DEVELOPING LIGHT-WEIGHT 3D-PRINTED BRAKE-PAD WITH INTERNAL GEOMETRY FOR LOW FRICTION & WEAR

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BACHELOR OF MECHANICAL ENGINEERING TECHNOLOGY (AUTOMOTIVE TECHNOLOGY) WITH HONOURS

2022

Faculty of Mechanical and Manufacturing Engineering Technology

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

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**A thesis submitted
in fulfillment of the requirements for the degree of
Bachelor of Mechanical Engineering Technology (Automotive Technology) with Honours**

Faculty of Mechanical and Manufacturing Engineering Technology

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2022

DECLARATION

I declare that this Choose an item. entitled "**DEVELOPING LIGHT-WEIGHT 3D-PRINTED BRAKE-PAD WITH INTERNAL GEOMETRY FOR LOW FRICTION & WEAR** "" is the result of my own research except as cited in the references. The Choose an item. has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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APPROVAL

I hereby declare that I have checked this thesis and in my opinion, this thesis is adequate in terms of scope and quality for the award of the Bachelor of Mechanical Engineering Technology (Automotive Technology) with Honours

Signature : ....

Supervisor Name : Dr. Muhammad Ilman Hakimi Chua Bin Abdullah

Date : ....

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DEDICATION

This research is entirely dedicated to my beloved parents, who have been our source of inspiration and have given me strength, especially for my mother, who has survived the covid-19 deases. When I am on the verge of giving up, they are always there to provide moral, emotional, and spiritual support.

This is also dedicated to my supervisor, who has provided unconditional support, as well as to my dear friends and lecturer, who have always shared words of advice and encouragement throughout this research to ensure its completion.

And lastly, I am so grateful to ALLAH swt and thank you for the guidance, strength and giving me a healthy life. Also, thank you for giving me inspiration of idea to finish this resear

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ABSTRACT

In the automotive sector, we all know that the brake pad is a crucial component that functions as a mechanism to slow down or to stop the vehicle. Besides choosing the right material to be applied as friction material, the design of the brake pad in terms of optimal geometry also had to be considered as a factor of brake pad wear. Internal geometry plays a big role in any design including the brake pad. The purposed of this research to study the design of internal geometry that can produce low friction and wear toward the brake pad. There are a few methods that considered in terms of design that can make brake pads less friction and wear. In this project, the method was choosen was to applied certain pattern of geometry toward the surface of brake pad.The real brake pad has been chosen and drawn using CATIA V5R21software. The next process is to analyze the real brake pad design using SIMSOLID software and from that analysis, it will come out with the new geometry and dimension. From that drawing, the new brake pad replica is produced by using the 3D printing method or the be specific, those processes are using SLS machine. The analysis that been applied was normal traction, displacement magnitude, von mises stress and maximum shear stress. All of this analysis was been made find out which geometery pattern was the best in terms of less wear and friction

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ABSTRAK

Dalam sektor automotif, kita semua tahu bahawa pad brek adalah komponen penting yang berfungsi sebagai mekanisme untuk melambatkan atau menghentikan kenderaan. Selain daripada memilih bahan yang sesuai untuk digunakan sebagai bahan geseran, reka bentuk pad brek dari segi geometri yang optimum juga harus dipertimbangkan sebagai faktor kehausan pad brek. Geometri dalaman memainkan peranan besar dalam sebarang reka bentuk termasuk pad brek. Tujuan penyelidikan ini adalah untuk mengkaji reka bentuk geometri dalaman yang dapat menghasilkan geseran dan kehausan yang rendah pada pad brek. Terdapat beberapa kaedah yang perlu dipertimbangkan dari segi reka bentuk yang boleh menjadikan pad brek kurang geseran dan haus. Dalam projek ini, kaedah yang dipilih adalah menggunakan corak geometri tertentu ke atas permukaan pad brek. Pad brek sebenar telah dipilih dan dilukis menggunakan perisian CATIA V5R21. Proses seterusnya adalah menganalisis reka bentuk pad brek menggunakan perisian SIMSOLID dan dari analisis itu, ia akan mengeluar geometri dan dimensi baru. Dari gambaran itu, replika pad brek baru dihasilkan dengan menggunakan kaedah percetakan 3D atau yang spesifik, proses tersebut menggunakan mesin SLS. Analisis yang digunakan ialah daya tarikan normal, magnitud anjakan, tegasan von mises, dan tegasan ricih maksimum. Kesemua analisis ini dibuat untuk mengetahui corak geometri mana yang terbaik dari segi kurangnya kesan haus dan geseran.

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ACKNOWLEDGEMENTS

In the Name of Allah, the Most Gracious, the Most Merciful

First and foremost, praises and thanks to the Allah, the Almighty, for His showers of blessings throughout my research work to complete the research successfully.

I would like to express my deep and sincere gratitude to my research supervisor, Dr. Muhammad Ilman Hakimi Chua Bin Abdullah, Department of Mechanical Engineering Technology , Universiti Teknikal Malaysia Melaka (UTeM) and my co- supervisor, Mr.Mohd Suffian Bin Ab Razak for giving me the opportunity to do research and providing invaluable guidance throughout this research and also for his support, advice, and inspiration. His constant patience for guiding and providing priceless insights will forever be remembered.

Finally, I am thankful to my loving parents, who were the cornerstone of the strength in my venture, from the very bottom of my heart. My eternal love for patience and understanding to all my siblings as well for showing an aspiration to complete this thesis successfully.

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LIST OF SYMBOLS AND ABBREVIATIONS

CAM – Computer-Aided Manufacturing

CAD – Computer-Aided Design

3-D – 3 Dimensional

SLS – Selective Laser Sintering

Mpa – Mega Pascal

MM– milimeter

UTeM

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CHAPTER 1

INTRODUCTION

1.1 Background

Brake pads are a key component of your vehicle's braking system and play an important role in making your car stop when you press the brake pedal. They are made of a flat piece of steel that has a thick friction material on one side. When you press the brake pedal, the brake pads make contact with the brake disc. This causes friction which stops the wheels from turning. As expected, wheels on a car may rotate incredible speed, which exerts stress on the brake pads to stop a heavy vehicle by employing friction, which ultimately wears it down over time. The speed with which your brake pads get weary relies on your driving style and how often you drive.

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Brake pads are stored in the brake callipers and serve to stop the vehicle's wheels each time the brakes are applied. So, when the brake pedal is stepped on closely, it is not difficult to imagine the pressure applied to expose it to wear and tear. Its convert kinetic energy into thermal energy throughout the friction. When driver step on the pedal brake it will hydraulically push the brake fluid contained in the master pump and it will spread evenly to all wheel. The pressured brake fluid will push out the piston inside the brake calliper and push brake pads to make a contact with the disc in order to slow down or stop the vehicle. It's actually not just for mechanics, but you as a vehicle owner should also be responsible. Not just observe visually, but also detect any changes in terms of the noise of the brake components, and the level of braking efficiency.

Due to the contacts with disc, it generates amount of friction depends on how the driver step on the brake pedal. The more the friction created the more heat produced and the hotter the disc the less efficient the brake system. However, during almost time the driver using brake untill one moment the brake system in uneficcient as the friction material wear. There is many factors that affecting brake pads wear and one of the factor is brake pad was design in not optimal paramater. The internal geometry on brake pad can increase lifespan of brake pad or in another word, this brake pad can be used much longer compare to conventional brake pad.

1.2 Problem Statement

Brake pads lifespan is always been major issue of any car's user, brake pads lifespan is depending on method of use by driver. Sometimes it might be more than 50 000 kilometres of used before need to be replace with new one. Abnormal brake wear also can happen due to wrong type of Brake pad use in brake system. Due to the economic compromises and engineering factor, the shape of brake pad may not be optimal. When the brake pad is not in harmony with disc and calliper, it will generate more friction that can cause reduce brake pad lifespan.

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However, if the friction of the brake pads can be decreased by designing the optimized geometry, the life expectancy of the brake pads can be increase. This project research will be focused on design and produce a light-weight and less friction brake pads using a new method or the be specifically using 3D printing. This project also will be analysing the 3D print brake pad in term of performance compare to current brake pad in market. 3D printing methodology is used in this project research to produce the brake pad with optimal and specific geometry, by using this method the design can be customize in short time compare to standard method in producing brake pad.

1.3 Objective

The objective of this project is stated as below;

a) To design and analyse a light-weight 3D-printed brake pad using CATIA

b) To fabricate the light-weight 3D-printed brake pad using SLS machine

c) To test the performance of printed brake-pad

1.4 Scope

The scope of the project is developed based on the objectives of the project as below;

- Designing a light-weight 3D-printed brake pad with Catia and analyse optimum parameter in 3D printed.
- Fabricating light-weight 3D-printed brake pad with optimised geometry using SLS machine.
- Analysis the performance of the light-weight 3D-printed brake pad in SIMSOLID software.

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CHAPTER 2

LITERATURE REVIEW

2.1 Brake system

The purpose of a braking system is to slow and stop the movement of a vehicle. Multiple components within the braking system must convert the vehicle's moving energy into heat in order to do this. Friction can be used to accomplish this. Friction is the resistance to movement that two things exert against one another. There are two types of friction that play a role in vehicle control: kinetic or moving friction and static friction. The degree of friction that prevents movement is determined by the type of material in contact, the smoothness of their rubbing surfaces, and the force that holds it together.

Thus, in a compact vehicle brake system works by applying a static surface (brake pad) to a moving surface of a vehicle (disc), this causing friction and converting kinetic energy into heat energy. As the brakes on a moving vehicle are put into motion, rough-textures brake pads or brake shoes are pressed against the rotating parts of vehicle, be it disc or drum. The kinetic energy or momentum of the vehicle is then converted into heat energy by kinetic friction of the rubbing surfaces and the car to slows down.

When vehicle comes to stop, it is held in place by static friction. The friction between surfaces of brakes as well as the friction between tires and roads resist any movement. To overcome the static friction that holds the car motionless, brakes are released. The heat energy of combustion of in engine is converted into kinetic energy by transmission and drive train, and the vehicle moves. In modern automotive there is two main types of brake systems:

Drum brake system, consisting in pushing outwards brake shoes mounted inside a drum against the inner surface of the drum. Disc brake system, consisting in pushing two brake pads on a disc

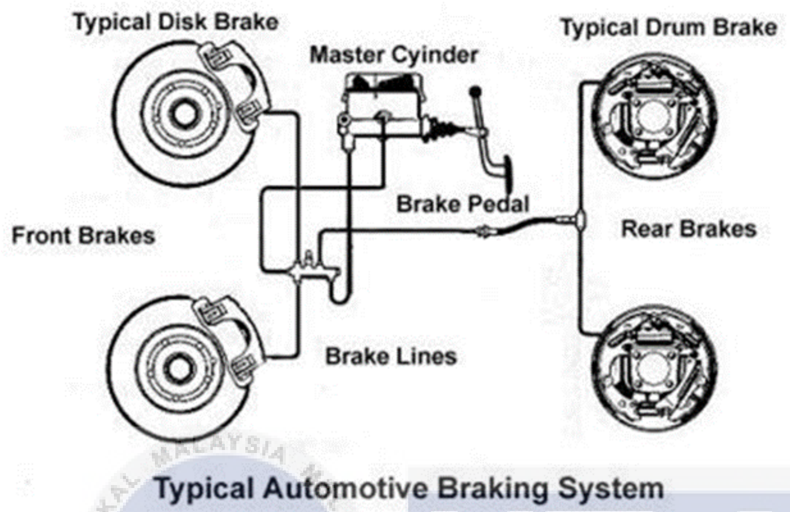

Figure 2.1 Typical Automotive Brake System

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2.1.1 Type of brake pads

Brake pads are the crucial component part of a vehicle's braking system. The brake pads located inside the caliper, and are the part of the system function to clamps down on the moving disc or rotor. By over the certain amount of milage the pad will become wear from the friction. There are four types of brake pads which in important for vehcicle owner to knwo which type are suit to vehicle.

Semi-Metallic These brake pads are 30 to 65 percent are made from metal and considered to be as the most durable among others type. These brake pads may also not function well in some extreme condition and during the low temperatures.These brake pads are cheaper and easier on the rotors than ceramic brake pads, but that the most louder and do not longer compare to ceramics.These brake pads are generally used on high performance and race cars.

Figure 2.2 Semi metallic brake pad

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Ceramic These brake pads are generally the most expensive but are cleaner and produce less noise than other materials. Ceramic brake pads last longer than semi-metallics as well.

Figure 2.3 Ceramic brake pad

Low-Metallic, Non-Asbestos Organic (NAO) These brake pads are known as the most noisy and create a lot of brake dust compare to other material. However, the copper or steel that is used in these pads helps with heat transfer and breaking a lot.

Figure 2.4 Low-Metallic, Non-Asbestos Organic (NAO)

Non-Asbestos Organic These brake pads are generally made from organic materials such as fiber, glass, rubber, and Kevlar. These pads are generating less sound or quieter than others but can wear faster and produce a lot of brake dust.

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Figure 2.5 Non-Asbestos Organic (NAO)

2.1.2 Friction material

Brake pads usually made from blend of multiple material, some of those brake pads are made up to 10 to 20 kind of raw of material. There are three categories or component divided in this raw material. First is “friction adjustment material” next is “bonding material” and the last category is “stiffener”.

The friction adjustment material purposely in to adjust capability of friction material. The way it works it for enhance the effectiveness or stabilizing the performance of friction materials.There were various of raw material including organic and inorganic fillers, abrasive material, metal powder and some lubricant were mix together. The bonding-material strengthen the raw materials and gives the materials their intensity as mostly phenol resin is used currently. The stiffener gives the friction materials further strength. Various types of organic and inorganic fibers, such as aramid fibers and metal fibers, are used in the category.

Figure 2.6 Friction raw materials

Furthermore, friction materials must maintain consistent effectiveness (minimal variation in effectiveness) under a variety of conditions, including vehicle speed, laden weight, and temperature changes caused by brake use, as well as different environmental influences such as humidity, water, and mud. Mechanical strength and the ability to endure thermal disturbances are essential design requirements as well. Durability is another significant element in the utilisation of friction materials. Squealing, noise and vibrations must also be reduced when the brakes are engaged. In addition, the friction materials, such as the disc rotors, should not harm the material they come into touch with. Friction materials also need low heat conductivity to prevent the brake or brake fluid from accumulating at temperatures.

2.1.3 Brake pad geometry

The shape of the brake pad lining is an example of a design modification that may be implemented later in the design phase. The pad lining geometric features include chamfers and slots. An extra sub-layer that may affect the pad's mechanical and thermal qualities. Slots and chambers can be modelled or machined, and generally the friction surface is the pad-flatness requirement must be accomplished through machining. On the friction surface of brake pads, a chamfer is used to provide a transitional surface between two sharp edges. The chamfer keeps the brake pad's leading edge from rising off the brake disc, induces even pad wear and reduces noise.

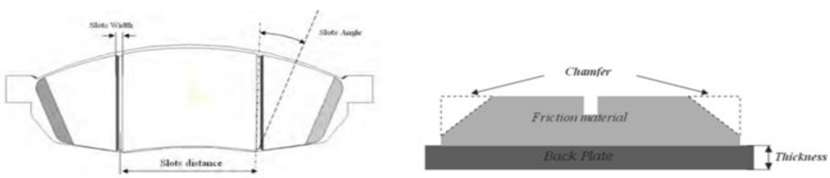

Figure 2.7 The brake pad geometry

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2.2 Design software

There is a variety of software for design and drawing that can be performed. Design software function for technical engineering it was known to as computer aided design for technical documentation. Computer-aided design software (CAD) refers to a type of software program used by designers and engineers to create two-dimensional and three-dimensional models of physical components. One benifit of design sofware is the designer can comunicate each other only by the drawings as both side are able to understand and inditified everything regarding the design.

The power distribution network components typically begins with the Main-In-Take or transmission/distribution interface substation (TDIS) that is fed by the transmission or grid supply system (GSS) through one or more transmission lines, as shown in Figure 2.4. At the TDIS, HV/MV substation transformers channels the incoming power/energy at transmission-level voltage and steps it down to medium voltage (MV) feeders. The distribution transformers (MV/LV) performs the final voltage transformation in order to obtain a voltage level adequate for LV customer use. The outgoing feeders from the MV/LV transformers operating at a low-voltage (LV) level finally delivers the energy to the customer's interconnection point. Occasionally, large power consumers (LPC) such as large industrial facilities, are usually served by dedicated "bulk feeders" (connected at the MV level) as they require large amount of load.

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2.2.1 3-D software

3-D software is a type of computer graphics software that allows for the creation, design, and development of 3-D visuals and animations. Users may see, develop, and manipulate an item, environment, or any graphical element in three dimensions with 3-D software. Computer-aided design (CAD) applications and animation packages are examples of 3-D software. 3-D software operates principally on the mathematical idea of geometry, which is translated into three separate axes for each element: X to width, Y to length and Z to depth. These include image or object modelling, layout, animation and rendering, On most current computers, mobile devices and operating systems the designed element may be viewed or implemented.

2.2.2 CATIA V5R21

CATIA stands for computer-aided three-dimensional interactive application. It is far more than a software programmed called CAD (Computer Aided Design). It is a comprehensive software package that combines CAD, CAE and CAM (Computer-Aided Manufacture). For developing and defining the whole digital product model, CATIA V5 is the top CAD software solution. CATIA V5 can provide the possibility of buying as much or as little capability as necessary, enabling specific user profiles and technical discipline. CATIA also has the ability to create orthographic, isometric, and detailed 2-D drawing views. Model dimensions can also be generated, and the drawing views can be referenced. Many of the sectors presently used are covered by this software, including design from beginning until finish, a wide range of scans, simulations and optimizations, drawings, and also programmed for manufacturing.

2.3 3-D printing

3D printing, also known as additive manufacturing, is a method of creating three-dimensional solid items from a digital file. The production of a 3D printed item is accomplished via the use of additive techniques. An item is built in an additive technique by laying down successive layers of material until the product is complete. Each of these levels is a finely cut cross-section of the item. 3D printing is the inverse of subtractive manufacturing, which involves cutting or hollowing out a piece of metal or plastic with a milling machine, for example. 3D printing makes it possible to create complicated forms with less material than traditional production processes. Subtractive manufacturing procedures, in which a final design is cut from a larger block of material, are the polar opposite of additive manufacturing (Almaliki, 2015). For a long time, car makers have used 3D printing. Automobile manufacturers print spare parts, tools, jigs and fixtures, as well as end-use parts. On-demand manufacturing has been facilitated by 3D printing.

2.3.1 SLS printing

Selective laser sintering is an additive manufacturing process that sinters microscopic particles of polymer powder into a solid structure based on a 3D model using a high-power laser. For decades, SLS 3D printing has been a popular choice among engineers and manufacturers. The technology's low cost per part, great productivity, and proven materials make it suited for a variety of applications ranging from quick prototyping to single quantity or custom manufacture. Recent developments in gear, materials, and software have made SLS printing more accessible to a broader variety of organizations, allowing an increasing number of enterprises to employ these technologies that were previously confined to a few high-tech sectors.

Table 2.1 3D Printing techniques comparison

Parameter	Fused Deposition Modeling	Stereolitography	**Selective Laser Sintering**	Selective Laser Melting
Abbreviation	FDM	SLA	**SLS**	SLM
Operation principle	Extrusion of melted filament	UV curing	**Laser sintering**	Laser melting
Material printed	Thermoplastic polymer in the form of string (filament) i.e. PLA, ABS	Resins/photocurable liquid materials	**Powdered sinter able polymers (i.e. polyamides, TPU, TPE)**	Various metal alloys
Advantages	• low cost • fast printing time	• high print resolution • high process automatization	• **no support structures** • **quality prototyping** • **movable parts**	• printouts durability
Disadvantages	▪ need of support structures	▪ narrow material variety	▪ **long printing time**	▪ high cost

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	▪ thermal shrinkage of filament	▪ high maintenance costs		
Applications	▪ fast prototyping ▪ education ▪ low volume production	▪ complex internal geometry prototypes ▪ dental models	▪ **education** ▪ **functional prototypes** ▪ **medical models** ▪ **prototyping moveable parts**	▪ automotive and aviation industry ▪ functional parts
Layer thickness	0.1 - 0.3 mm	0.05 - 0.15 mm	**0.060 - 0.15 mm**	0.02 - 0.1 mm
Printing without support structures	No	Not always necessary	**Yes**	Not always necessary
Printing objects with movable parts	not always achievable (lower precision)	No	**Yes**	no

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2.3.2 Material of 3-D printing

The materials used in 3D printing are as varied as the end products. As a result, 3D printing gives manufacturers the ability to customize the shape, texture, and strength of their products. Best of all, these characteristics can be achieved with far fewer steps than traditional manufacturing methods. Furthermore, a variety of 3D printing materials can be used to create these products. Thermoplastics, metals, resins, and ceramics are among the materials used in 3-D printing. The materials used in 3-D printing are varied as the products that are produced as a result of the process. As a result, 3-D printing is versatile enough to allow manufacturers to customize the shape, texture, and strength of a product. these characteristics can be accomplished with far fewer steps than are typically required in traditional manufacturing methods. Consider the application, function, and design of the finished product when selecting materials for your next 3-D printing project. Heat deflection, chemical resistance, and material durability are all factors to be consider. Although Nylon 12 and Nylon 11 are single-component powders, some SLS 3D printers can use two-component powders such as coated powders or powder mixtures. Nylon composites containing aluminide, carbon, or glass are being developed to improve parts' strength, stiffness, or flexibility. Only the component with the lower glass transition point is sintered in these two-component powders, binding both components.

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2.3.3 Printing

To get started with 3-D printing, we need to create a three-dimensional digital file, of the object we want to print. The most common method of creating a digital model is through computer-aided design, or CAD. Other important thing is the files need to be converted to the suitable file format, STL is the most common 3-D printing file type, which is called STereo Lithography and has been named after the first ever 3-D printing method. The 3D drawing that has been transferred to the specific will give the machine the instruction that tells where the material will be solidified, and the 3D structure will be obtained.

2.3.4 Finishing

Finishing in SLS also important procedure that required right techniques that only can be achieved by practice time over time. Before any further finishing can take place, the excess powder must be removed, and which is usually accomplished with a burst of compressed air. SLS prints generally feel grainy first and may have visible layers after printing depending on how you set your layer thickness. The consequences are heavily influenced by the orientation of a part surface during the construction process. to achieve a smooth finishing, it also can be done by using solvents that dissolve certain SLS materials, such as acetone, butanone, or tetrahydrofuran. A perfectly uniform surface finish is virtually impossible to achieve with a raw printed object (Tyson, 2017).

CHAPTER 3

METHODOLOGY

3.1 Overview

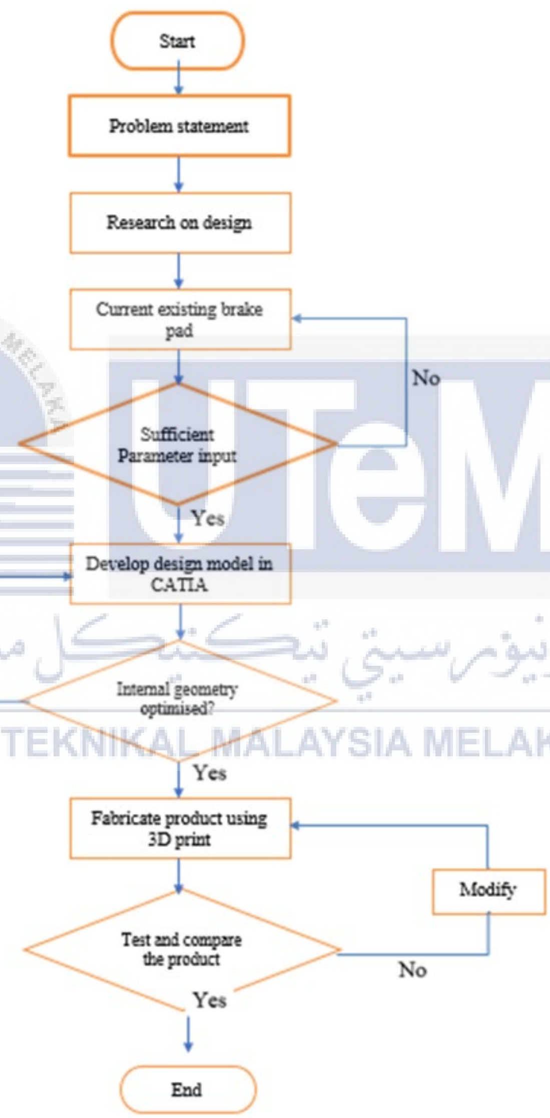

Figure 3.1 Flow chart process for overall research work

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Methodology in research is defined as the systematic method to resolve a research problem through data gathering using various techniques, providing an interpretation of data gathered and drawing conclusions about the research data. Essentially, a research methodology is the blueprint of a research or study. To meet the goals of this project, this chapter gives a general overview of research and development. This is the beginning of data investigation, product design, optimization parameters, manufacturing and product analysis.

3.2 Data research and analysis

A research and analysis is a tool used to collect, measure, and evaluate data from participants related to the study topic. It must be select an instrument based on the sort of research you are performing. Data analysis is the systematic use of statistical and/or logical tools to describe and display, summarise and assess data.

3.2.1 Instrument of research

The internet was employed to research more information regarding brake pad, web research time should be utilized in terms of productivity while planning lessons and activities. Questioning, summarizing, and assessing are all phases in getting as much information as feasible. We should arrange the queries before going on the Internet to establish a search strategy and a list of sites to study. The data is acquired by creating a list of various questionnaires in order to choose the correct one. A suitable data collection may be considered by meeting with the project supervisor to discuss the project in further detail.

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3.2.2 Design research

This research employs a technique of analysis to evaluate structural analysis such as internal geometry parameter, behaviour and process. Brake pad design in term of optimize geometry or have a significant impact lifespan of brake pad and a basic dynamic model is also necessary for analysis. The focus of future research will be on determining the appropriate bearing optimization parameter based on its lifespan.

3.3 Design Develop by Using Catia

Brake pad design was created using CATIA software and was based on brake pads used in automotive parts. After the design was finished all the data was collect and been analyses. The purpose of this project research is to work on automated modelling for different types of appliances by use of know-how-based engineering in traditional design processes. It also uses practical engineering-based knowledge in order to get right picture of all production process including the cost itself. Any design flaws might lead to extremely large losses. The design phase of the equipment development can be worth focusing on in order to reduce development costs.

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3.3.1 General sketching of the model

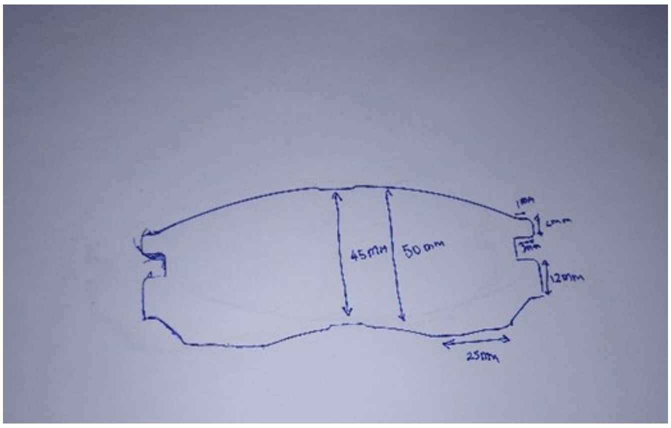

Figure 3.2 Sketch of brake pad

Before design the brake pad using the right parameter, it must be referring to real brake pad first. By using real brake pad from 1996 Proton Wira, the cat part was designed to give a clear picture what parameter that need to be change in order to reduce friction. But first, the measurement of the brake pad must be taken to make the sketch. By refering to this brake pad, it can be redesign in catia software. All the demension was taken and according to standard method to measure the brake pad and It is much easier to comprehend, diagnose, and provide solutions when a variety of features designed specifically for these purposes are used. CAD accelerates the manufacturing process by sending precise product information in an automated format that anybody can define.

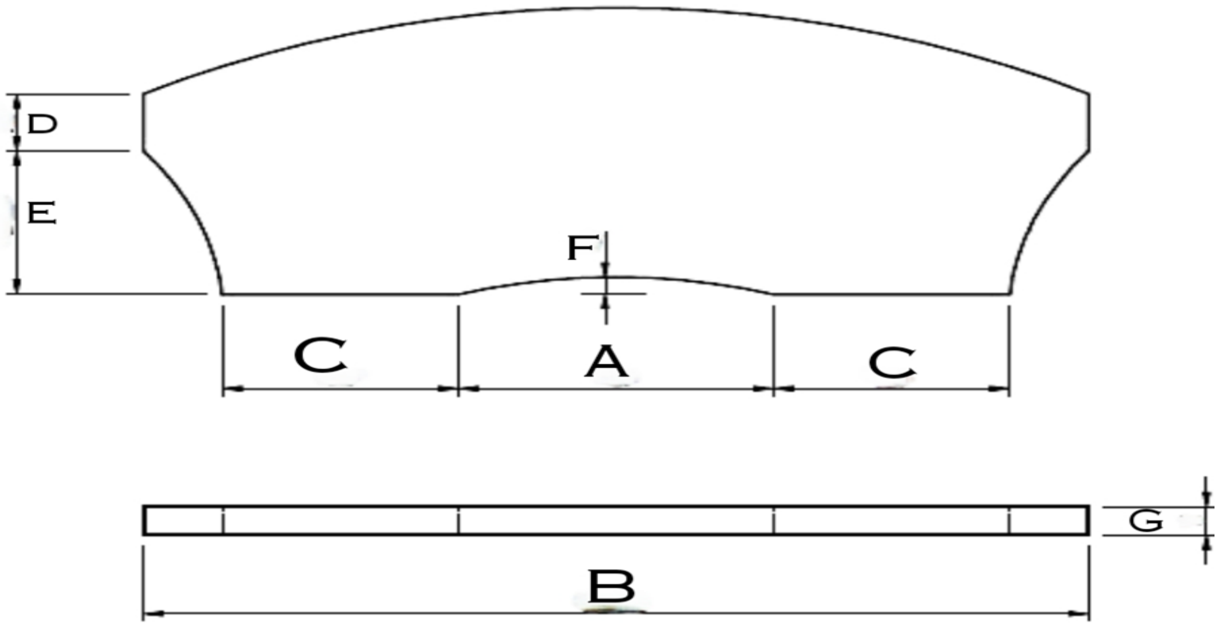

Figure 3.3 Dimension of brake pad

Table 3.1 Brake pad dimension

Unknown	Value
A	40 mm
B	110 mm
C	30 mm
D	10 mm
E	25 mm
F	5 mm
G	5 mm

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3.3.2 Part design of the model

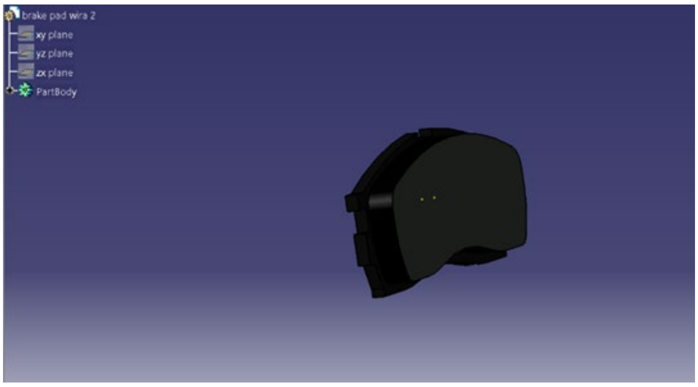

Figure 3.4 CATIA part

Conventionally , brake pad it only consist of two particular components that were attached together in beocme one part. Those components are the frcition material and the back plate. These components need a certain design in order to comply with technology and the environment to prevent failure. Because of that, the part doesn't required to do assembly process as the back plate and friction material can use different material in one design.

3.3.3 Material selection in Catia

The procedure of selecting materials already identified is more directly tied to design activities in technical. The main factor to be focussed on the selection of materials is identification of the needs for product design and potential materials. As if it is vital that the danger of failure is reduced and the capacity of the brake pad is guaranteed. Due to its highly sensitive differences in friction material, the current lightness and friction-efficient disc brakes are increasingly relevant to the quality of the installer. The problem of selecting a Quality Brake Pad is increasingly relevant. Friction and wear characteristics of friction materials are important in determining which new formulations developed are suitable for braking systems. Automotive brake pads have very complex friction and wear behaviour to forecast that they depend upon the various parameter.

Composition and formulation of brake pads also play a big role on the friction behaviour, and since composition-property relationship are not known well enough, the formulation task is based on trial and error and thus is expensive and time consuming (Österl & Urban, 2004). Generally brake pads have a friction coefficient, μ between 0.3 and 0.6 (Blau, 2001). to create a model using SLS 3D printing based on the original design and their drawing To identify the standard character, only a few characteristics are required. CATIA can measure or determine these factors based on geometric relationships. The following steps are intended to reverse engineer these spur gears. It allows for a more detailed search of the design suitability of material selection and loading conditions.

3.4 Optimal Parameter of model

The term "Parametric Optimization " refers to the process of solving problems in which certain design variables are implicit functions of some independent input parameters. For the entire parameter space of interest, optimal solutions and optimal objective function values are provided as functions of the input parameters. Because exact solutions are only available for linear or convex-quadratic parametric optimization problems, general non-convex non-linear problems require approximations.

3.4.1 Analyze the optimum parameter

One of the most important criteria in the design of brake pad is long life or longer lifespan and to meet the standards of brake pad design , designer must be determining the internal geometry of a brake pad. Based on the friction rate and temperature, the design must meet geometry and strength requirements. As the much that, designer also need to consider afew element before finalize the optimum parameter. The design should eco-friendly toward enviroment, the design also must not to complex. The complex design will increase that chances of design fail to operate. Either that the design also cannot be simple as real brake pad as the model became no different compare to real brake pad. A constraints violation study was carried out to assess the effectiveness of each constraint. A convergence analysis was performed to ensure the worldwide optimal solution in the design. By choosing one subset which still contains sufficient information for classification, the feature-based selection process reduces directly the number of original features. This design process cant be complete if the model was not analyze. The analysis will be performed by using sim solid software.

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3.4.2 Parameter and measurement selection

After analyzing optimum parameter of brake pad the size of brake must be able to determine that it is strong enough to provide the required or expected life under specified operating conditions. To ensure the correct selection, the standard geometry must be considered before selecting the optimum brake pad parameter. The basic braking system requirements – obtaining the highest and most stable coefficient of friction possible. Compression strength, friction coefficient, wear resistance, heat capacity, material density, and expenses are included.

3.5 Develop the fabrication of the design

It is one thing to design a product. Fabricating that product, on the other hand, necessitates taking an initial product design through an important step known as fabrication design.When it comes to the product development cycle, it all begins with conception, or an idea. This is followed by product design, engineering, prototyping, and, finally, fabrication. To put it another way, there are several steps between product design and production. After the model has been designated from CAD data software, this process is carried out on a 3-D printing machine. It is a design and manufacturing process in which digital data commands manufacturing equipment to produce a variety of part shapes. The consequences of the fabrication, including the cleaning, sanding and separation of the product, without affecting the product manufactured.

3.5.1 3D printing (SLS Printing)

Selective laser sintering (SLS) is an additive manufacturing technique that uses a laser as the power source to sinter powdered material (typically nylon or polyamide), automatically aiming the laser at points in space defined by a 3D model and binding the material together to form a solid structure. The two instantiations are of the same idea but are different in technological detail, which is similar to selective laser melting. SLS is a relatively new technique, which has previously been used primarily for rapid prototyping and low volume component parts production. As the marketing of additive manufacturing technology improves, production roles increase. The printer heats up the powder at a temperature just beneath the melting point for the raw material and makes it easier for the laser, while tracing the model, to increase the temperature for certain parts.

3.5.2 Printing process

In order to begin the printing process firstly is to design the model with any CAD software or 3D scan data, then export it in a 3D printable file format (STL or OBJ). Each SLS printer comes with software for configuring printing settings, orienting and arranging models, estimating print times, and slicing the digital model into layers for printing. When the setup is finished, the print preparation software sends the instructions to the printer via wireless or cable connection. after the machine is ready to print once all preprint checks have been completed. Depending on the size, complexity and density of the parts, the SLS 3D prints can take anywhere from a few hours to several days.

The powder is applied in a thin layer on top of a platform within the build chamber. The printer preheats the powder to a temperature slightly below the raw material's melting point, making it easier for the laser to raise the temperature of specific regions of the powder bed as it traces the model to solidify a part. The laser scans a cross-section of the 3D model and heats the powder to or under the melting point. This mechanically fuses the particles together to form a single solid part. The unfused powder acts as a support structure for the part during printing, eliminating the need for dedicated support structures. The platform then descends one layer into the construction.

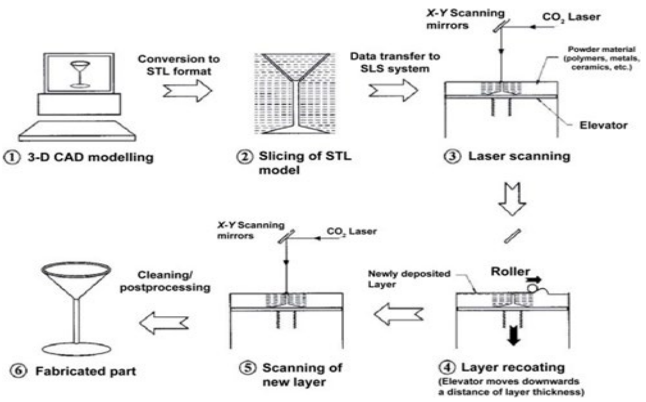

Figure 3.5 The Process of 3-D Printing

3.5.3 Cooling

To ensure optimal mechanical properties and avoid warping in parts, the build chamber must be slightly cooled down inside the print enclosure and then outside the printer after printing. This part is slowly cooled, usually for a couple of hours. A difficult series of events influences the exact cooling rate of each component. In-process cooling is frequently uniform, owing to a variety of factors that make prediction and measurement difficult. It can then be recharged as it slowly moves away from the heaters, depending on where the heater controls powder bed temperature. This is why the machine's design makes a significant difference Because of the powder reliance on conduction and its low therapeutic conductivity, cooling rates are typically slow. Many laser sintering models ignore cooling and assume that the powder bed is completely cooled at the end of construction.

3.5.4 Post-processing

When compared to other 3D printing processes, post-processing SLS parts takes the least amount of time and effort. Because of the lack of support structures, it is easily scalable and produces consistent results for batches of parts.After completing a print job, remove the completed parts from the build chamber, separate them, and clean them of excess powder. Typically, this process is carried out manually at a cleaning station using compressed air or a media blaster.

After part recovery, any excess powder is filtered to remove larger particles and recycled. Unfused powder degrades slightly when exposed to high temperatures, so it should be replaced for subsequent print jobs. SLS is one of the least wasteful manufacturing methods due to its ability to re-use material for subsequent jobs.

Separate devices for reclaiming, storing, and mixing powder are a common theme in the SLS industry. Fuse Sift, a single device in the Fuse one workflow, handles the extraction of parts and unsintered powder, as well as the storage, dosing, and mixing of streams. After sifting, SLS 3D printed parts are ready for use. However, for selective laser sintered parts, there are several other post-processing steps to consider.

SLS 3D prints have a grainy finish by default. For a smoother surface finish, Formlabs recommends media blasting or media tumbling SLS parts. Spray painting, lacquering, electroplating, and coating parts can achieve a variety of colours, finishes, and properties, such as watertightness (coating) and conductivity (electroplating). Formlabs SLS parts are dark in colour, making them unsuitable for dyeing.

3.6 Product analysis

The analysis of products includes the examination of product characteristics, costs, availability, quality, appearance and other aspects. Potential buyers, product managers attempting to understand competitors, and third-party reviewers conduct product analysis. As part of the product design, product analysis can also be used to convert a high-level product description into project results and requirements. It includes all facts, purpose, operation and characteristics of the product. In order to analyze the product ir has to been conduct by a few method or test to ensure the product achieve the object of this project research.

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3.6.1 SIMSOLID software

SimSolidTM by Altair is a virtual testing environment that is assisting so many of designers, engineers, and analysts at leading companies achieve a competitive edge by increasing efficiency.SimSolid allows you to quickly simulate various design possibilities under actual situation, allows for fast iterations on full-featured assembly designs. This early virtual testing improves quality while reducing the cost of various prototypes, physical testing, and rework.

Figure 3.6 SIMSOLID sofware

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CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

This chapter will discuss the results and data analysis of the project outcome. In order to analysis any data , it will be done by simulation method. In order to obtain better outcome, SIM SOLID software is used for the primary features of analysis. Sim Solid is a game-changing simulation technology for designers, engineers, and analysts because it performs structural analyses on fully featured CAD assemblies in minutes. It eliminates geometry preparation and meshing, which are the two most time-consuming, labor-intensive, and error-prone tasks in a traditional structural simulation.

4.2 COF Constant for SIMSOLID Analysis

The dry sliding process was carried out using a DUCOM pin-on-disc tribometer. All pin samples were permitted to slip against 72-mm diameter carbon chromium-steel discs in accordance with ASTM G99-05 (Standard Test Method for Wear Testing with a Pin-on-Disk Apparatus). The experiment was carried out over a 1000-meter sliding distance at a temperature of 27 degrees Celsius. Various normal loads (ranging from 19.62 to 58.68 N) and sliding speeds (from 400 to 600 rpm) were employed.

According to the findings, COFs and wear rates range from 0.27 to 0.51 and 2.7 105 to 2.4 104 mm3 /Nm, respectively. These figures were computed using various pin internal geometries and sliding scenarios. COF values for pins with solid, squares, rectangles, circles, and triangles, for example, ranged from 0.33 to 0.47, 0.31 to 0.50, 0.34 to 0.46, 0.28 to 0.43, 0.29 to 0.42, and 0.27 to 0.43. The low COF of the various 3D-printed ABS structures was linked to their contact stress distribution pattern, which avoided wear during the braking process. As a result, finite element analysis was used to investigate the distribution of stresses induced on the contact surface.

Table 4.1 Coefficient of Friction

Samples	Coefficient of Friction
Solid	0.4113
Rectangle	0.3870
Triangle	0.3852
Square	0.4200

4.2.1 Effect of Different Geometry on The COF

In this simulation, different geometry patern has been aplied toward the surface of each brake pads. As a result come out, it give different value of normal traction between the brake pads and the disc or rotor. Different amount of traction give different performance of braking in terms of friction and wear.

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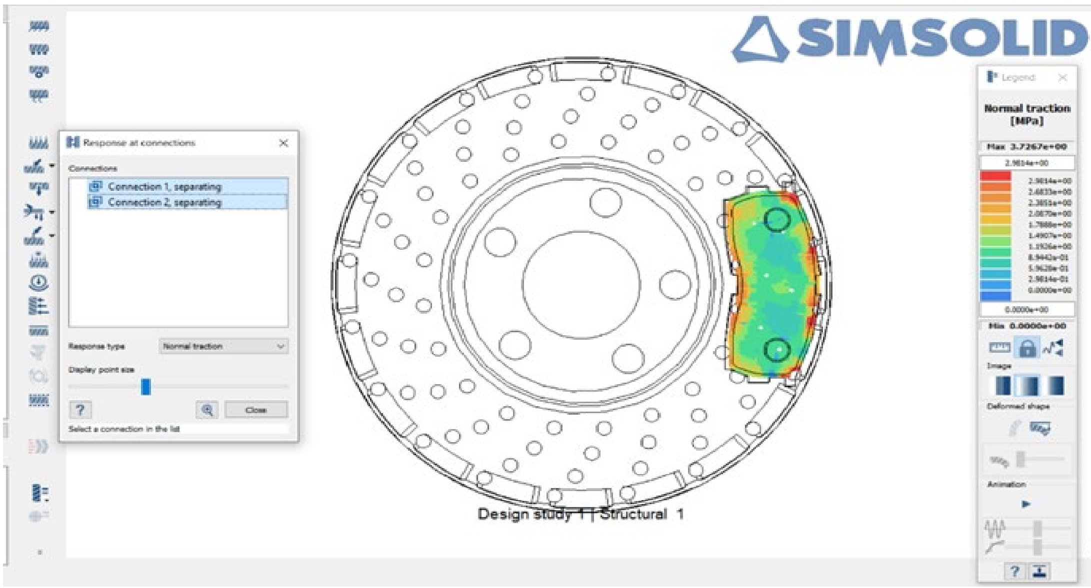

Figure 4.1 Solid normal traction

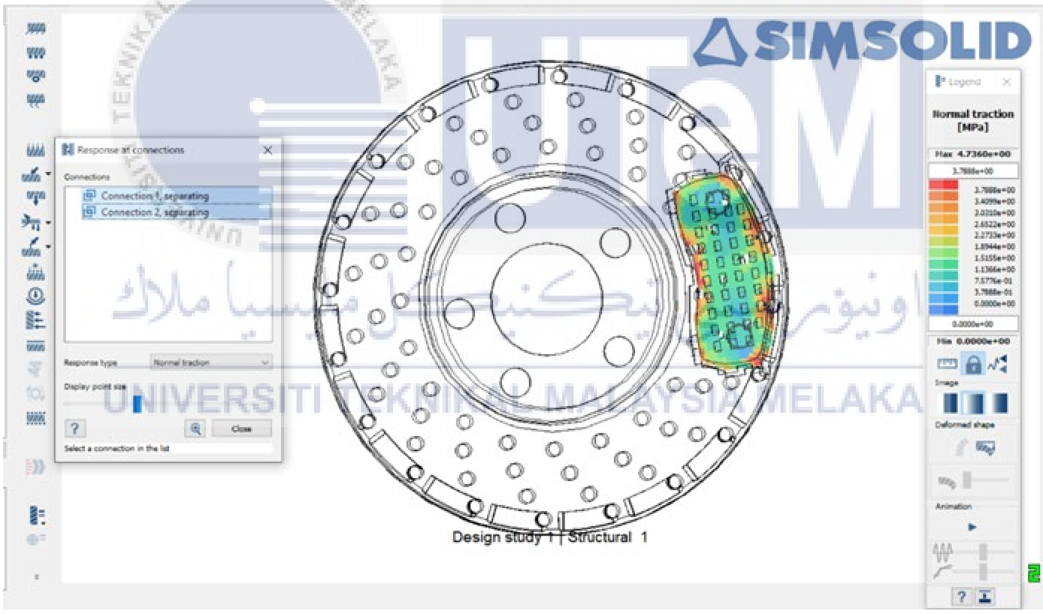

Figure 4.2 Rectangle normal traction

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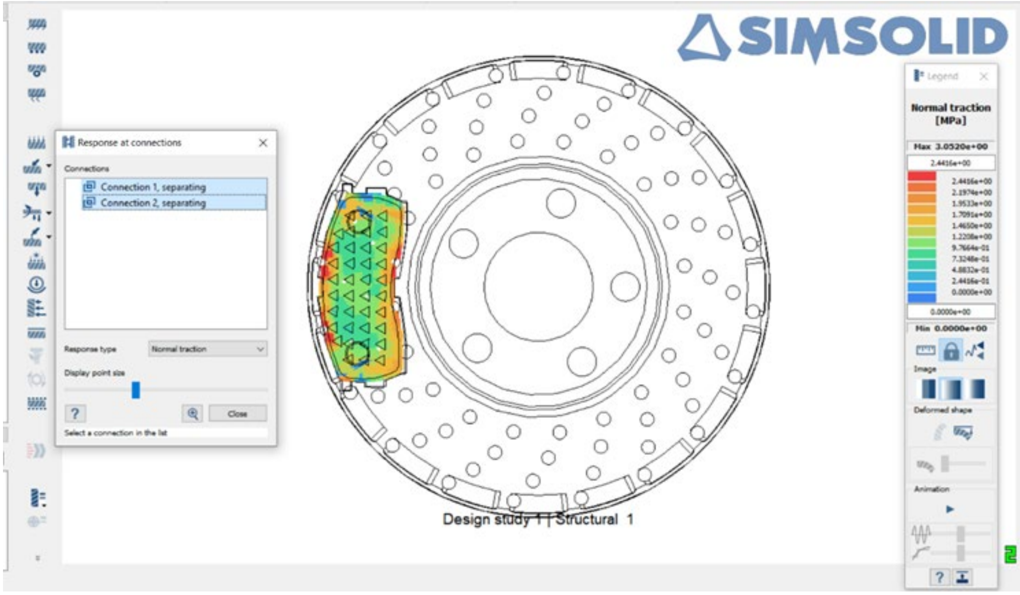

Figure 4.3 Triangle normal traction

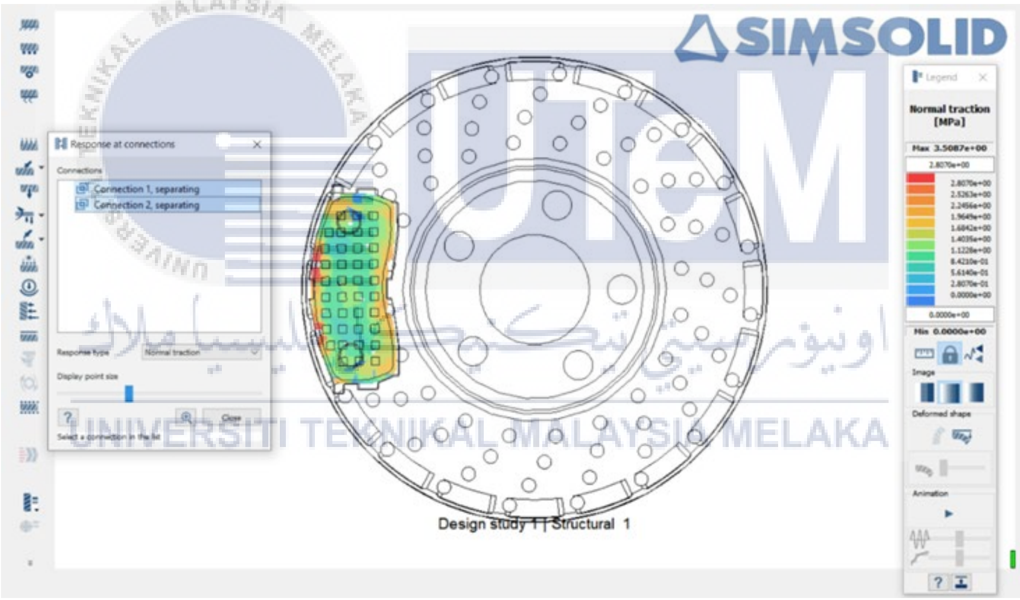

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Figure 4.4 Square normal traction

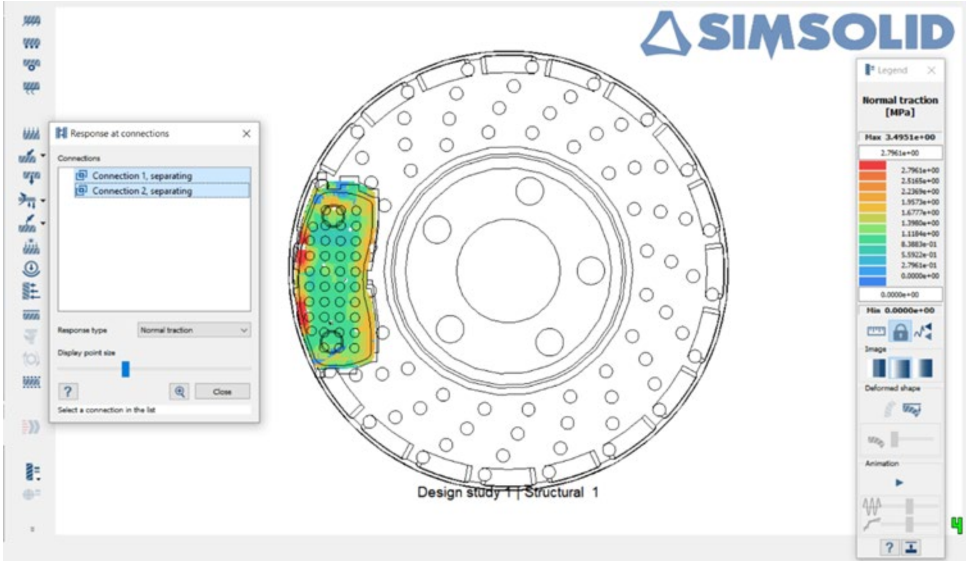

Figure 4.5 Circle normal traction

Figures 4.1, 4.2, 4.3, 4.4, 4.5 illustrate the stress distribution induced in solid brake pad, rectangle brake pad, triangle brake pad, square brake and circle brake pad samples. The colour red represents the highest stress location, while the colour greenish indicates a moderate stress location and the colour blue denotes the lowest stress location. The geometry has an effect on both the finite element analysis result and the coefficient of friction. Different geometry pattern give different result of traction, The brake pad with rectangle geomtery patern has the highest amount of normal traction which is it indicate that brake pad has worse traction compare to other sample. As the given data, the rectangle brake pad has MORE red spot that indicate highest stress and has less blue spot that indicate less stress.

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Table 4.2 Result of normal traction

Samples	Normal Traction (Mpa)
Solid	3.7267 e+00
Rectangle	4.7360 e+00
Triangle	3.0520 e+00
Square	3.5087 e+00
Circle	3.4591 e+00

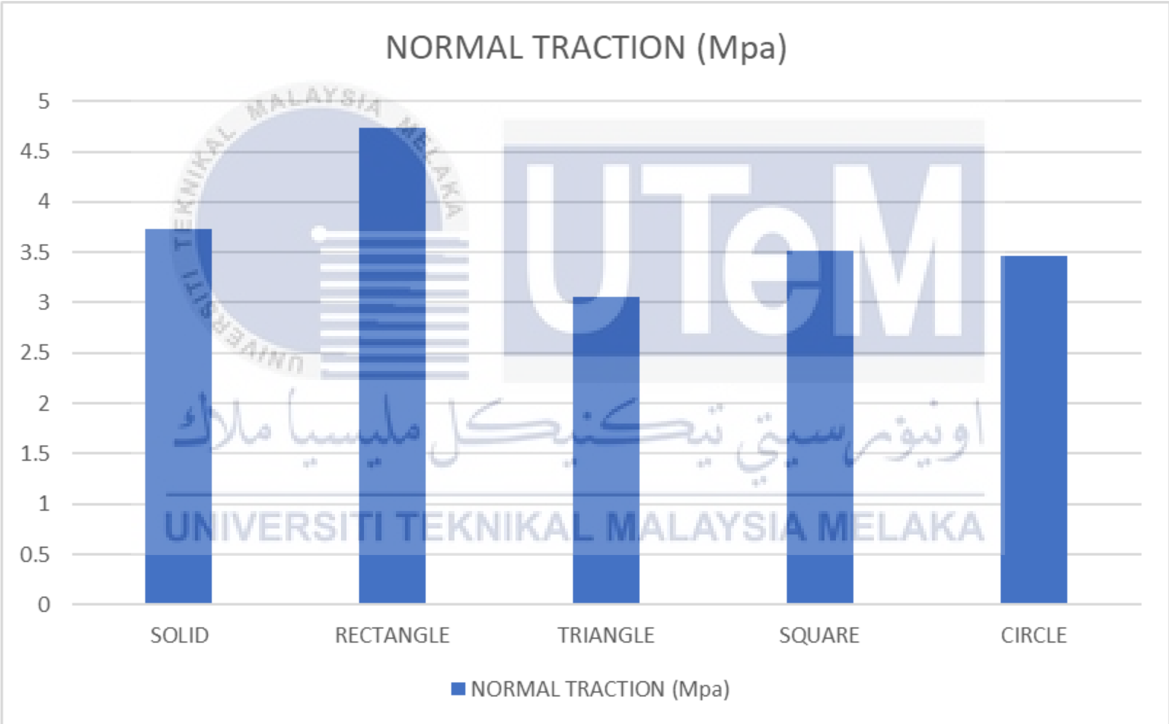

Figure 4.6 Normal Traction Comparison

4.3 Structural Non-Linear (SIMSOLID)

This creates a mechanism that allows parts to partially or fully separate from one another. Forces only transfer through the still connected portion of the connection when this happens. The sticking/sliding threshold is determined by a friction coefficient. Fully sliding indicates a value of 0.0, while fully bonded indicates a value of 1.0. Friction values range from 0.1 to 0.2. Nonlinear analysis operations require the solver to iterate in order to find the value of interest. Expect this to take a little longer, and as such, make sure the analysis defined makes physical sense. Despite of all simulation, nylon 6 was choosen as the material in simulation. Other component were added to this simulation, the other component is brake disc and the material of this component was a steel. Adding the brake disc is essential process as the pads need something to be hold on the all forces that been applied. In this simulation the brake disc was rotating at 35.5 Rad/sec and the force the been applied toward the surface of the brake pad is 500 newton.

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4.3.1 Displacement Magnitude

Displacement analysis is a field of engineering that focuses on calculating the displacement field within a structure that is subjected to external forces. Every point in the structure shifts when a solid deforms under external stress. The maximum displacement was shown by the red colour, while the least displacement was indicated by the blue colour.

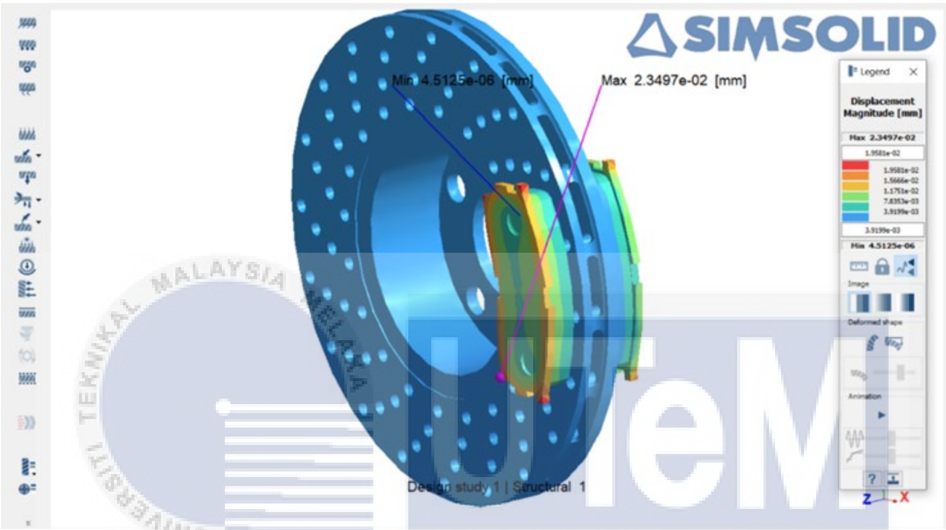

Figure 4.7 Solid patern displacement magnitude

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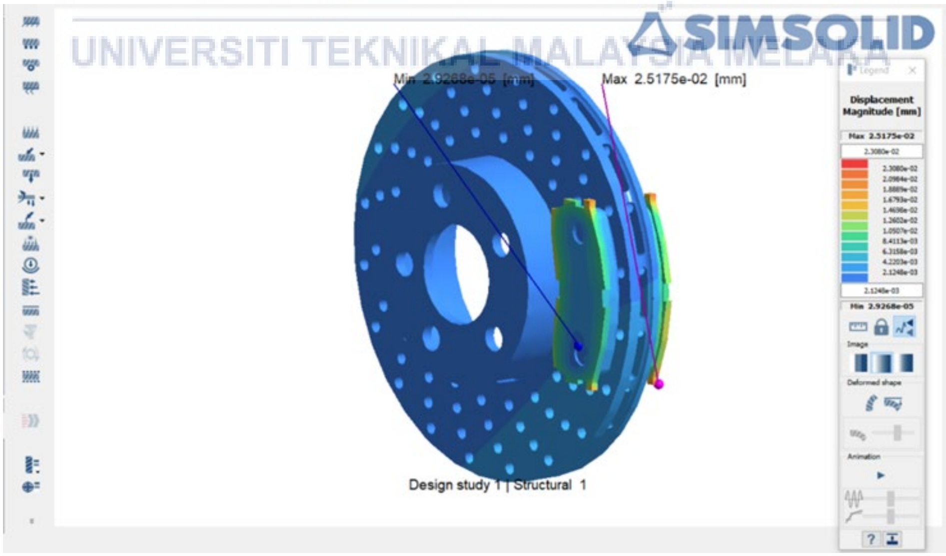

Figure 4.8 Rectangle patern displacement magnitude

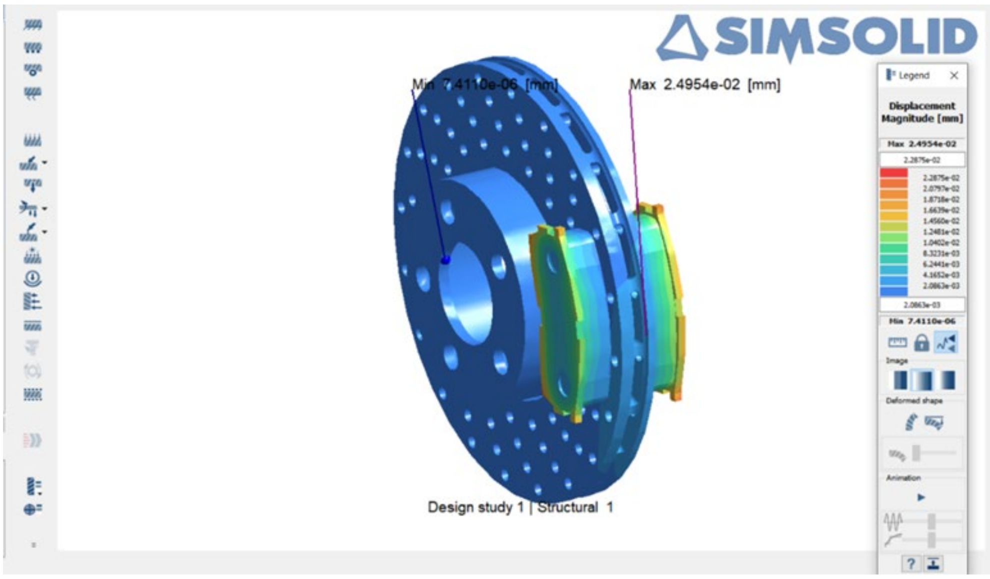

Figure 4.9 Triangle patern displacement magnitude

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Figure 4.10 Square patern displacement magnitude

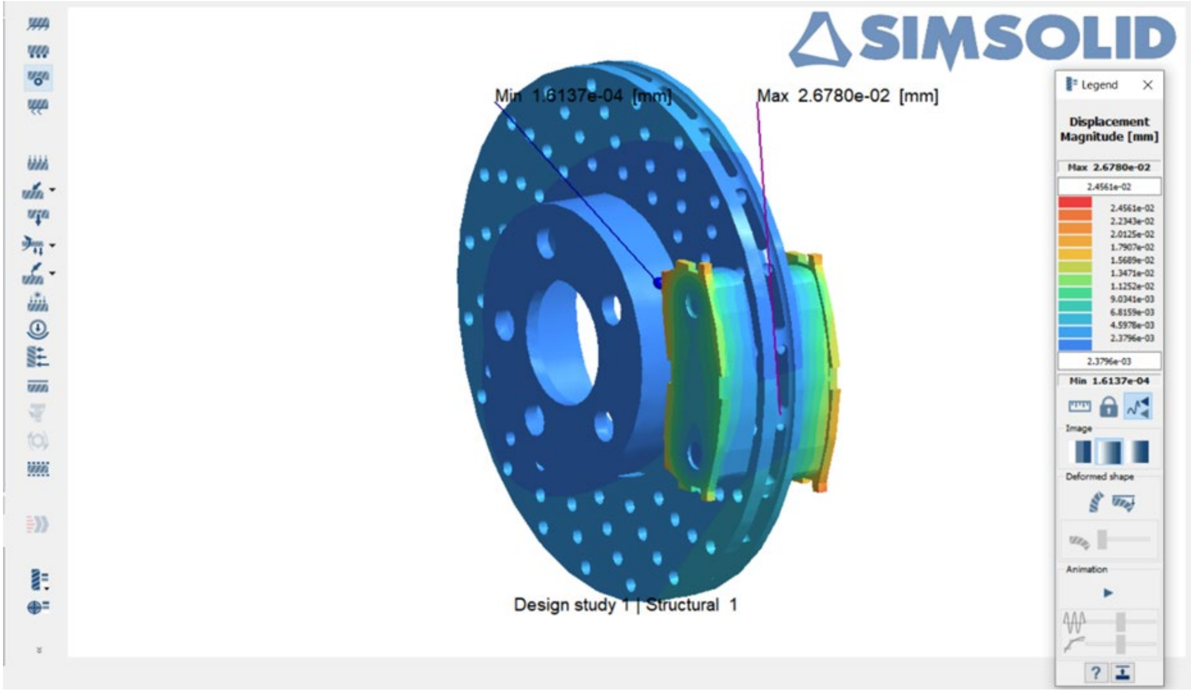

Figure 4.11 Circle patern displacement magnitude

The maximum displacement which is indicate by red colour occur many spots at outer side of backing plate. The solid geometry has redder spot to be appear compare to other geometry, but it doesn't mean that the displacement of solid geometry was greater than other geometry. The result of all displacement simulation shown that circle geometry has the higher amount of displacement which only mean that the circle geometry has more tendency or possibility to be failed and solid geometry has less tendency to be failed as it has lowest amount of displacement. The solid geometry has the lowest maximum value while the triangle pattern has the lowest minimum value. The highest maximum amount is 2.6780e-02 and the lowest maximum amount is 2.3497e-02, and the average of maximum displacement magnitude amount is 2.5067 e-02.

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Table 4.3 Displacement Comparison

Samples	Min. Displacement (mm)	Max. Displacement (mm)
Solid	4.5125e-06	2.3497e-02
Rectangle	2.9268e-05	2.5175e-02
Triangle	7.4110e-06	2.4954e-02
Square	2.0409e-06	2.4929e-02
Circle	1.6137e-04	2.6780e-02

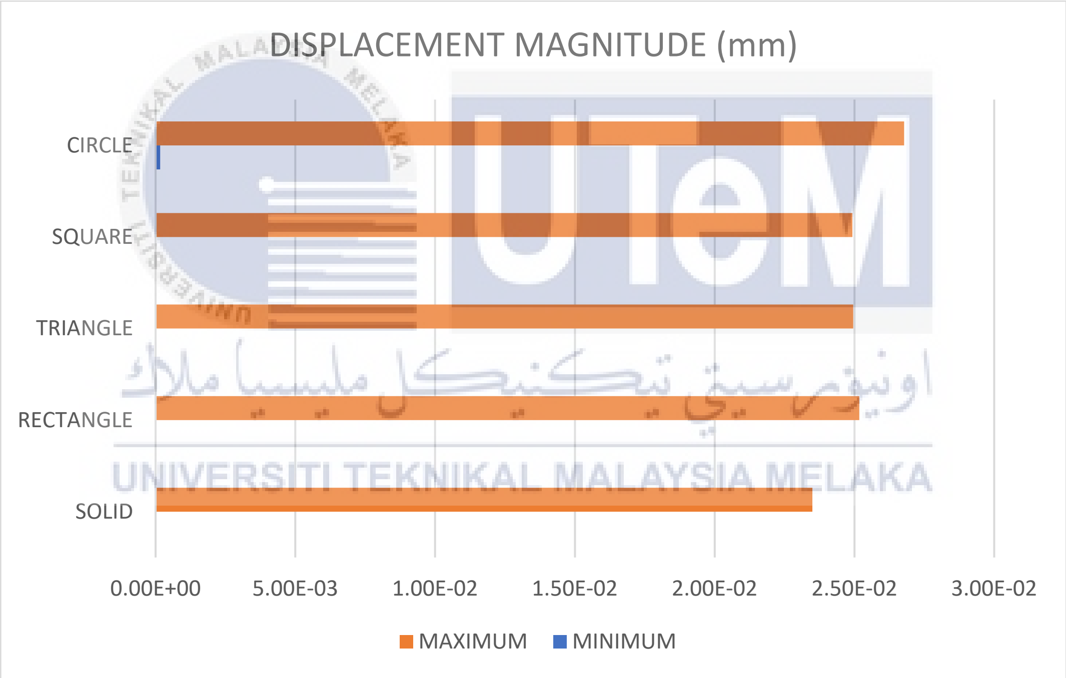

Figure 4.12 Displacement Comparison Graph

4.3.2 Von Mises Stress

Von Mises stress is a value that is used to determine whether a stress exceeds or fracture. It is typically applied to ductile materials such as metals. According to the von Mises yield criterion, a material will yield if its von Mises stress under load is equal to or greater than its yield limit under simple tension.

Figure 4.13 Solid von mises stress

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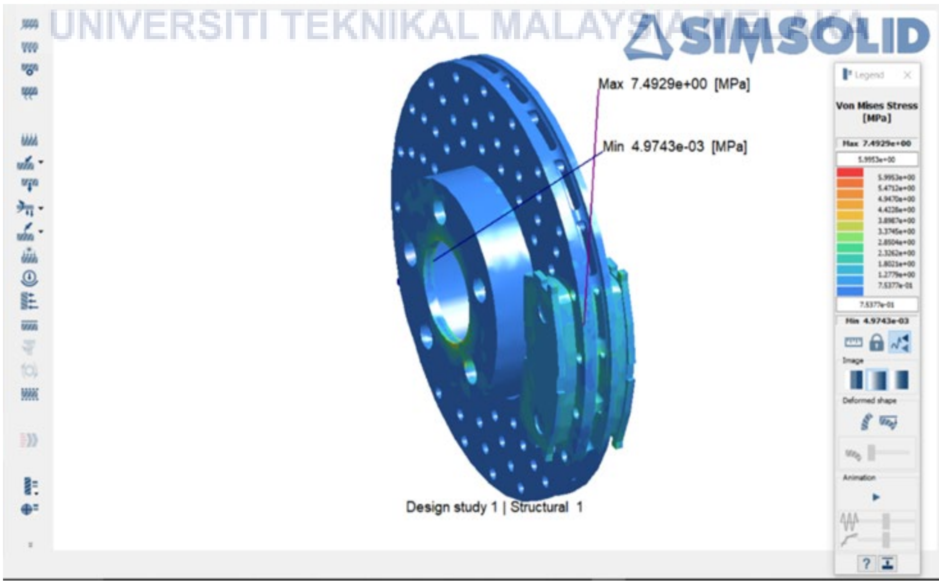

Figure 4.14 Rectangle patern von mises stress

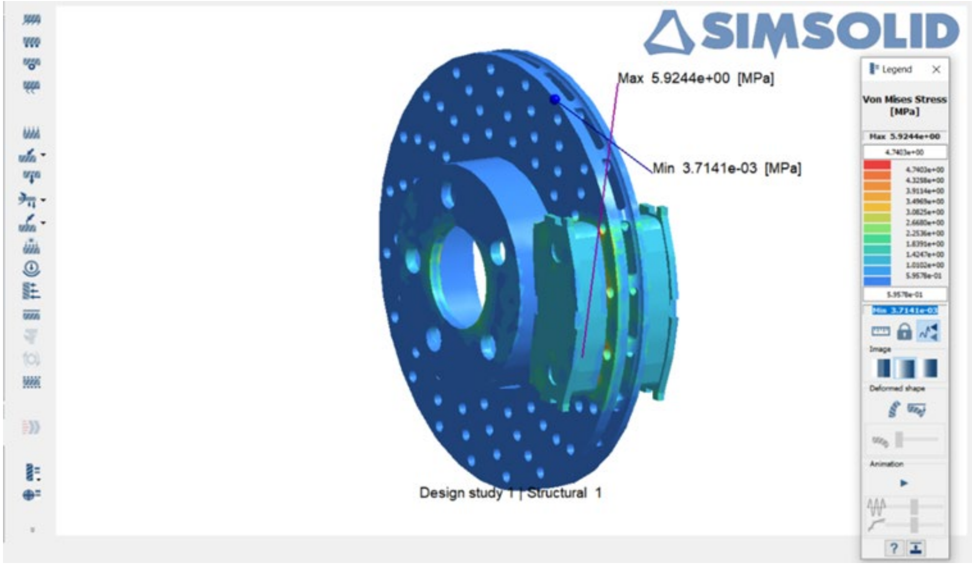

Figure 4.15 Tritangle patern von mises stress

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Figure 4.16 Square patern von mises stress

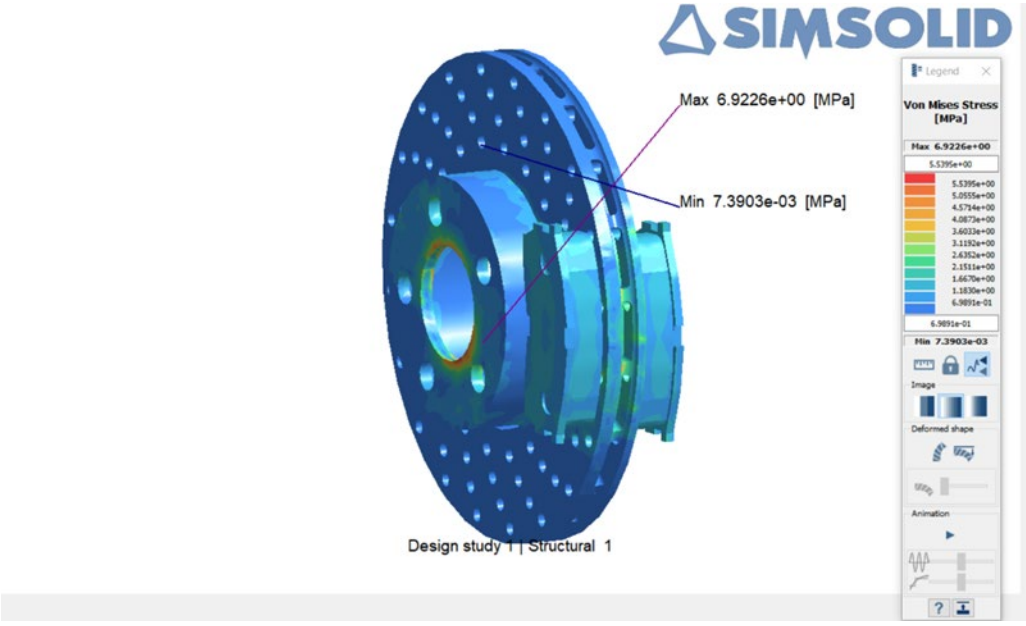

Figure 4.17 Circle patern von mises stress

In von mises simulation result was different from displacement magnitude. It is because the data shown that redded spot that represent highest amount von mises was at brake disc instead of brake pad. Most of the are affacted area was grenish and blue colour which mean it has moderate and low value of von mises stress. Table 4.3 shown that rectangle patern has the highest value of von mises stress ni mega pascal unit and the average of maximum von mises stress is 6.101e+00. Solid geometry still has the lowest value which indicate that solid geometry has a lower chance of failure or been yeild.

Table 4.4 Von Mises Comparison

Samples	Min. Von Mises Stress (Mpa)	Max. Von Mises Stress (Mpa)
Solid	2.0790e-03	4.9838e+00
Rectangle	4.9743e-03	7.4929e+00
Triangle	3.7141e-03	5.9244e+00
Square	3.4293e-03	5.1823e+00
Circle	7.3903e-03	6.9226e+00

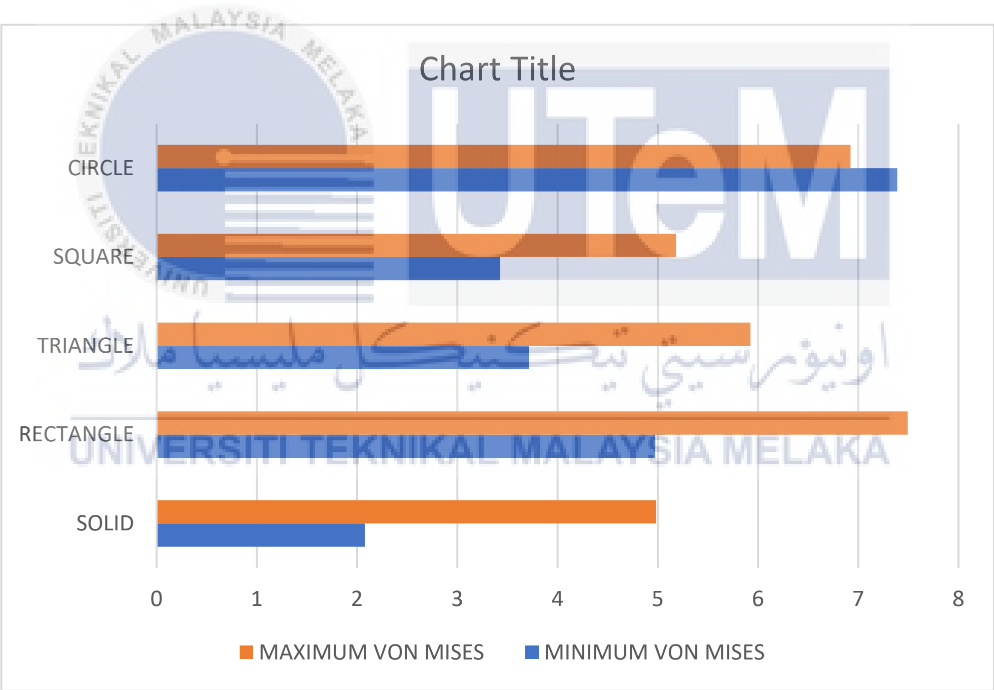

Figure 4.18 Von Mises Stress Comparison Graph

4.3.3 Max Shear Stress

In general, a ductile material fails or yields when its maximum shear stress equals or exceeds the shear stress value at the yield point in a uniaxial tensile test. The red colour represents the maximum shear stress at which a ductile material can fail, while the blue colour represents the minimum shear stress.

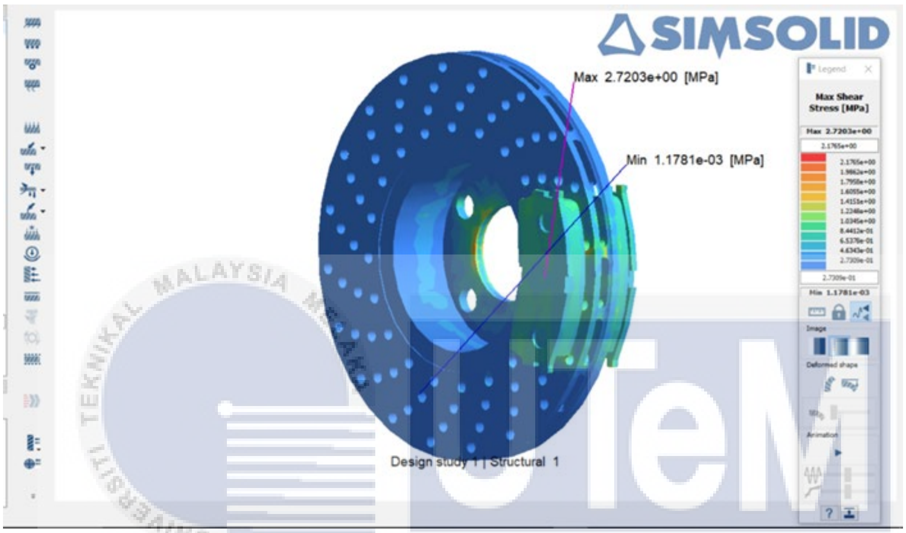

Figure 4.19 Solid max shear stress

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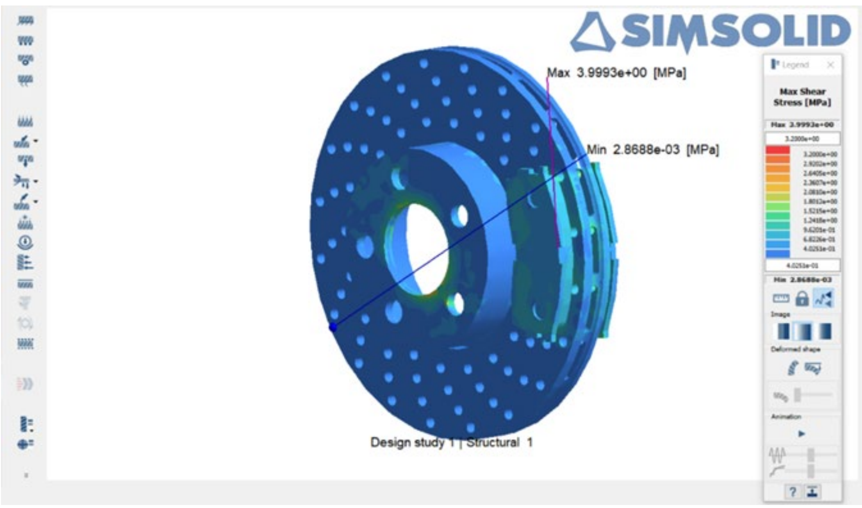

Figure 4.20 Rectangle patern max shear stress

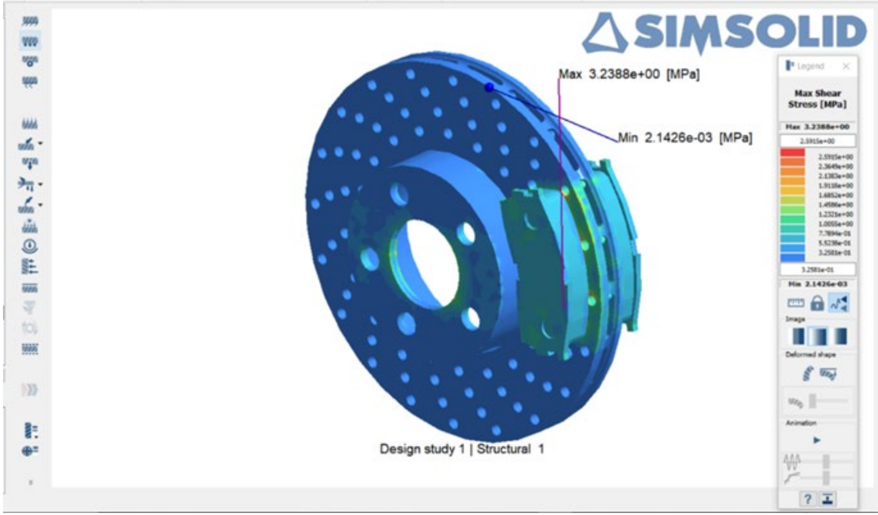

Figure 4.21 Tritangle patern max shear stress

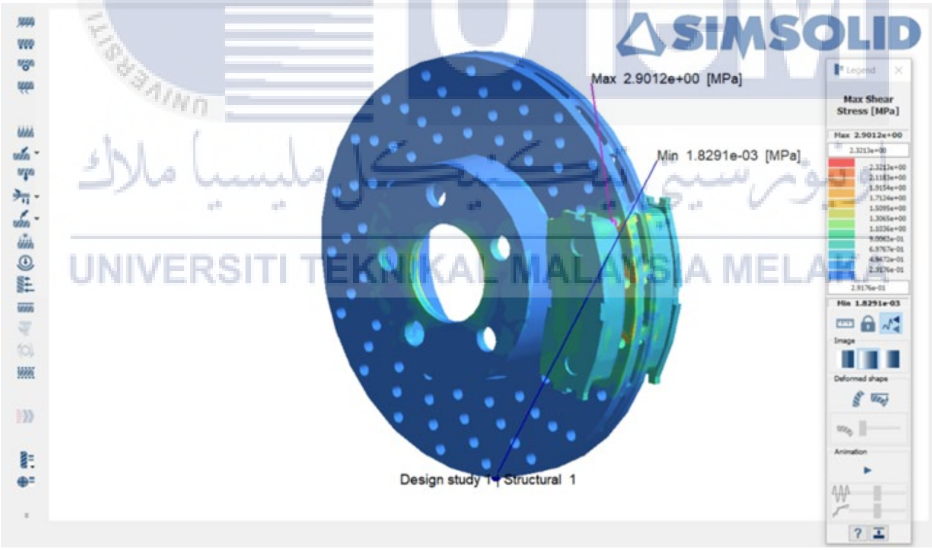

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Figure 4.22 Square patern max shear stress

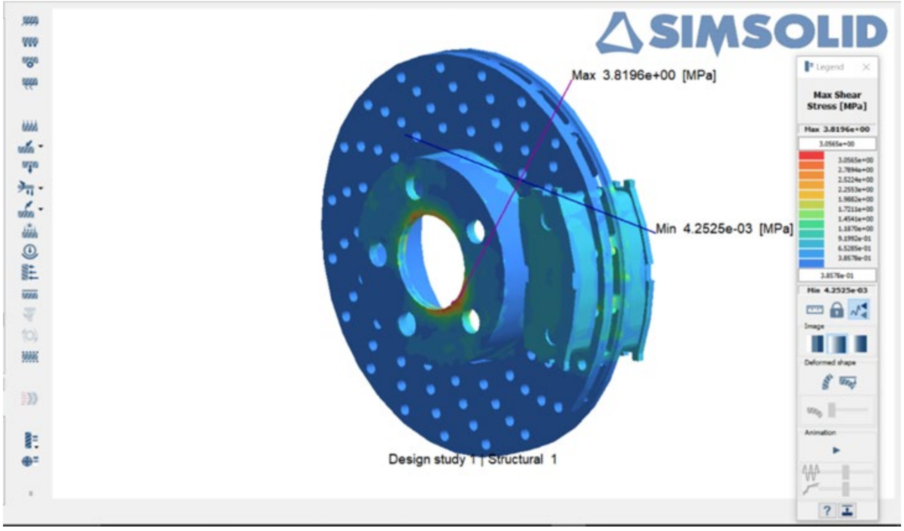

Figure 4.23 Circle patern max shear stress

In this simulation, maximum shear stress was representing as red colour. But same like previous simulation, the most redded area wasn't from the brake pad but at the brake disc. It because the simulation detected the most area affected was the rotating brake disc that produce maximum shear stress more than brake pad. The brake pad more likely grenish and blue colour which is indicate less value of von mises stress. Based on figure 4.23 the maximum value of max stress is 3.993e+00 and it comes from rectangle geometry while the solid geometry has the lowest value of max shear stress and the average value of maximum shear stress is 3.236e+00. The rectangle geomtery has higher chance or probability to fail as it has the highest value of maximum shear stress.

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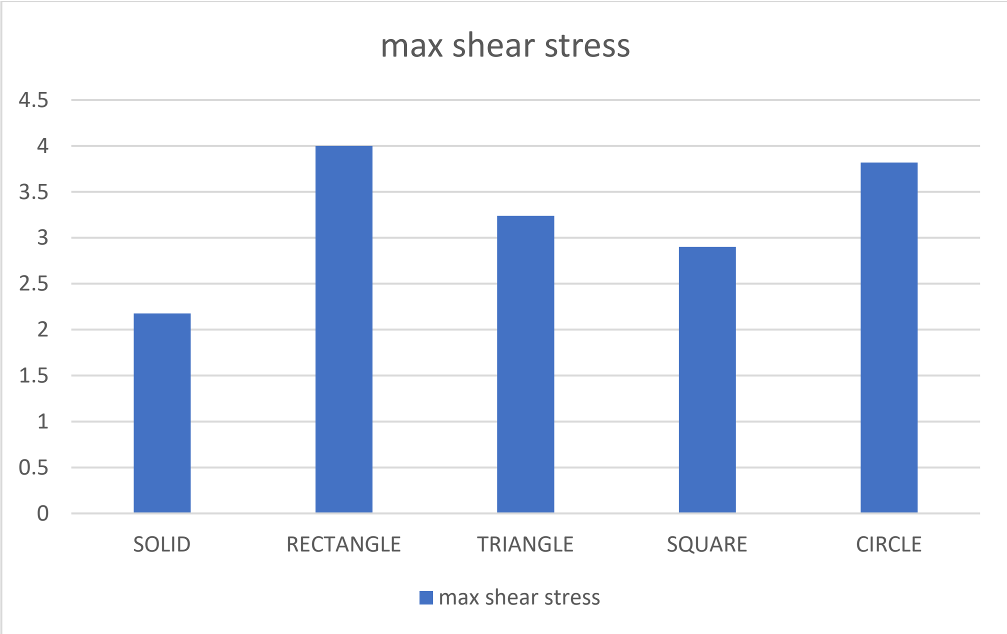

Figure 4.24 Max. Shear Stress Comparison Graph

4.4 Prototype and Actual Product Differentiation

1996 Proton Wira 1.6 Brake pad (actual brake pad)

Figure 4.25 Actual brake pad

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4.4.1 Product comparison

Sample 1 (SLS Solid Geometry Brake Pad)


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Figure 4.26 Solid geometry brake pad

Sample 2 (SLS Rectangle Geometry Brake Pad)


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Figure 4.27 Rectangle geometry brake pad

Sample 3 (SLS Triangle Geometry Brake Pad)

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Figure 4.28 Triangle geometry brake pad

Sample 4 (SLS Square Geometry Brake Pad)

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Figure 4.29 Square geometry brake pad

Sample 5 (SLS Circle Geometry Brake Pad)

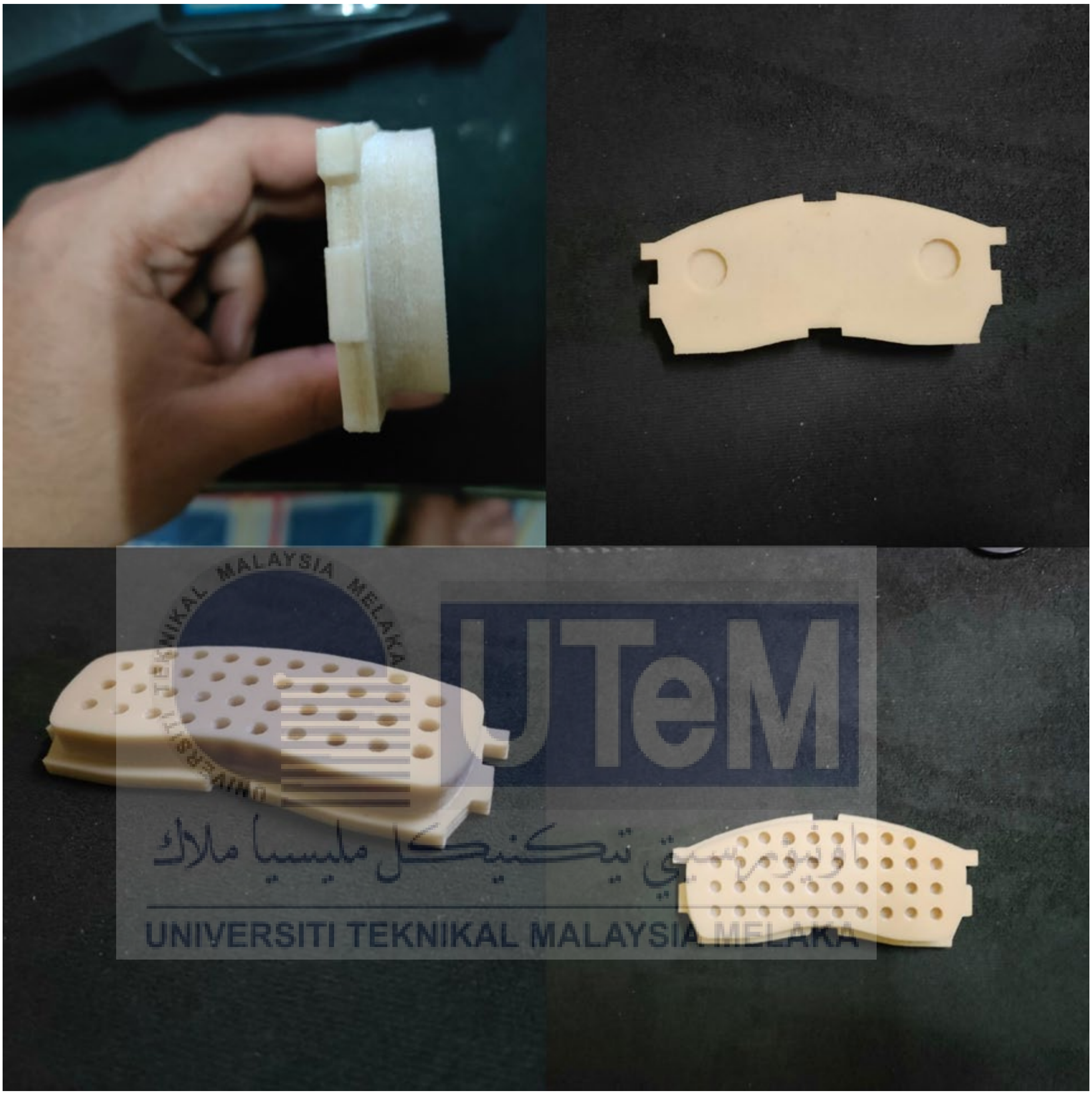

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Figure 4.30 Circle geometry brake pad

4.4.2 Product Specifications

In idea of optimizing the parameter of the brake pad, product specification especially for dimension must be focused on. The sample brake pad in this study was compared to a real industrial brake pad, with some tweaks and changes made along the way. This specification also help to develop futher idea of advancing the parameter of brake pad.

Table 4.5 Product Dimensions

Parameter	Value
Long	130mm
Width	50mm
Back plate thickness	5mm
Pad width	40mm
Pad thickness	10mm
Pad width	110mm
Overall thickness	15mm
Product weight	100gram
Pocket depth	5mm
Geometry diameter	5-6mm
Number of geometries	38

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Table 4.6 Material Properties of Nylon 6

Parameter	Value
Elasticity modulus	2760
Poisson's ratio	0.35
Density	1120 kg/m^3
Ultimate tensile stress	70.40 MPa
Tensile yield stress	75.70 MPa
Compressive yield stress	70.40 MPa
Thermal expansion coefficient	2.8100

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4.5 Product Readiness

Product readiness can be very crucial part after all of process in making of those products. Some application might be good for certain situation, so that why the parameter must be set in order to differentiate or compare any kind of product. Given that scale from 1 to 5 to be representing the performance of printed brake pad. Scale 1 indicate poor performance and 5 as excellent. Based on figure 4.31, the solid geometry can be represented as any kind of real brake pad. With other geometry that been applied toward the surface of the brake pad, solid geometry seems to be dominant at most of the simulation. But the solid geometry got scale 2 in normal traction which made other geometry has the same performance as if solid geometry. Square geometry has very outstanding performance as that sample has more good scale more than other sample which mean that the square geometry was the best geometry compare to other. Rectangle geometry somehow consist of three bad result of performance and maybe are the most not relevant geometry to applied.

SAMPLE	DISPLACEMENT MAGNITUDE	VON MISES STREES	MAX SHEAR STRESS	NORMAL TRACTION
SOLID	5	5	5	2
RECTANGLE	2	1	1	1
TRIANGLE	3	3	3	5
SQUARE	4	4	4	3
CIRCLE	1	2	2	4

Figure 4.31 Product performance

1	2	3	4	5
Very bad	Bad	Good	Fairly Good	Excellent

Figure 4.32 Guidelines for product readiness

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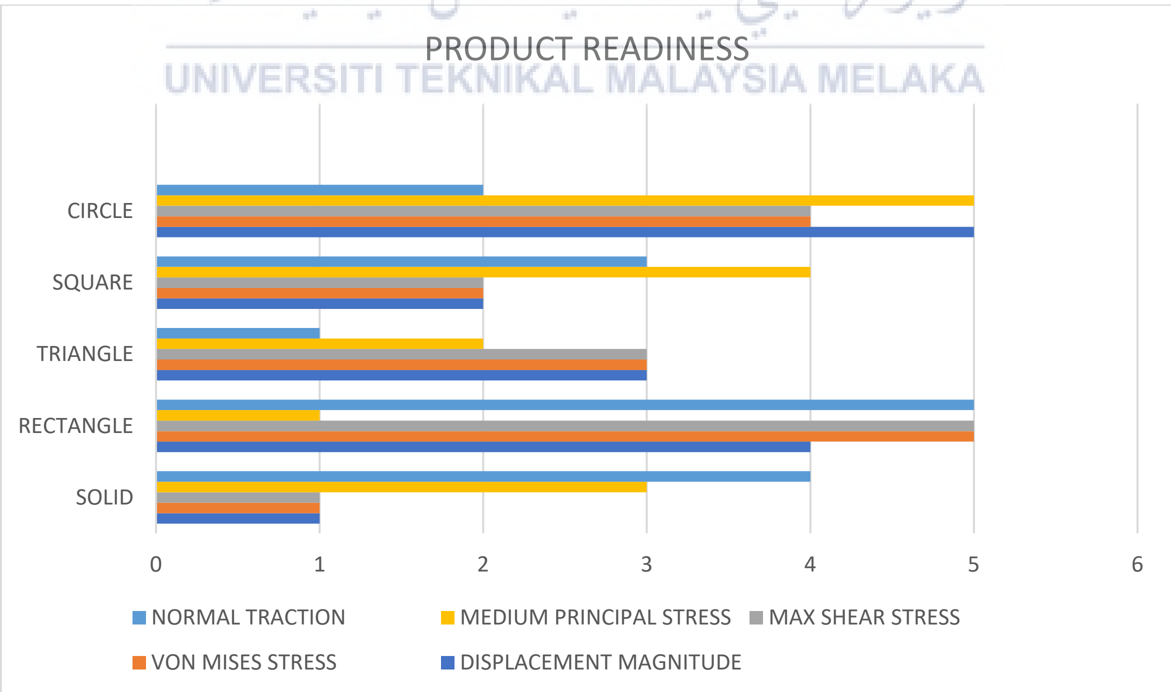

Figure 4.33 Product readiness

4.5.1 Potential application

As the analysis provide on this project shown that some product's geometry has a better result or below average from a solid geometry that representing real brake pad. The data show that some of geometry improve the strength of the product. Thus improving some properties, this method also can reduce the cost of making brake pad as some dimension of product are been modify.

At an early stage, this product has a potential to be apply on small vehicle that can only achieve top speed not more than let say 30km/h, for an example motorized wheel chair. This method (apply geometry pattern on brake pad surface) potentially can be used as producing real brake pad method. It also can be potential to make it through out other industries that focus on braking mechanism.

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4.5.2 Product Improvement

As for improvement, this product can make more improvement in terms of adding other geometry pattern such as hexagon pattern. Hexagons pattern are believed to be said as the better geometry than other shape or pattern. For next improvement, printing method of this product also can be upgrade by using SLM printing method. Brake pad design are not complicated compare to other mechanical components, that why this product is relevant to be implemented by SLM printing method.

Furthermore, this project also can be improving by implement this method to more than one brake pad model. As many data were collected and analyses done, it will giving more information to comparing each brake pads models and to figure it out that are this kind of method are suitable to be apply to all kind of brake pads model or just some of it.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

This chapter summarised the project's conclusions and recommendations for further research. Overall, extensive research into the optimum geometry of brake pad has been conducted in analysis and fabrication to determine the best sample selection. The conclusion section includes an outline of the research as well as a summary of the findings. The recommendations section includes ideas for additional research and development of this project.

5.1 Conclusion

The first goal of this research is to design and model a brake pad with optimal geometry. Essentially, this goal was accomplished by designing and building a model of bearing samples in CAD software. The optimum geometry ideas have been decided, with five types of geometry to be chosen: solid, rectangle, triangle, square and circle geometries. According to the findings, the addition of geometries toward the surface of the samples has an effect on changes in parameter structure.

Furthermore, the second objective also was fullfil after the 5 sample was printed using sls machine. According to the flow chart, some of geometry brake pad was printed but not in optimize condition that expected. So in order to achieve it, the sample must going to redesign process and finally the optimize parameter sample that has been printed. This sample strictly cannot be use in real application as is made from nylon that is very different from real brake pad. Despite of that circumstances , it really give a clear picture of what does the geometry affects the performance of braking if the geometry pattern was been applied towards the surface of brake pad.

5.2 Recommendations of future development

With all of the data, this project always can be evolve, here are some suggestion toward this project in the future.

1. Conducting the real physical test toward the sls sample through out any machine or can be tested as real brake pad.
2. Futher the research of slot and chamfer design to be added with geometry applied at the surface of brake pad.
3. Considering new type of material for same fabrication method.

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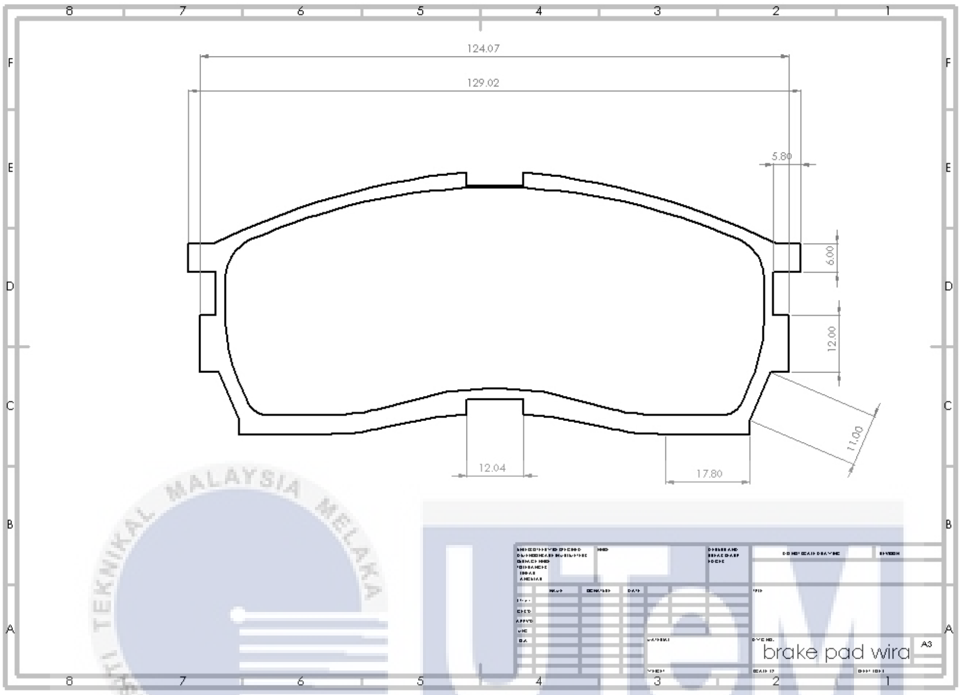
APPENDICES

APPENDIX A Dimension of solid geometry brake pad



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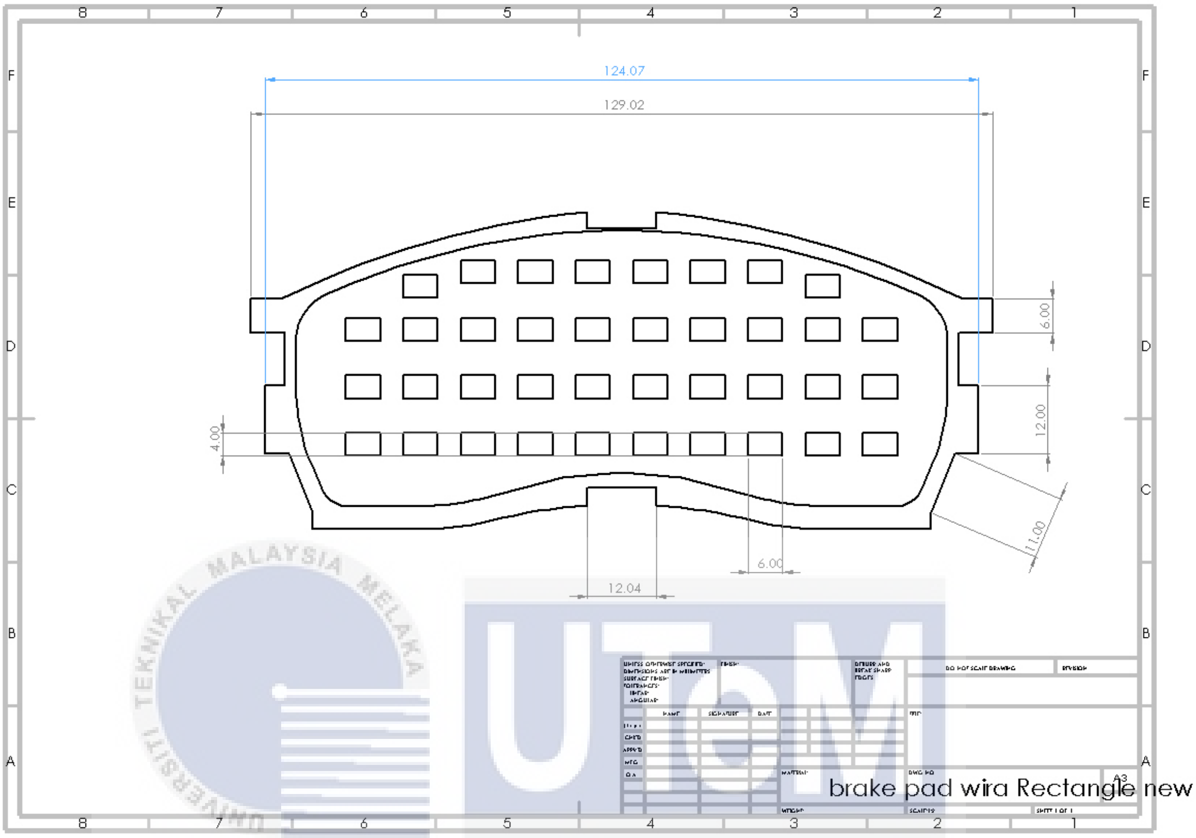
APPENDIX B Dimension of Rectangle geometry brake pad



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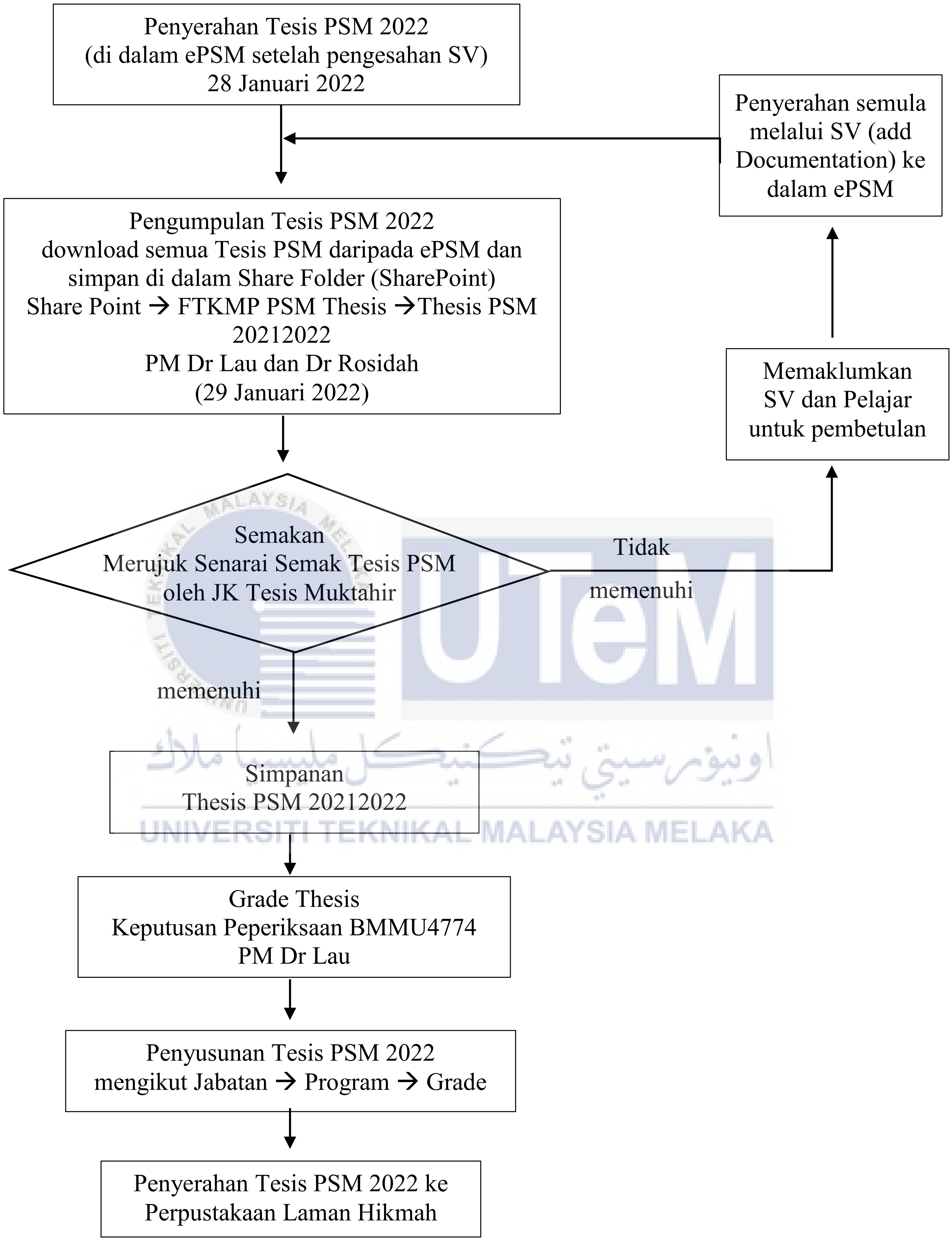

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