also needs to be appliedexactlyon the correct area or contact point of the brake pad because it can affect the value of bending moment and torque experienced by the brake pedal. This may also affected the distances L_1 and L_2 in the strain theoretical analysis or calculation.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Based on the main objective of the project which is to measure the stress and strain condition on the brake pedal, it can be said that this objective has been successfully carried out though the overall results showed high percentage of differences between the experimental and theoretically determined strain results. The project has been conducted with the static loading is subjected to the brake pedal by using theUniversal Tensile Machine produced by Instron Inc., USA. The machine applied the concentrated force on the brake pedal with travelling distance is varied between 20mm to 40mm to get various level of static loading. This travelling distance of brake pedal was decided based on the actual travelling distance of the brake system for the locally manufactured passenger car.

It is found that the brake pedal has its own critical area when the force is applied. The area 1 where the strain gauges were installed has the highest value of strain or stress compare to the area 2. Thus, area 1 is considered more critical part of the brake pedal in terms of deformation compare to the area 2. This is because area 1 has experienced greater changes of dimensions in the direction of measured strain in comparison with changes of dimension for area 2.

In order to carry out this project a specially design testing jig or fixtures to hold the brake pedal has been produced. The main function of the jig is to hold the brake pedal while applying the compression force to the brake pedal at 3 different locations. The load applied from the InstronTesting machine will create bending and twisting or torsional effect on the brake pedal hence resulted in strains and stresses generated in the pedal's material.

5.2 Recommendation

There are many aspects that need to be improved in order to make this project more successful. First of all, the strain gauges installation needs to be improved by focusing on the procedure of installation. The surface area of the brake pedal need to be ground but the grinding process should not be too deep because it will affect the initial dimensions of the cross-sectional area and later the deformation of the brake pedal while under loading. The axis that need to be drawn on the brake pedal must be accurately marked at the centre of the intended surface as this inaccuracy will affect the results of strain during the tension and compression tests on the brake pedal.

Other than that, the installation of strain gages on the brake pedal need to be done at the right locations so that it will record the bending and twisting effects on the brake pedal. Installation of the strain gauges at the neutral axis of the pedal may be avoided as this will not give any meaningful data to be analyzed.

The design of the testing jig that need to be fixed to the Universal Tensile Machine must ensure that the jig will not move while the compression force is applied on the brake pedal. When fabricating the jig, the materials need to be cut accordingly and accurately with the dimensions that have been decided. Inaccuracy in dimensions may also affect the final results of strain.

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APEENDICES

APPENDIX A: FLOWCHAR

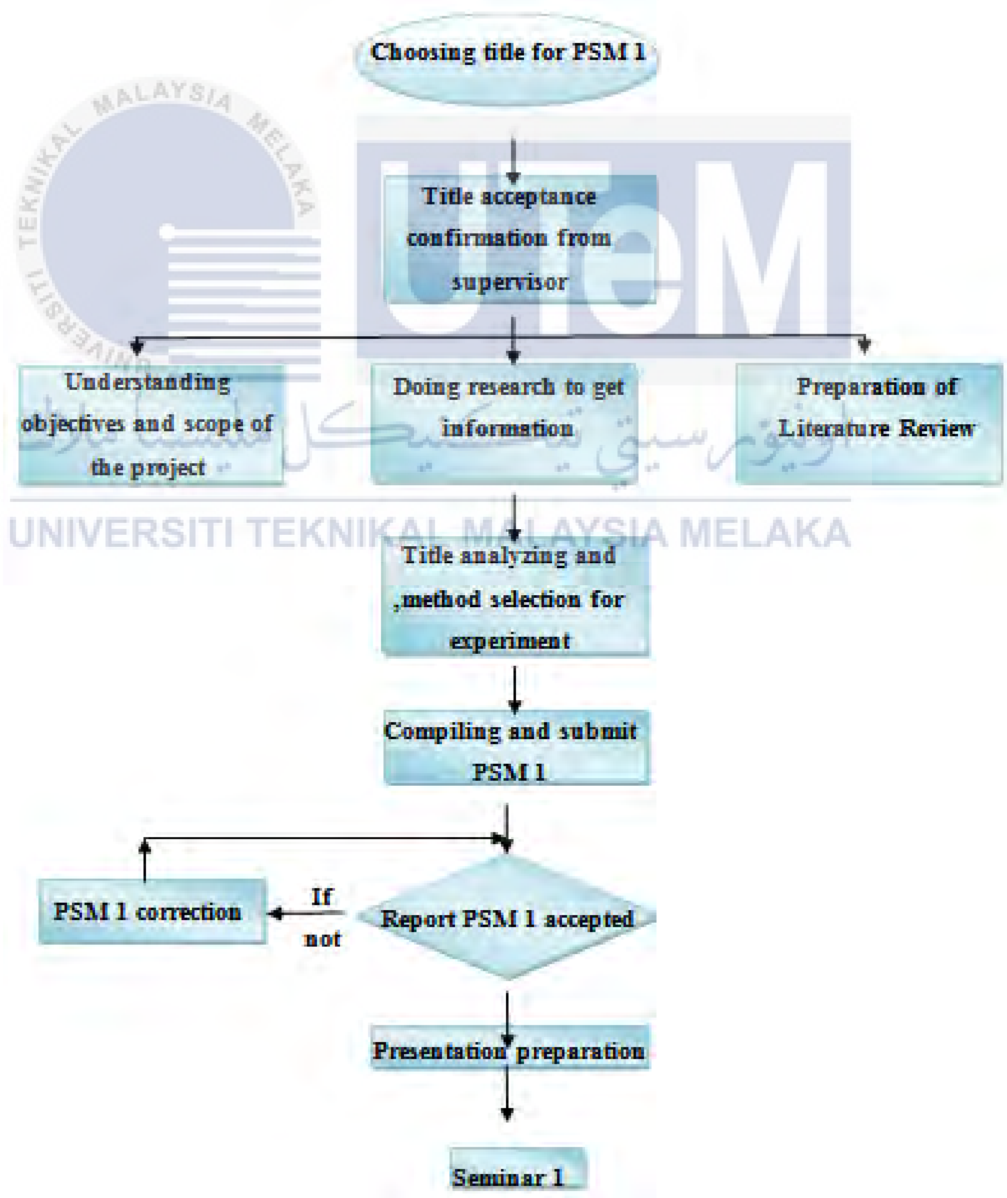


Figure A1 PSM I flow chart

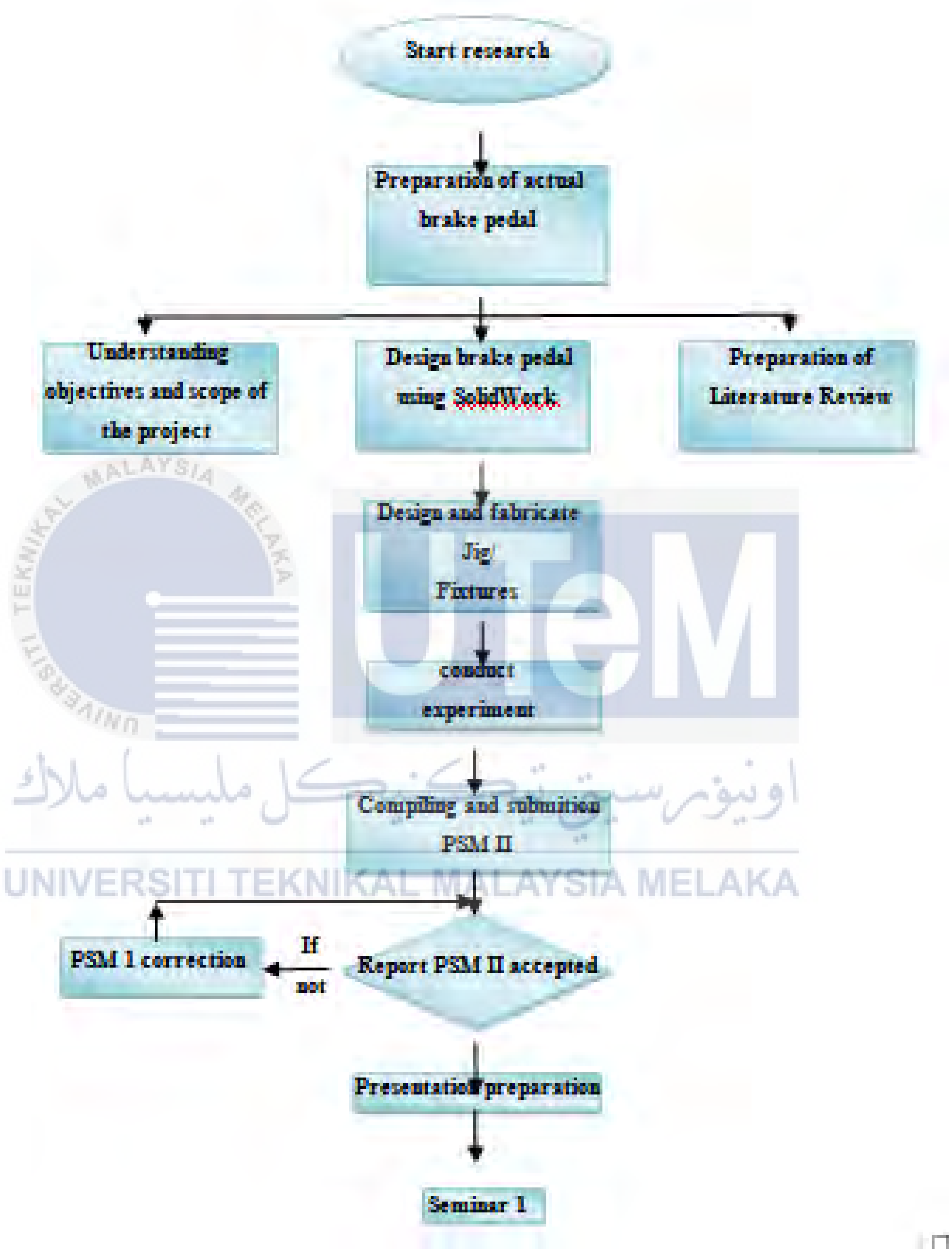


Figure A2 PSM II Flowchart

APPENDIX B: GANTT CHART

Table B1 Gantt Chart PSM I

Activities / Events	Week 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Title Selection								SEMESTER BREAK								STUDY WEEK
Title confirmation																
Meeting supervisor																
Briefing PSM 1																
Chapter 1																
a) Introduction																
b) Problem Statement																
c) Scope																
d) Objectives																
Submission progress report 1																
Chapter 2																
a) Literature review																
b) Highlighted issues																
Chapter 3																
a) method																
b) Process flow																
c)Procedure																
Chapter 4																
Correction and Submission																
Submission repot																
Presentation preparation																
Seminar PSM 1																

Table B1 Gantt Chart PSM II

Activities / Events	Week 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Meeting with supervisor								SEMESTER BREAK								STUDY WEEK
Brake pedal design using Solidwork																
Jig design																
Hardness Test																
Preparation of progress report PSM II																
Submission progress report PSM II																
Meeting with supervisor																
Jig fabrication																
a) Material selection and cutting																
b) Drilling																
c) Welding																
d) Finishing																
Installation of strain gauges																
Meeting with supervisor																
Experiment																
Chapter 4 Preparation																
a) Analysis and discussion																
b) Theoretical calculation																
c) Comparing theoretical and experimental results																
Chapter 5 Preparation																
a) Conclusion																
b) Recommendation																
Meeting with supervisor																
Final report compilation and submission																
Presentation preparation																
Seminar PSM II																

APPENDIX C : HARDNESS TEST

Rockwell Hardness Results = 73.9 HRB

Tensile strength from the conversion table : 440 MPa

Table C Hardness conversion table

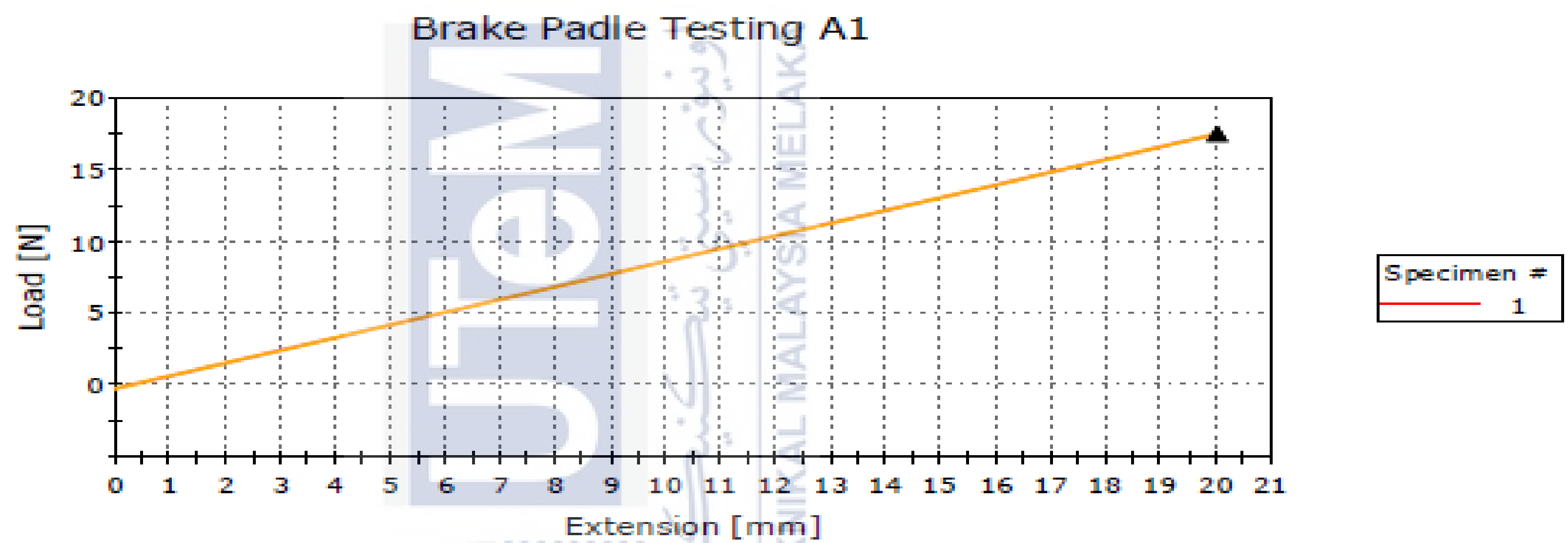
Hardness Conversion Table				
Tensile Strength (N/mm^2)	Brinell Hardness (BHN)	Vickers Hardness (HV)	Rockwell Hardness (HRB)	Rockwell Hardness (HRC)
285	86	90		
320	95	100	56.2	
350	105	110	62.3	
385	114	120	66.7	
415	124	130	71.2	
450	133	140	75	
480	143	150	78.7	
510	152	160	81.7	
545	162	170	85	
575	171	180	87.1	

By doing interpolation,

$$\frac{x - 415}{450 - 415} = \frac{73.9 - 71.2}{75 - 71.2}$$

$$Tensile\ strength\ = 440\ MPa$$

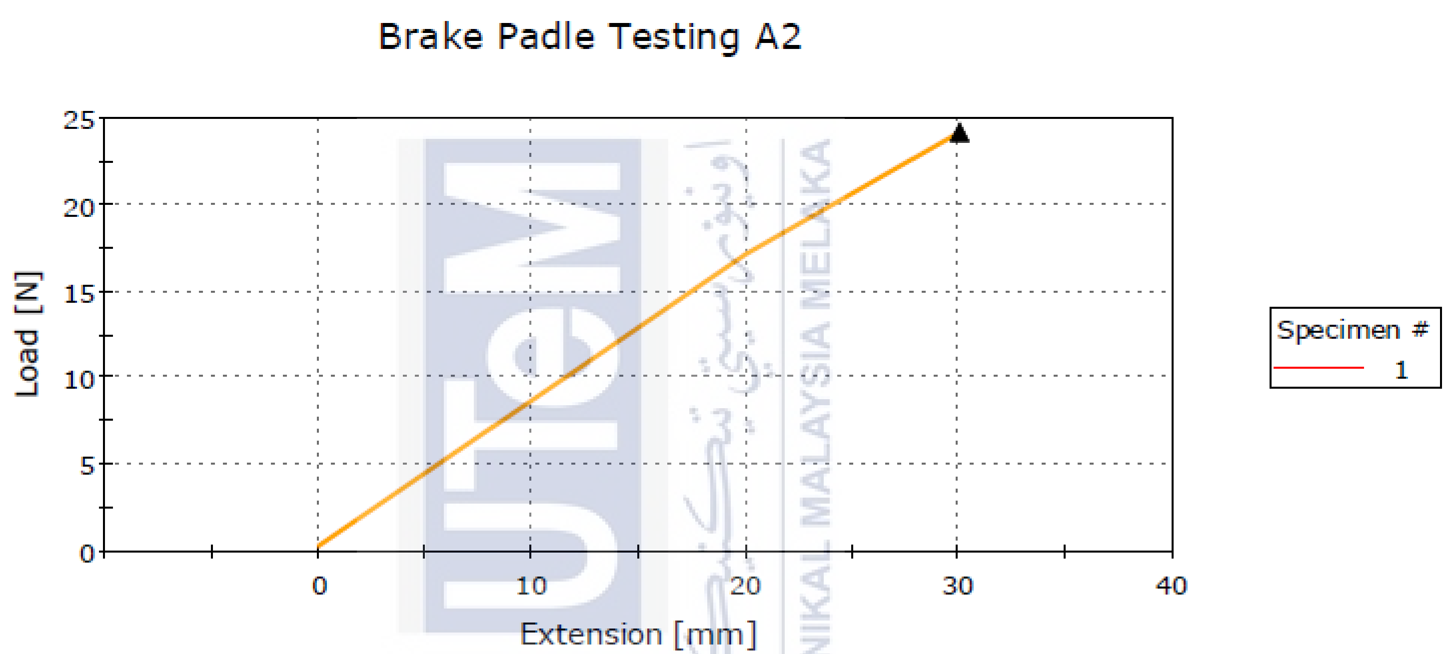
APPENDIX D : EXPERIMENTAL DATA



	Max Load [kN]	Compressive stress at Maximum Load [MPa]	Compressive strain (Extension) at Maximum Load [mm/mm]	Compressive extension at Maximum Load [mm]
1	> 0.0174	> 0.07	> 0.20	> 20.00

	Energy at Maximum Compressive stress [J]
1	0.17

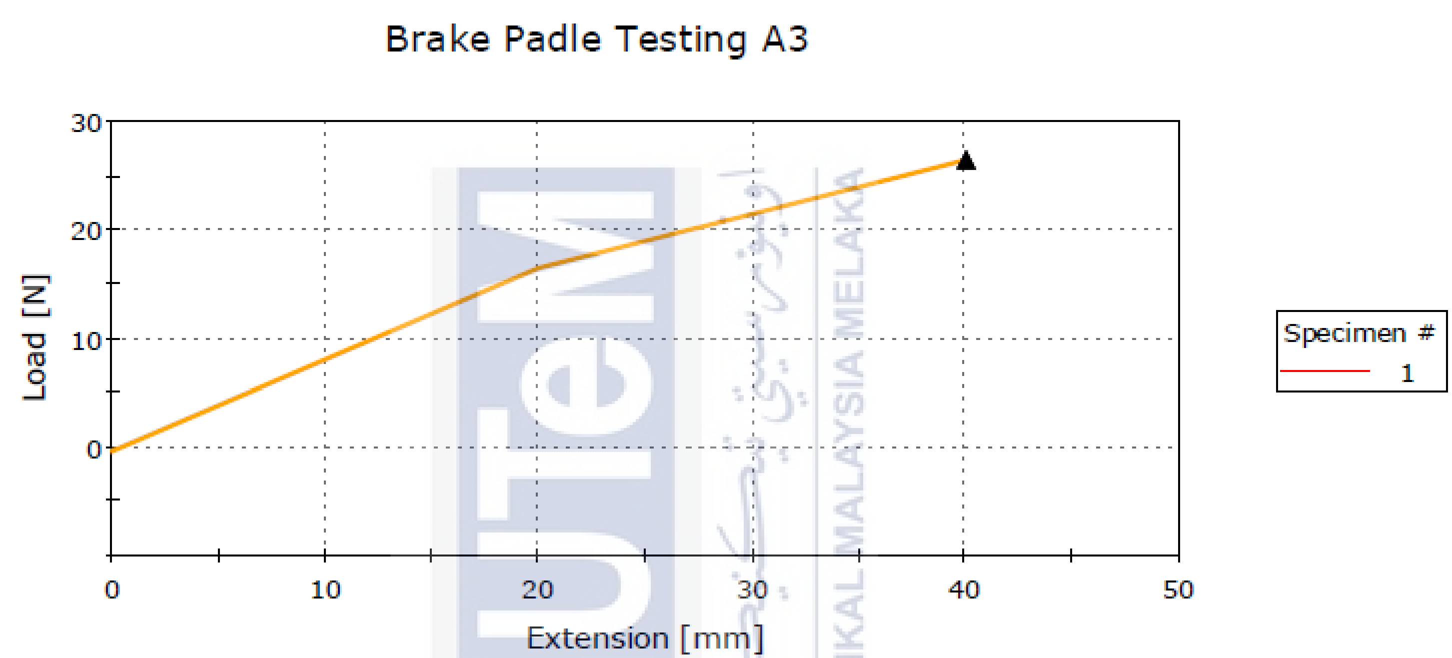
Figure D1 Experimental data 20 mm centre



	Max Load [kN]	Compressive stress at Maximum Load [MPa]	Compressive strain (Extension) at Maximum Load [mm/mm]	Compressive extension at Maximum Load [mm]
1	> 0.0242	> 0.10	> 0.30	> 30.00

	Energy at Maximum Compressive stress [J]
1	0.38

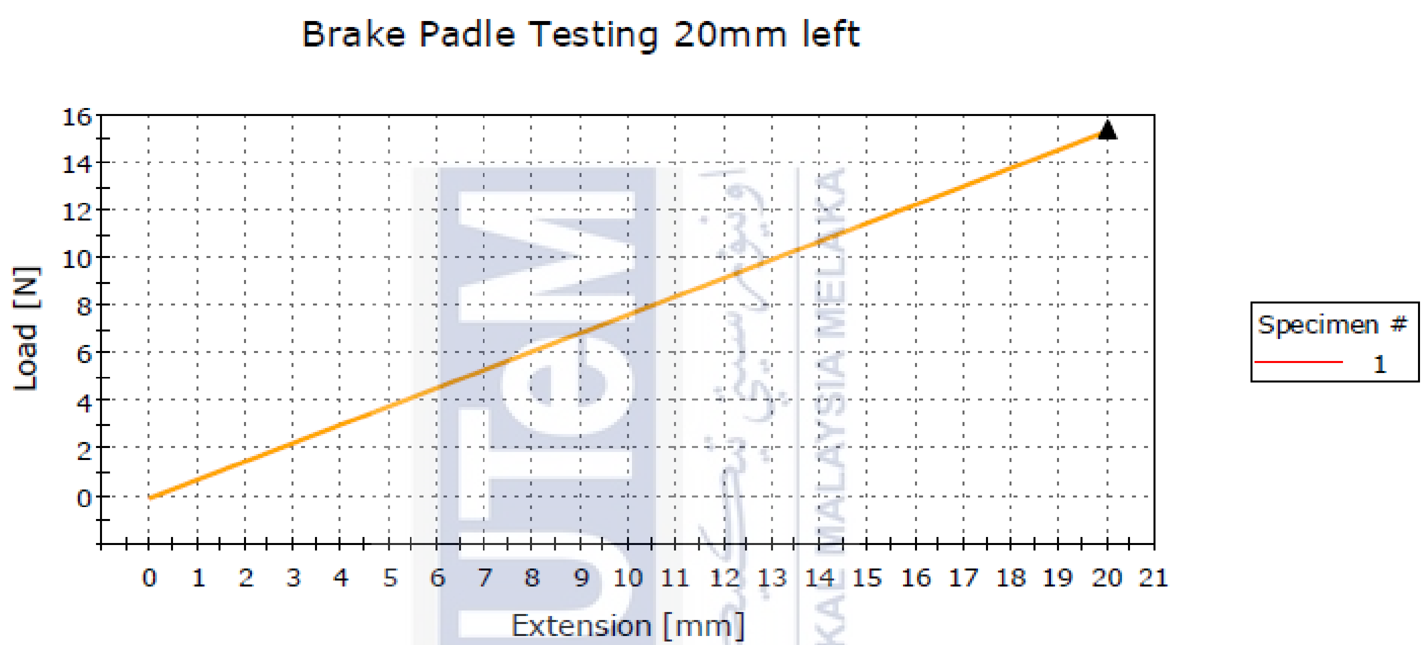
Figure D2 Experimental data 30 mm centre



	Max Load [kN]	Compressive stress at Maximum Load [MPa]	Compressive strain (Extension) at Maximum Load [mm/mm]	Compressive extension at Maximum Load [mm]
1	> 0.0264	> 0.11	> 0.40	> 40.00

	Energy at Maximum Compressive stress [J]
1	0.59

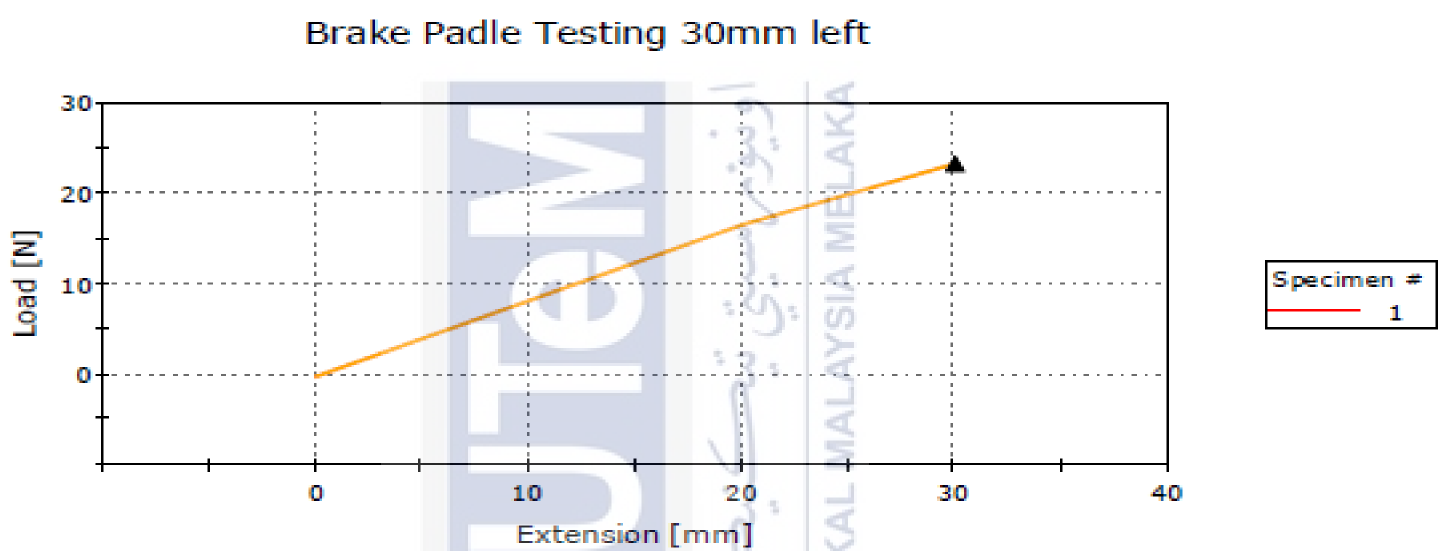
Figure D3 Experimental data 40 mm centre



	Max Load [kN]	Compressive stress at Maximum Load [MPa]	Compressive strain (Extension) at Maximum Load [mm/mm]	Compressive extension at Maximum Load [mm]
1	> 0.0154	> 0.06	> 0.20	> 20.00

	Energy at Maximum Compressive stress [J]
1	0.15

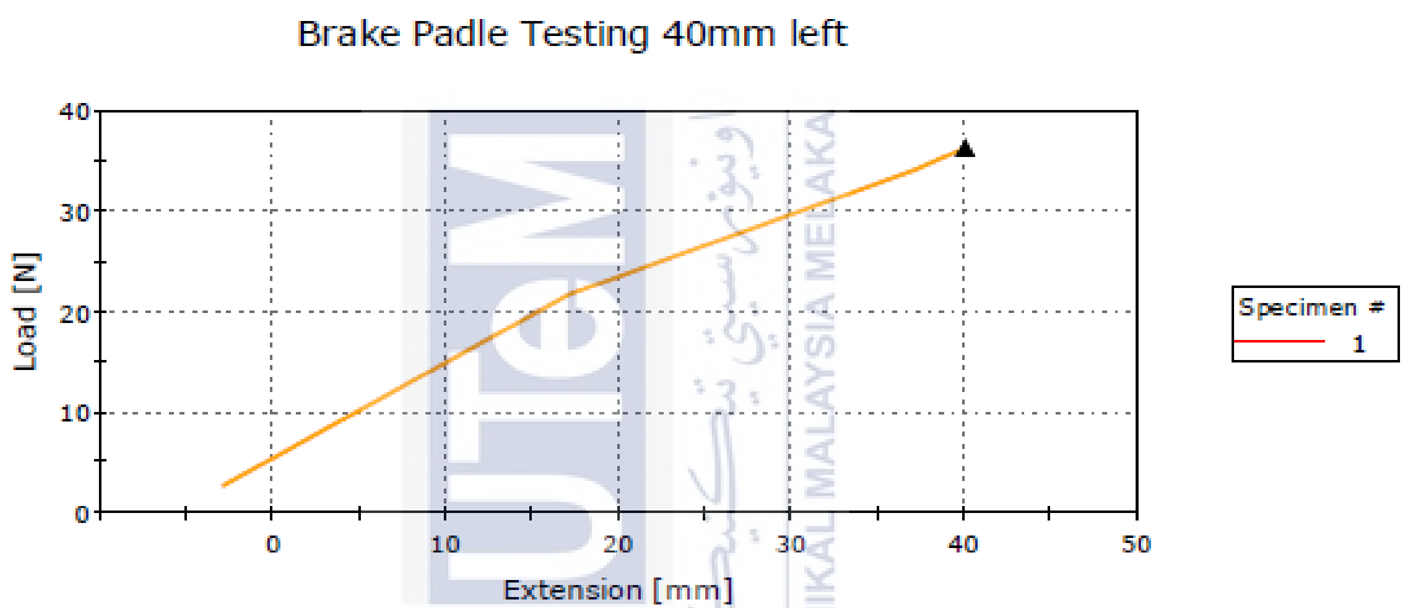
Figure D4 Experimental data 20 mm left



	Max Load [kN]	Compressive stress at Maximum Load [MPa]	Compressive strain (Extension) at Maximum Load [mm/mm]	Compressive extension at Maximum Load [mm]
1	> 0.0232	> 0.10	> 0.30	> 30.00

	Energy at Maximum Compressive stress [J]
1	0.36

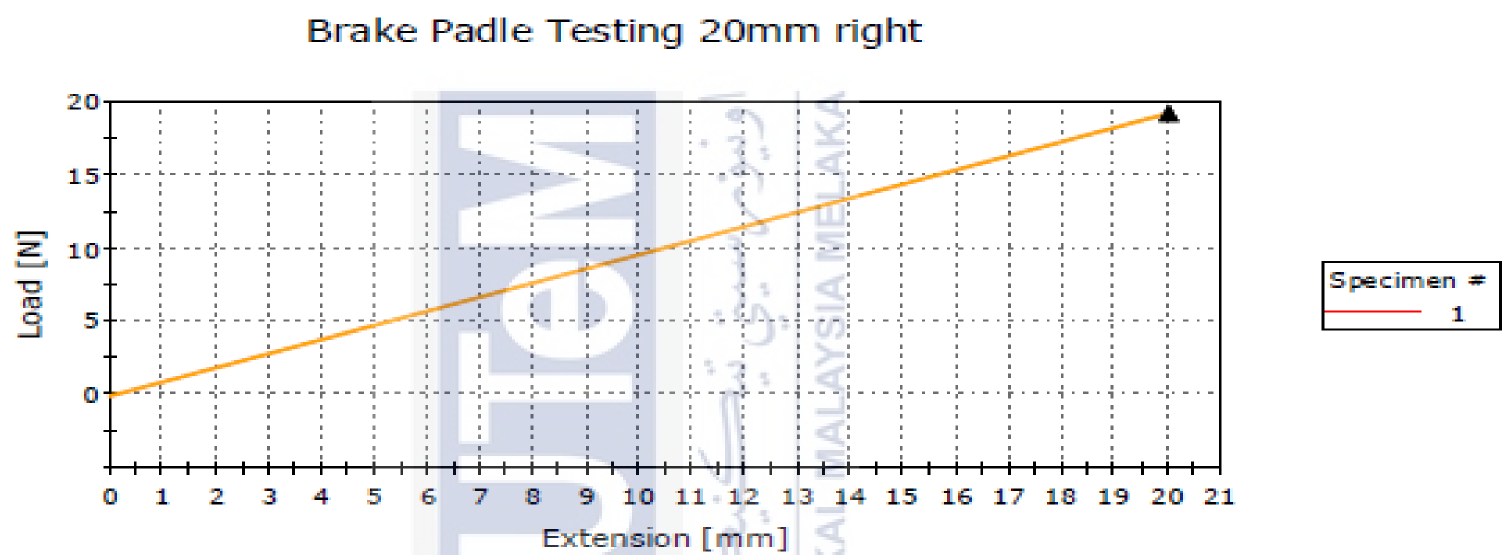
Figure D5 Experimental data 30 mm left



	Max Load [kN]	Compressive stress at Maximum Load [MPa]	Compressive strain (Extension) at Maximum Load [mm/mm]	Compressive extension at Maximum Load [mm]
1	> 0.0363	> 0.15	> 0.40	> 40.00

	Energy at Maximum Compressive stress [J]
1	0.91

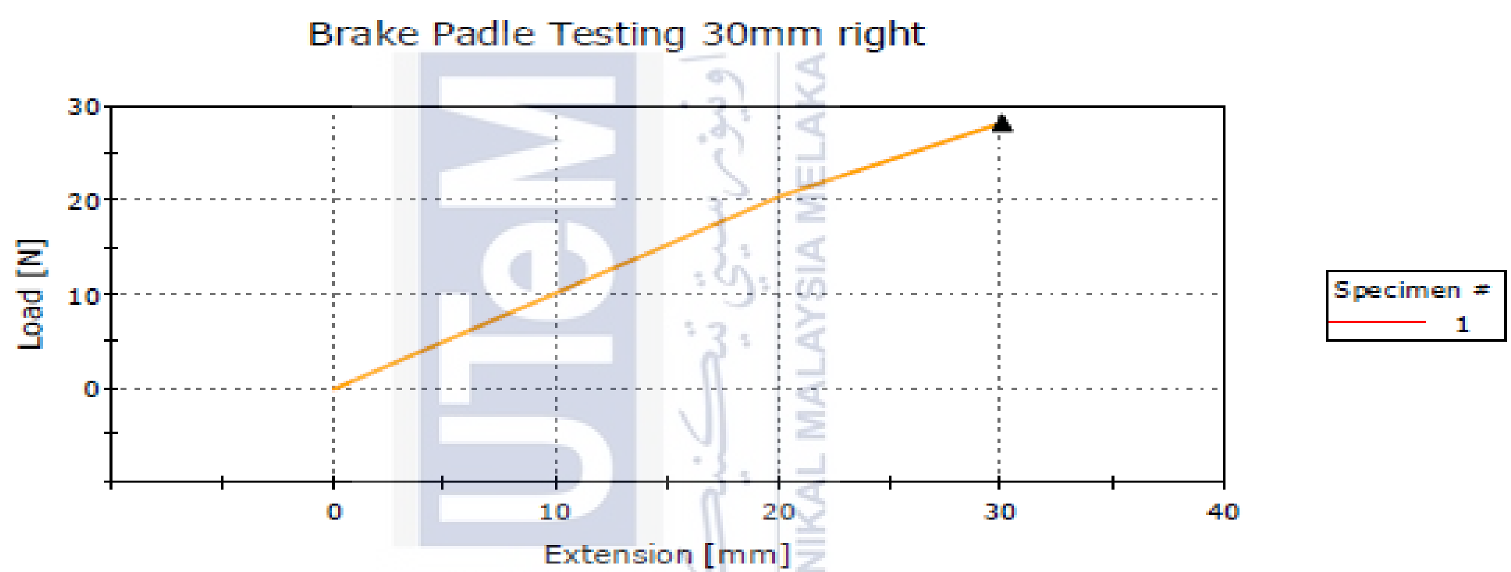
Figure D6 Experimental data 40 mm left



	Max Load [kN]	Compressive stress at Maximum Load [MPa]	Compressive strain (Extension) at Maximum Load [mm/mm]	Compressive extension at Maximum Load [mm]
1	> 0.0192	> 0.08	> 0.20	> 20.00

	Energy at Maximum Compressive stress [J]
1	0.19

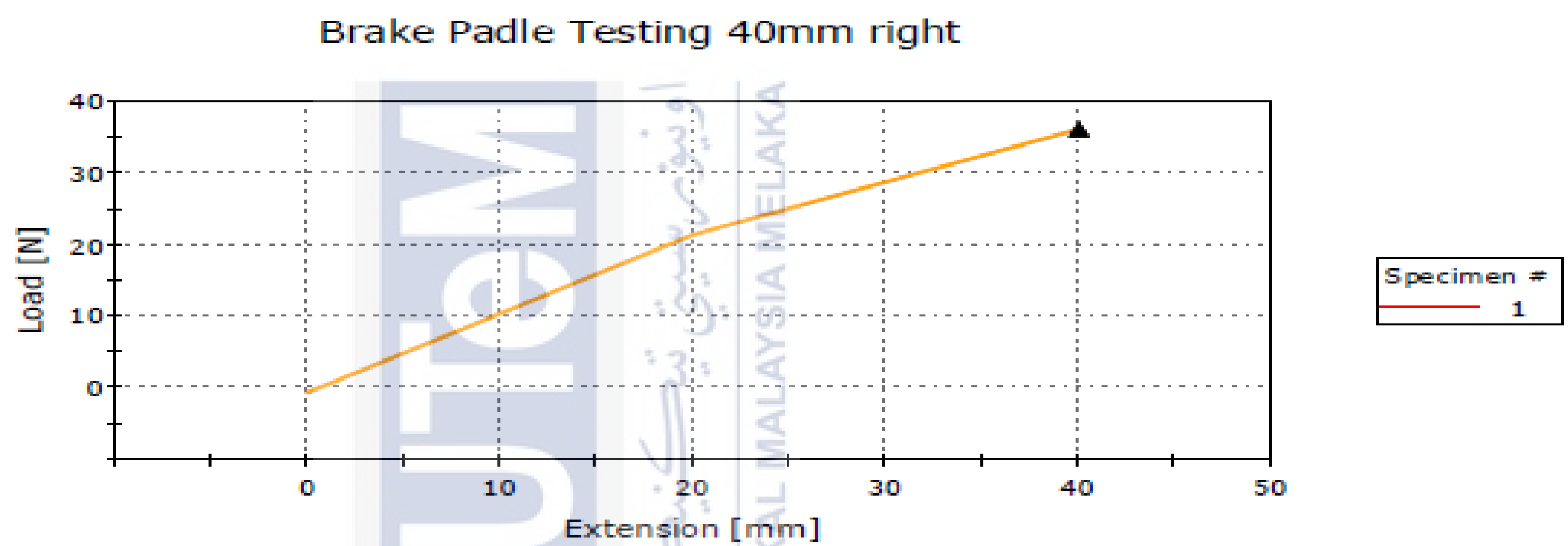
Figure D7 Experimental data 20 mm right



	Max Load [kN]	Compressive stress at Maximum Load [MPa]	Compressive strain (Extension) at Maximum Load [mm/mm]	Compressive extension at Maximum Load [mm]
1	> 0.0282	> 0.12	> 0.30	> 30.00

	Energy at Maximum Compressive stress [J]
1	0.45

Figure D8 Experimental data 30 mm right



	Max Load [kN]	Compressive stress at Maximum Load [MPa]	Compressive strain (Extension) at Maximum Load [mm/mm]	Compressive extension at Maximum Load [mm]
1	> 0.0360	> 0.15	> 0.40	> 40.00

	Energy at Maximum Compressive stress [J]
1	0.78

Figure D9 Experimental data 40 mm right

APPENDIX E: MACHINE FOR FABRICATING

Figure E1 Shearing machine

Figure E2 Bend Saw machine

Figure E3 Welding Machine

Figure E4 Drilling machine

Figure E5 Universal Tensile Machine INSTRON

Figure E6 Digital Strainmeter

Figure E7 Load cell

APPENDIX F: FABRICATION OF JIG

Figure F Jig

APPENDIX G: EXPERIMENT OF BRAKE PEDAL

Figure G Experiment of brake pedal