DEVELOP A NEW MODEL OF BRAKE PAD MADE OF NYLON-BASED MATERIAL WITH PRECISION GEOMETRY FOR LIGHWEIGHT INDUSTRIAL APPLICATION

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DARWISH ASHRAF BIN ABDUL SAMAD

A thesis submitted
in fulfillment of the requirements for the degree of
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2025

DECLARATION

I declare that this Choose an item. entitled “Design A New Model of Nylon-Based Brake Pad with Precision Geometry for Light-Weight Industrial Application 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.

Signature	:	
Name	:	Darwish Ashraf Bin Abdul Samad
Date	:	10/1/2025

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 : 14/01/2025

DEDICATION

I would like to dedicate my gratitude to my supervisor, Dr. Muhammad Ilman Hakimi Chua Bin Abdullah, a wonderful lecturer from Universiti Teknikal Malaysia Melaka whose expert guidance and insightful mentorship have been invaluable throughout my academic journey. Your commitment to excellence and your steadfast support have not only shaped the direction and quality of this work but have also inspired and challenged me to achieve my fullest potential. Thank you for your patience, encouragement, and belief in my abilities, which have been instrumental in helping me reach this significant milestone.

ABSTRACT

Within the car segment, it is generally known that brake pads are basic components that work as components to moderate down or halt a vehicle. Other than selecting appropriate materials to be utilized as contact materials, the plan of brake pads in terms of ideal geometry must too be considered as a figure in brake pad wear. Inner geometry plays a noteworthy part in any plan, counting brake pads. The reason of this study is to investigate the inner geometric plans that can result in low contact and wear on brake pads. There are a few strategies to be considered in terms of plan that can make brake pads have less friction and wear. In this extend, the chosen strategy is to utilize particular geometric designs on the surface of the brake pad. A genuine brake pad was chosen and drawn utilizing CATIA V5R21 program. Another target is to analyze the brake pad plan utilizing SIMSOLID program, and from that examination, it'll create unused geometry and measurements. A reproduction of the optimized brake pad was successfully fabricated using SLS 3D printing. Results from the analysis, including displacement magnitude, von Mises stress, and maximum shear stress, confirmed that the square geometry minimized wear and friction effectively, demonstrating its superiority among the tested designs.

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 factor 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. Hasil daripada analisis, termasuk magnitud anjakan, tegasan von Mises, dan tegasan ricih maksimum, mengesahkan bahawa geometri segi empat adalah yang paling berkesan dalam mengurangkan kehausan dan geseran, serta menunjukkan keunggulannya di antara reka bentuk yang diuji.

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

First and foremost, I am profoundly grateful to Allah, the Most Gracious and Most Merciful, for His divine guidance and strength throughout my studies. This final year project stands as a testament to His enduring grace and support. I dedicate this achievement to Allah, who has endowed me with wisdom and perseverance to reach this milestone. Through His will, I have overcome challenges and successfully completed this significant work. May this project reflect the blessings I have received, and may it serve as a means to earn His pleasure. Alhamdulillah, all praise and thanks are due to Allah, for His unwavering guidance and the patience He has bestowed upon me.

To my parents, thank you for the strong foundation you've given me, which has shaped my dreams and aspirations. Your sacrifices, hard work, and perseverance have instilled in me the strength to overcome challenges and strive for excellence in every aspect of life. This project is a tribute to your unwavering support and faith in me.

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This project reflects the collective efforts, guidance, and belief of the most influential figures in my life. As I present this work, I am reminded of the invaluable lessons and the loving support you have all provided. Thank you for being my pillars and my inspiration. This accomplishment is not just my own but a testament to your significant impact on my growth academically and personally.

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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

CHAPTER 1

INTRODUCTION

1.1 Background

Braking systems date back to the invention of the wheel, with early methods involving manual blocks applied to wheels. Significant advances began with the industrial revolution, introducing the drum brake in the late 19th century, using shoes or pads for friction within a rotating drum, significantly enhancing vehicle control.

Brake pads have been central to the evolution of braking systems. Initially utilizing materials like leather, the 20th century saw the widespread use of asbestos-based pads for their heat resistance. However, health risks associated with asbestos led to its replacement with safer materials such as ceramics, metallic compounds, and organic formulas. Each material offers different benefits and challenges, balancing performance, noise, and wear characteristics.

Brake systems have significantly evolved from their primitive origins to become a crucial element of modern vehicle design, enhancing road safety. With ongoing advances, particularly in electric and autonomous vehicles, brake technology continues to focus on integrating electronic controls with mechanical systems and improving regenerative systems' efficiency. These innovations not only boost vehicle performance and safety but also align with environmental goals by reducing emissions and enhancing energy efficiency.

1.2 Problem Statement

In the realm of light-duty application of brake, the demand of requirements of a brake pad can differ significantly from those used in the heavier industries such as automotive. The traditional brake pad style material nowadays is focused on heavy-duty application that can withstand such high temperature and intense wear, a condition rarely experienced in less intensive, light duty application (Fulfillment et al., 2008). This often leads to inefficiencies with overengineering, extremely high cost and the disturbance made by unnecessary noise made by the material, which can be fixed by using a new material base that can suit operational demands in this field.

The existing brake pad material nowadays that are mostly based of ceramic and metal composites does not align well with light-duty operation where low mechanical loads, these applications typically involve tasks like moving household items, operating light commercial machinery, or handling loads that require frequent, gentle stopping and starting. In these contexts, the robust nature of traditional brake pads can actually be a disadvantage, leading to excessive wear on related components and increased maintenance costs (Lifting & Handling - WorkSafeBC, n.d.).

The adoption of brake pads has been limited by concerns over their performance under varied temperature ranges and their long-term durability. To address these challenges, there is a pressing need for innovative research to enhance the thermal resistance and mechanical properties of nylon through material engineering and additives. Luckily, there are many academicians nowadays that specializes in this field and they can surely help in making this dream come true.

Advancing the development of nylon-based brake pad materials suitable for light-duty work could lead to significant improvements in efficiency, cost-effectiveness, and environmental sustainability. Such developments would not only fulfill the specific needs of less demanding applications but also align with broader goals of reducing environmental impact and enhancing safety in everyday settings.

1.3 Research Objective

The objectives of this project are as follows:

a) To designed an optimized geometry of a brake pad.

b) To analyse the designed brake pad using simulation software.

c) To fabricate optimized-geometry brake pad using SLS printing machine.

1.4 Scope of Research

The scope of this research are as follows:

a) Design the optimized geometry of brake pad on CAE/CAD software, CATIA.

b) Test the performance of the developed brake pad in SIMSOLID software.

c) Fabricate the developed optimized geometry brake pad using SLS machine.

CHAPTER 2

LITERATURE REVIEW

2.1 Brake system

The primary function of a braking system is to decelerate and halt the motion of a vehicle. In order to accomplish this, several components within the braking system must transform the kinetic energy of the vehicle into thermal energy. This may be achieved via friction. Friction is the opposing force that arises when two objects come into contact and try to move relative to each other. Vehicle control is influenced by two forms of friction: kinetic (moving) friction and static friction. The level of friction that inhibits motion is governed by the composition of the materials in contact, the level of smoothness of their rubbing surfaces, and the magnitude of the force that keeps them in contact.

Therefore, in a small car, the braking system operates by pressing a stationary brake pad against a moving vehicle disc, resulting in friction and the conversion of kinetic energy into heat energy. When the brakes of a moving vehicle are activated, the abrasive surfaces of the brake pads or brake shoes are forced against the spinning components of the vehicle, whether they be disc or drum-shaped. The vehicle's kinetic energy or momentum is then transformed into thermal energy by the kinetic friction between the rubbing surfaces, causing the automobile to decelerate.

When a vehicle comes to a halt, it remains stationary due to the force of static friction. The interaction between the surfaces of brakes and the friction between tires and roadways impede any motion. In order to surpass the resistance caused by static friction that prevents the automobile from moving, the brakes are disengaged. The combustion heat energy in the engine is transformed into kinetic energy through the transmission and drive train, resulting in the movement of the vehicle. In the field of contemporary vehicle, there are two primary categories of braking systems.

The drum brake system operates by exerting pressure on brake shoes positioned inside a drum, causing them to push against the inner surface of the drum. The disc brake system operates by exerting pressure on a disk using two brake pads.

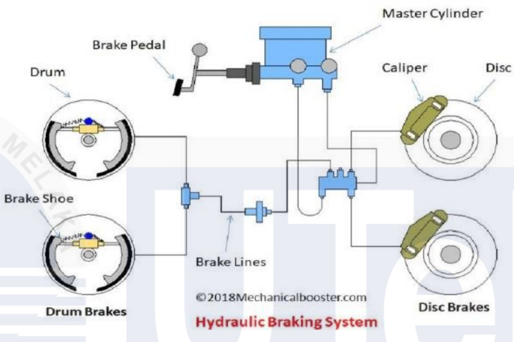

Figure 2.1 Basic brake system design

2.1.1 Types of brake

Brake pads are crucial elements of a vehicle's braking mechanism. Located within the calliper, they operate by applying pressure to the rotating disc or rotor. Over a period of time and as the mileage increases, the brake pads gradually deteriorate as a result of friction. car owners must comprehend the four distinct categories of brake pads in order to ascertain the most appropriate sort for their car.

Semi-metallic brake pads are composed of 30 to 65 percent metal, which gives them the highest level of durability compared to other varieties. Nevertheless, their effectiveness may be less than optimum under challenging circumstances and at low temperatures. Although these pads are more affordable and result in less rotor damage than ceramic brake pads, they tend to generate more noise and have a shorter duration of use. High-performance and race automobiles sometimes utilize semi-metallic brake pads.

Figure 2.2 Semi metallic brake pad

Ceramic brake pads are the most expensive compared to the others as they produce less noise and waste than the others. It is also the most long lasting if compared to other material including the famous semi metallics.

Figure 2.3 Ceramic brake pads

Low-metallic, non-asbestos organic (NAO) brake pads are distinguished by their elevated noise levels and substantial brake dust generation, surpassing those of alternative brake pad varieties. Although there are certain disadvantages, the addition of copper or steel to their composition greatly enhances heat transmission and braking performance. The nature of this material guarantees efficient dissipation of heat, consequently improving the overall effectiveness of braking.

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

Non-asbestos organic brake pads are commonly made up of organic components, including fibre, glass, rubber, and Kevlar. These brake pads are renowned for their quieter performance, generating much less noise in comparison to alternative brake pad varieties. Nevertheless, this benefit is accompanied with a compromise; non-asbestos organic pads have a tendency to deteriorate more quickly and produce a significant quantity of brake dust. Notwithstanding these disadvantages, their more subdued operation renders them a favoured option for several vehicle proprietors in search of diminished noise levels.

Figure 2.5 Non-Asbestos Organic Brake Pad

2.1.2 Brake friction material

Brake pads are often made from a combination of several materials, with many pads including as many as 10 to 20 distinct kinds of raw materials. The materials are classified into three primary components: friction adjustment materials, bonding materials, and stiffeners.

The friction adjustment materials are particularly engineered to alter the frictional characteristics of the brake pads. These materials improve the efficiency and ensure the consistency of the brake pads' function. To produce the necessary frictional qualities, a mixture of various raw materials such as organic and inorganic fillers, abrasive compounds, metal powders, and lubricants are combined.

The bonding materials are essential for enhancing the composite structure of the brake pads, ensuring their endurance and integrity. Phenolic resin is often used in this category because of its efficacy in bonding the different raw elements together, guaranteeing that the pads retain their structural integrity when subjected to stress.

Stiffeners are included to enhance the reinforcement of the brake pads. This component comprises a variety of organic and inorganic fibres, including aramid fibres and metal fibres, that enhance the strength and stability of the friction materials. The presence of these fibres enhances the durability and heat resistance of the brake pads, allowing them to endure the mechanical and thermal pressures experienced during braking. As a result, the lifetime of the brake pads is prolonged and their overall performance is enhanced.

Figure 2.6 Raw brake friction materials

In addition, friction materials must consistently retain their efficiency with minimum modification throughout various situations, such as variable vehicle speeds, fluctuating weights of the load, and temperature variations caused by brake use. Additionally, they must exhibit consistent performance in the face of diverse environmental factors, including humidity, dampness, and dirt. Key design criteria include robust mechanical strength and the capacity to withstand heat disturbances without experiencing any deterioration. Ensuring a long service life, durability is a crucial component in the application of friction materials. Furthermore, it is crucial to reduce screaming, noise, and vibrations while using the brakes in order to improve driving comfort. Friction materials must also be non-detrimental to the components they come into contact with, such as disc rotors. In addition, in order to avoid overheating and ensure optimal brake performance, it is necessary for friction materials to possess a low thermal conductivity. This characteristic helps to prevent the accumulation of excessive heat in both the braking system and the brake fluid.

2.1.3 Brake pad geometry

Modifications may be made to the design of brake pad linings throughout later phases of the design process. These alterations usually include making changes to the shape and design of the pad liner, which may involve adding chamfers and slots. Furthermore, an extra sub-layer might be implemented to have an impact on the mechanical and thermal characteristics of the pad. Slots and chambers may be created either by modelling or machining. The smoothness of the pad's friction surface, which is necessary, is usually accomplished using machining methods. Chamfers, located on the friction surface of brake pads, are used to provide a seamless transition between two sharp edges. Their primary purpose is to prevent the brake pad's leading edge from detaching from the brake disc, ensure uniform wear of the pad, and reduce noise during braking manoeuvres.

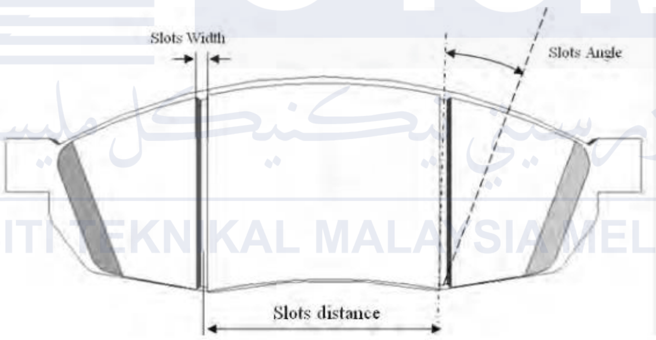

Figure 2.7 Brake pad geometry

2.2 Design software

There is many drawing software that can be used to draw and design 3D models in the engineering field. This software is generally known as computer-aided design or CAD software for technical documentation. Designers and engineers extensively use CAD software to generate accurate representations of an object in 2D or 3D. An important benefit of using design software is the enhanced ability for designers to successfully communicate with each other by means of comprehensive drawings. These visual representations provide a clear understanding and identification of all components of the design by all parties involved.

CAD software offers more than just drawing capabilities as it supports the full design process by offering tools for modelling, simulation and even analysis. This combined feature guarantees that designs are precise and operational prior to the creation of actual prototypes. In addition, computer-aided design (CAD) software has the capability to efficiently store and organize vast quantities of design data, facilitating the management and retrieval of design documents. CAD software improves communication among designers and makes the design and engineering process more efficient, resulting in higher productivity and shorter development time.

2.2.1 3D designing software

3-D software is a distinct kind of computer graphics program designed specifically for the production, design, and advancement of three-dimensional images and animations. Users use its functionalities to perceive, create, and modify various aspects, environments, or graphical objects inside the immersive domain of three-dimensional space. This program includes several applications, including as computer-aided design (CAD) software and animation packages. It provides a wide variety of features, including picture and object modelling, layout design, animation, and rendering. 3-D software utilizes geometric concepts and three distinct axes (X for width, Y for length, and Z for depth) to convert visual components into a spatial context. This allows for accurate modification and improvement of designs.

In addition, 3-D software has exceptional adaptability, effortlessly integrating with a wide range of modern computer devices and operating systems. This interoperability guarantees that designs made inside the program may be easily seen and executed on many platforms, ranging from desktop workstations to mobile devices.

2.2.2 CATIA V2R21

CATIA, an acronym for Computer-Aided Three-Dimensional Interactive Application, is a sophisticated software suite that goes beyond conventional Computer-Aided Design (CAD) tools by including CAD, Computer-Aided Engineering (CAE), and Computer-Aided Manufacturing (CAM). CATIA V5 is a highly regarded software for creating digital models of products. It is noted for its modular design, which enables users to choose and buy certain features that suit their requirements. This enhances its adaptability and usefulness in many sectors. The program demonstrates exceptional proficiency in producing orthographic, isometric, and highly detailed two-dimensional drawing views. It includes automatic model proportions and facilitates easy referencing of views. CATIA is an essential tool in contemporary engineering and manufacturing industries since it supports the full design process, from idea to finished product. It is capable of activities such as scans, simulations, optimizations, detailed drawings, and contains programming capabilities for manufacture.

2.2 3D model printing

Three-dimensional (3D) printing, also known as additive manufacturing, is a method of creating three-dimensional solid items from digital information. This procedure utilizes additive processes, whereby an item is created by incrementally adding layers of material until the ultimate result is achieved. Every layer corresponds to a thinly cut part of the item. Unlike subtractive manufacturing, which entails the removal of material from a bigger block using processes like milling, 3D printing enables the production of intricate forms while minimizing material consumption in comparison to conventional manufacturing methods. Subtractive manufacturing, characterized by the process of cutting a final design from a bigger material block, is fundamentally different from additive manufacturing (Almaliki, 2015).

The automobile sector has extensively used 3D printing to manufacture spare parts, tools, jigs, fixtures, and even end-use components. This technology has significantly improved the ability to manufacture products as needed, resulting in more adaptability and effectiveness in the production process. Moreover, the capacity to swiftly create and refine designs has further established 3D printing as a significant resource in contemporary production.

2.3.1 SLS printing process

Selective laser sintering is one form of additive manufacturing that uses a very high-power laser to enable this approach. They are fused as small polymer powder particles into a solid part according to a 3D model design. It has been one of those that have been trusted by engineers and manufacturers given its low cost, rapidity, and the use of materials that are exceptionally well proven over the years. The SLS printing offers applications over quite a range of functions, from fast prototyping to creating traditionally hard-to-source or limited-volume-manufactured parts.

It has vastly increased the accessibility of SLS technology with recent hardware, material, and software development breakthroughs. As a result, the application base of out-of-the-box applications in the high-tech areas significantly increased. With it, more companies increasingly found themselves able to introduce SLS technology into their chain of production and thereby exploit the economy of that technology.

Table 2.3 Comparison of different 3d printing techniques

Feature	Fused Deposition Modelling (FDM)	Stereolithography (SLA)	Selective Laser Sintering (SLS)	Digital Light Processing (DLP)	Binder Jetting
Material	Thermoplastic filaments	Photopolymer resins	Polymer powders	Photopolymer resins	Metal or ceramic powders
Process	Melts and extrudes filament layer by layer	Cures resin layer by layer using UV laser	Sintering of powder particles using laser	Cures resin layer by layer using digital light	Binds powder particles with a liquid binder
Accuracy	Moderate	High	High	High	Moderate
Surface Finish	Moderate, often requires post-processing	Smooth, high-quality	Rough, often requires post-processing	Smooth, high-quality	Variable, often requires post-processing
Strength	Good, but dependent on layer adhesion	Excellent for small, detailed parts	Strong, good for functional parts	Excellent for small, detailed parts	Moderate to high, depending on material
Speed	Moderate to fast	Moderate	Fast	Fast	Fast

Cost	Low to moderate	Moderate to high	Moderate	Moderate to high	High
Applications	Prototyping, hobbyist projects, low-cost parts	Detailed prototypes, jewellery, dental molds	Functional prototypes, low-volume production	Detailed prototypes, dental molds	Full-color prototypes, complex geometries
Materials Available	PLA, ABS, PETG, nylon, etc.	Various resins (standard, tough, flexible, etc.)	Nylon, TPU, composites, etc.	Various resins (standard, tough, flexible, etc.)	Metals, ceramics, sand, composites
Advantages	Low cost, easy to use, versatile	High detail, smooth finish, complex geometries	Strong parts, high productivity	High detail, smooth finish, complex geometries	Complex shapes, multiple materials
Disadvantages	Lower resolution, limited material strength	Higher cost, post-processing required	Rough surface finish, higher cost	Higher cost, post-processing required	Higher cost, post-processing, limited materials

2.3.2 3D printing material

The variety of materials used in 3D printing is as extensive as the range of final goods it can produce. Therefore, 3D printing enables producers to customize the form, surface characteristics, and durability of their items with exceptional accuracy. Importantly, these modifications may be accomplished with far fewer procedures in comparison to conventional production techniques. 3D printing utilizes a range of materials such as thermoplastics, metals, resins, and ceramics, highlighting its flexibility. The versatility of this feature enables producers to create items with precise characteristics, effectively adjusting to various demands.

When choosing materials for a 3D printing project, it is essential to take into account the application, function, and design of the final product. Factors such as the capacity to withstand high temperatures, resistance to chemicals, and long-lasting quality of materials are crucial considerations when choosing a material. For example, while Nylon 12 and Nylon 11 are often used as single-component powders, many SLS 3D printers have the ability to utilize two-component powders, such as coated powders or powder mixes. In addition, researchers are also working on developing nylon composites that include aluminide, carbon, or glass materials in order to improve the strength, stiffness, or flexibility of various components. These two-component powders selectively sinter the component with the lowest glass transition point, effectively amalgamating both components.

2.3.3 Printing process

The very first step in the 3D printing process is creating a three-dimensional digital file that depicts an item that can be built. The alternative way traditionally used to produce such files is computer-aided design (CAD), a standard tool for engineering and design communities. The big question arises in the initial primary process of converting digital information into a form usable in the 3D printing process. The default format used for preparing objects to be produced by a 3D printer is STL file format. The actual term for stereolithography, therefore, is given to the 3D printing technology, not STL, as many would have thought. To detail exactly where the setting material should be hardened, detailed instructions are after that sent by the printer whenever the 3D model is received. It then follows that this configuration results in the final desired three-dimensional form.

2.3.4 SLS finishing

Completing a task in SLS is also an essential process that requires the correct approaches, which can only be done by consistent practice over a period of time. Prior to proceeding with any more finalization, it is necessary to eliminate the surplus powder, often done by releasing a burst of compressed air. SLS prints often have a coarse texture initially and may display discernible layers after printing, contingent upon the chosen layer thickness configuration. The implications are significantly impacted by the orientation of a component surface during the building process. In order to get a polished surface, one may use solvents that have the ability to dissolve certain SLS materials, such as acetone, butanone, or tetrahydrofuran. Obtaining a completely even surface texture is quite challenging when working with a freshly printed item (Tyson, 2017).

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter offers a detailed examination of the methodologies utilized throughout the experimental process, aimed at achieving the research objectives. It starts with a thorough review of the bearing design, followed by an extensive discussion on the use of SIMSOLID simulation techniques critical to the experimental setup. The narrative then explores the sophisticated manufacturing processes involved in Selective Laser Sintering (SLS) 3D printing, shedding light on the technical complexities and challenges faced. The chapter continues with a meticulous evaluation of bearing performance, involving rigorous testing procedures, comprehensive data collection, and precise analysis of the results. Furthermore, it delves into the methods for surface validation, exploring various parameters such as surface roughness, wear patterns, textural features, material orientation, and chemical composition. This in-depth exploration ensures a clear and thorough understanding of the experimental methodologies, promoting transparency and replicability in the research.

Figure 3.1 shows the process of completing this project. These crucial steps are essential to achieve the best result of the development of the new nylon-based brake pad.

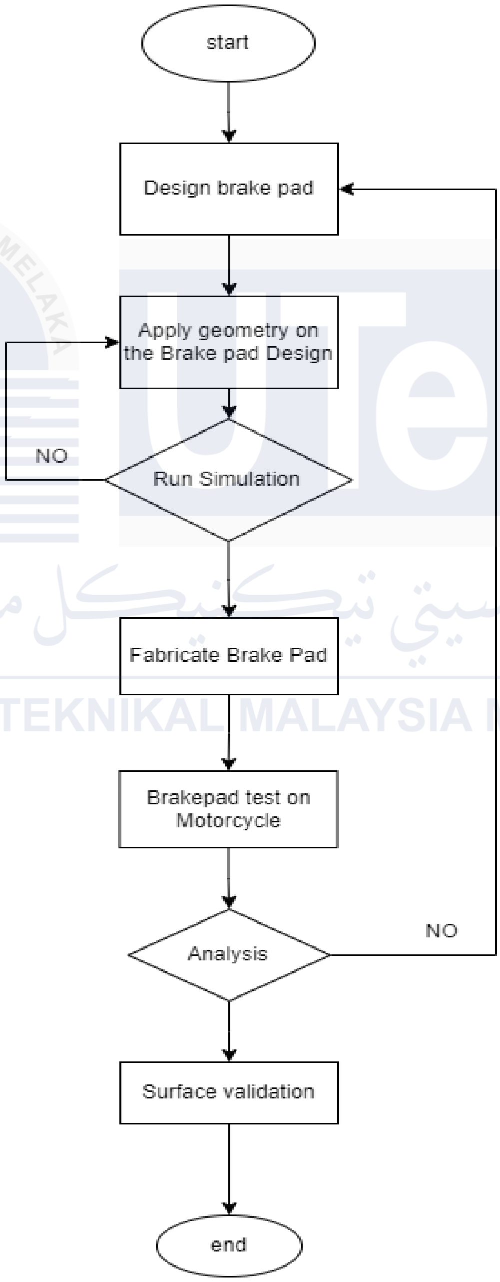

Figure 3.1 Process flow of experiment

3.2 Data study and analysis

A research and analysis are a methodology used to gather, quantify, and assess data obtained from participants pertaining to the subject of study. It is important to choose an instrument that aligns with the kind of study you are doing. Data analysis is the methodical use of statistical and/or logical methods to accurately characterize, present, summarize, and evaluate data.

3.2.1 Research Tool

The internet had been leveraged to get further information about brake pads. Web research time was optimized for efficiency when designing classes and activities. Questioning, summarizing, and evaluating were all stages involved in acquiring the maximum amount of information possible. Prior to accessing the Internet, it was advisable to organize the questions in order to develop a search strategy and compile a list of websites to examine. The data was obtained by compiling a comprehensive set of questionnaires to choose the appropriate one. An appropriate method for gathering data had been arranging a meeting with the project supervisor to have a more in-depth discussion about the project.

3.2.2 Conducting design research

This study utilized an analytical approach to assess the structural analysis, including internal geometric parameters, behavior, and processes. Optimizing the geometry of brake pad design had a substantial influence on the lifetime of the brake pad. Additionally, a basic dynamic model was essential for analysis. Future study prioritized establishing the optimal bearing optimization parameter depending on its longevity.

3.3 CAD Design development

The process of designing a motorcycle brake pad using CATIA software had begun by analyzing an existing brake pad in Figure 3.2 to understand the specific needs such as load capacity, operational speed, and environmental factors. The selection of the appropriate material like organic, ceramic, or metallic composites had been crucial, considering each material's unique properties for motorcycle use. Precise measurements had been gathered from the reference brake pad using tools like Vernier calipers, which were essential for developing the CAD model. This model had incorporated design features like slots, chamfers, and wear indicators, enhancing functionality and safety. Through a series of simulations and refinements using tools like SIMSOLID, the design had been iteratively improved until it met all specifications. Upon final validation, detailed production drawings had been produced, which included dimensions, tolerances, and manufacturing details, ensuring the brake pad was ready for production and suitable for motorcycle application as a test subject.

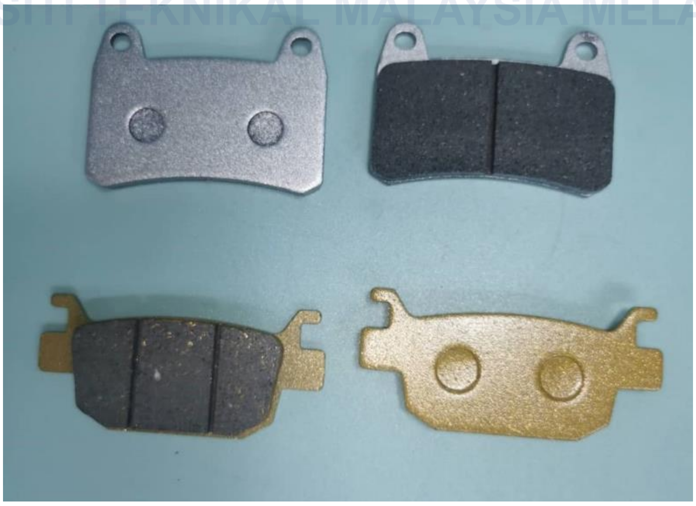

Figure 3.2 Actual brake pad from a motorcycle

3.3.1 General sketching of the model

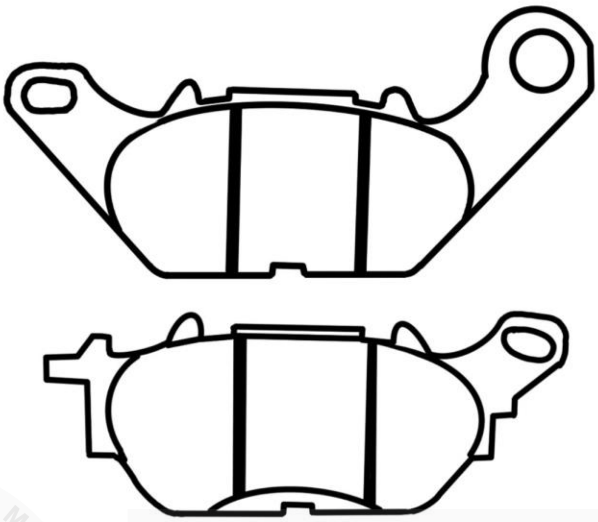

Figure 3.3 Sketch of brake pad

This had been a sketch based on a real standard Yamaha moped-motorcycle brake pad. It had been necessary to refer to the actual brake pad before designing the brake pad with the appropriate parameters using a genuine motorbike brake pad. This component had been made to provide a clear image of the parameters that had to be altered in order to lower the mistakes. To create the sketch, the brake pad's measurement had been taken using a Vernier calliper. It had been possible to remodel the brake pad in CATIA software by making reference to it. The brake pad had been measured using a standard procedure, and all measurements had been made. Using a range of characteristics created especially for these reasons had made it much simpler to understand, diagnose, and offer solutions. By transmitting accurate product information in an automated format that anybody could customize, computer-aided design (CAD) had expedited the production process.

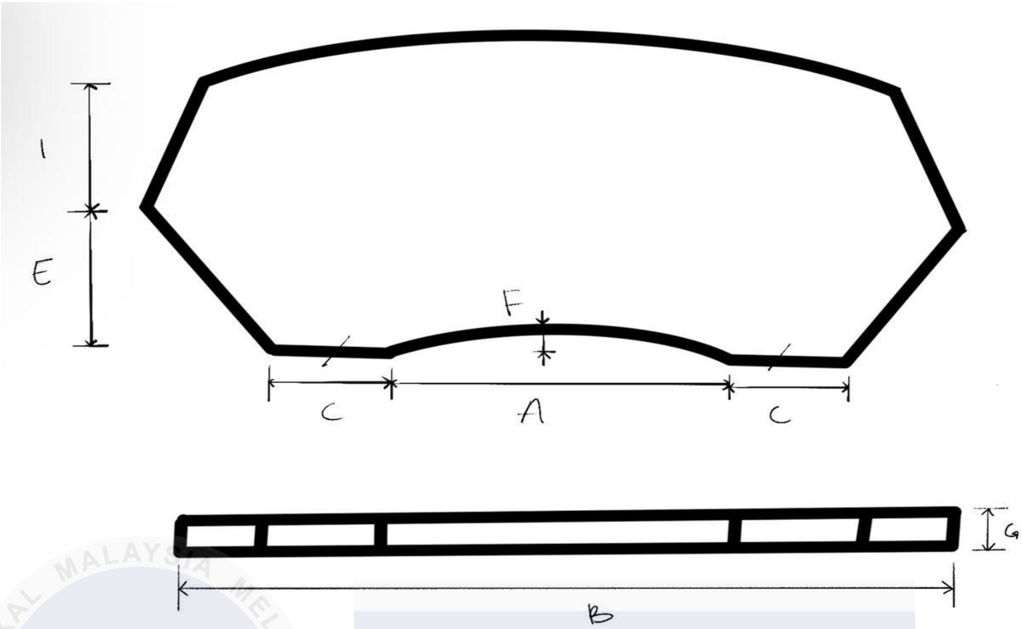

Figure 3.4 Dimension of brake pad

Table 3.1 Measurements of brake pad dimensions

Unknown	Value (mm)
A	43.1
B	87.5
C	7.2
D	19.0
E	18.5
F	4.0
G	8.5

3.3.2 Model part design

On average, a brake pad took the form of two independent parts that integrated in order to form a singular unit. The components consisted of the friction material and the rear plate. The design of these components had been essential to guarantee compliance with technical and environmental requirements, thereby reducing the risk of possible failures. Given the unique design requirements, there had been no need for an extra assembly procedure, since the back plate and the friction material had been built using distinct materials in a cohesive design. This comprehensive method had simplified the production process and improved the overall functioning and dependability of the brake pad.

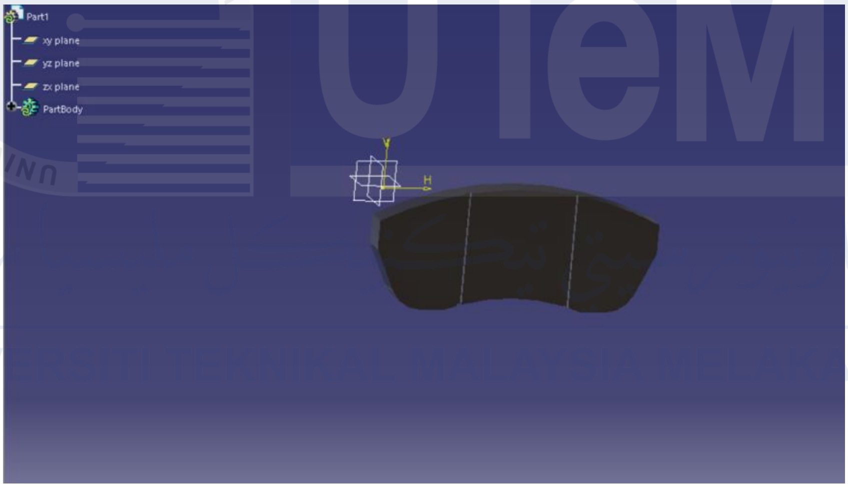

Figure 3.5 CAD design of the brake pad

3.3.3 Selecting material in CATIA

The process of material selection had been closely interconnected with design activities in technical disciplines. When choosing materials, the main objective had been to determine the specifications for product design and the possible materials that could fulfil these criteria. Minimizing the danger of failure and ensuring the functionality of the brake pad had been of utmost importance. Considering the delicate nature of friction materials, the present focus on lightweight and friction-efficient disc brakes had underscored the significance of the installer's level of excellence. The task of choosing a brake pad of superior quality had become more important. The friction and wear properties of friction materials had played a crucial role in assessing the appropriateness of novel compositions for braking systems. Automotive brake pads had had intricate friction and wear characteristics, which had been affected by several aspects.

The friction behaviour of brake pads had been substantially influenced by their composition and formulation. Nevertheless, the formulation process had strongly depended on trial and error owing to the poor comprehension of the link between composition and properties. This reliance on trial and error had made the procedure both expensive and time-consuming (Österle & Urban, 2004). Brake pads typically had a friction coefficient, denoted as μ, that had fallen within the range of 0.3 to 0.6 (Blau, 2001). In order to create a model utilizing SLS 3D printing, it had been necessary to choose a few certain qualities that would establish the standard features of the model, depending on the original design and drawings. The CATIA program had had the capability to measure or determine these elements by analysing geometric relationships. The subsequent procedures had aimed to reverse engineer these spur gears, enabling a more comprehensive analysis of the design's appropriateness in terms of material choice and loading circumstances.

3.4 Parametric Optimization of the model

Parametric optimization had symbolized the method of solving issues when design variables had depended on independent variables in the input. This approach had entailed determining the best possible solutions and values of the objective function based on the input parameters within the complete range of parameters of interest. Precise solutions had occurred for parametric optimization difficulties that had been constant or convex-quadratic in nature. However, for general non-convex non-linear issues, the level of complexity had increased considerably, making it necessary to use approximations. This technique had been essential for managing the complexities of non-linear systems, guaranteeing the acquisition of realistic and practical solutions.

3.4.1 Optimum parameter analyzation

One of the most crucial factors to consider in the design of brake pads had been to make sure that it had been long-lasting. In order to comply with brake pad design guidelines, designers had to determine the internal geometry of the brake pad. The design had had to meet both geometric and structural criteria by taking aspects like friction coefficient and temperature into account. In addition, designers had to take into account many factors before determining the most suitable specifications. The design had needed to prioritize environmental sustainability and avoid excessive complexity since a complicated design had heightened the likelihood of operational failure. On the other hand, the design had not been too simple, since it would have made the model impossible to differentiate from already existing brake pads.

An assessment of constraint violations had been carried out to measure the efficacy of each restriction. A convergence study had been conducted to verify that the design had attained a globally optimum solution. The technique of feature-based selection had aimed to decrease the total number of original characteristics by choosing a subset that had retained enough information for classification purposes. Thorough analysis had been an essential need for completing this design procedure. The study had been conducted with SimSolid software to assure the durability and efficiency of the design.

3.4.2 Selecting parameter and measurement

Once the brake pad had undergone the optimal characteristics process, it had been crucial to verify that the size of the brake had been sufficiently strong to provide the necessary or anticipated lifetime under the stated working circumstances. In order to choose the right option, it had been necessary to take into account the standard geometry before determining the optimal brake pad specifications. The primary criteria for the braking system had been attaining the utmost and consistent coefficient of friction achievable. This had involved a range of parameters such as compressive strength, coefficient of friction, resistance to wear, and heat capacity, which had been crucial on a brake pad. It had been important to thoroughly assess all of these factors to guarantee that the brake pad design had satisfied both performance and durability criteria.

3.5 Fabrication

Product creation had been one thing. On the other hand, an initial product design had needed to go through an important procedure called fabrication design in order to be made into that thing. The idea had been where the product development cycle had begun. This had been followed by product engineering, design, prototyping, and manufacture. Put another way, there had been several steps in the product design process before it had been created. After the model had been recognized using CAD data software, this process had been carried out on a 3-D printer. It had been a design and production technique wherein manufacturing machinery had employed digital data commands to manufacture a variety of part shapes. The manufacturing process outcomes, like product separation, sanding, and cleaning, had occurred without affecting the final product.

3.5.1 3D Printing (SLS printing)

Selective Laser Sintering (SLS) 3D printing had been an advanced manufacturing technique that had created complex components by layer-by-layer fusing powder material with a laser. During this process, the build area had been uniformly covered with a thin coating of powder. For metal parts, the powder could have been titanium; for plastic parts, it could have been nylon. The powder had been precisely melted using a strong laser in accordance with the exact design criteria given by a computer-aided design (CAD) model. After completing a layer, the build platform had glided slightly downward to reveal a new layer of powder. This process had been repeated until the part being constructed had been finished. SLS had been extremely useful in engineering applications because it could create complex, sturdy parts without the need for extra support structures, meaning it could have maximized material efficiency and lowered the number of post-processing processes needed. Because of this, it had been a great method for producing working parts directly from the prototype and for rapid prototyping.

3.5.2 Model printing process

The first step had involved the creation of a three-dimensional model using computer-aided design (CAD) software. Subsequently, the model had been exported in either OBJ or STL file format to facilitate the process of selective laser sintering (SLS) printing. In order to prepare this model for printing, it had been necessary to use specialist software that had segmented it into layers, organized the models, estimated the duration of the printing process, and determined the appropriate printing settings. Commands had been sent to the printer, and preliminary tests had verified that the hardware was set up correctly. Inside the build chamber, there had been a platform that had been coated with a thin coating of powder, which had been heated to a temperature slightly below the melting point of the material. A laser had been used to selectively heat and melt the powder, which had solidified layer by layer to form the final product. As the loose powder around the item had provided support, there had been no need for additional structures. Following each layer, the platform had gradually lowered to make room for the subsequent one. The finished item had to undergo a cooling process before it could have been removed, which might have taken many hours or even days depending on its intricacy and size. Excess powder had been reserved for a subsequent printing task.

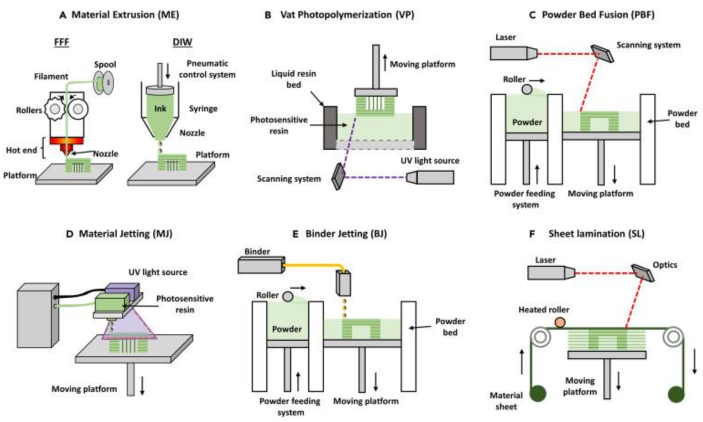

Figure 3.6 SLS printing process

3.5.3 Cooling process

During the Selective Laser Sintering process, the laser had precisely melted the powder particles and caused them to fuse together. The rapid cooling directly after the printing process had resulted in uneven shrinkage, risking internal stresses and warping. Implementing a controlled and gradual cooling process that had allowed the building to evenly collapse while preserving its geometric integrity had prevented such problems. Furthermore, the pace of cooling had had an impact on the crystalline structure of materials, which had subsequently influenced the substance itself. The laser had selectively melted the powder particles during the SLS process, resulting in the bonding of the particles. Rapid cooling of the product immediately after printing had resulted in uneven shrinkage, leading to internal stresses and warping. Implementing a method of controlled and gradual cooling had effectively averted any structural difficulties by ensuring that the structure collapsed evenly while preserving its geometric integrity. Moreover, the pace of cooling had directly affected the crystalline structure of materials, which had in turn influenced their mechanical properties, including strength, flexibility, and endurance. Hence, it had been imperative to effectively control the cooling process in order to ensure that the final product not only met the desired design standards but also maintained the required mechanical properties, including durability, strength, and flexibility, that had been important for its intended use. Hence, effective management of the cooling process had been essential to guarantee that the finished product adhered to design specifications and retained the necessary material properties for its intended use.

3.5.4 Post-processing

Compared to other 3D printing methods, post-processing SLS (Selective Laser Sintering) parts had generally been quicker and easier due to the absence of support structures, making the process scalable and consistent for batch production. After printing, parts had been removed from the build chamber, separated, and cleaned of residual powder, usually manually at a cleaning station with compressed air or a media blaster.

In the industry, devices like the Fuse Sift in the Fuse one workflow had handled the extraction, storage, dosing, and mixing of powder efficiently. Once sifted, SLS printed parts had been ready for use, although further post-processing like media blasting or tumbling might have been necessary for a smoother finish. Additional finishing options such as painting, lacquering, electroplating, and coating could have enhanced aesthetics and functionality, like watertightness and conductivity. However, Formlabs SLS parts' dark color had generally made them unsuitable for dyeing

3.6 Product analysis process

The process of simulating the properties of the built design of brake pad can be done by using the SIMSOLID software. It is a powerful tool that are widely used by engineers and even students to get a better understanding of structural analysis of an object especially in the scope of finite element analysis (FEA). This simulator’s best features are its ability to run analysis on a CAD model but without the big time-consuming mesh generation offered by many other simulating software and is widely used in the automotive, heavy machinery dan aerospace development process.

The absence of mesh allows a simultaneous iteration of design change, making simulating easier in many industries. The users, students and engineers, can refine their designs and initiate the analysing process immediately without sacrificing accuracy as it utilizes advance algorithms and mathematical models to simulate how models behave under loads provided. this software really helps engineers solve their challenges as it provides many types of analysis like thermals, statics, dynamics and modals.

3.6.1 Analysis & Iteration

In case of testing the brake pad design, the objective is to test the effects of load and thermal conditions on the brake pad. Initiating the examination is a simple process that involves clicking on the chosen command after the show improvement has been added up. The computing times are reduced both internally and externally due to SIMSOLID's advanced algorithms, which efficiently process data without overlapping. Following the analysis, SIMSOLID may provide data in the form of color-coded maps, visualizations of improvements, or deformations. When selecting areas for development, such as infrastructure, urban planning, and economic growth, these advancements are very advantageous. If any areas needing updates are identified, you may modify the shape, materials, or stack conditions of the brake pad and then retest the modifications in the examination. This iterative approach is notable for optimizing the coordination to achieve both performance and security.

CHAPTER 4

RESULT & DISCUSSION

4.1 Introduction

This chapter will examine the outcomes and data analysis of the project outcome. Data analysis will be conducted using simulation methods. To achieve superior results, SIMSOLID software is employed for the fundamental aspects of analysis. Sim Solid is a revolutionary simulation solution for designers, engineers, and analysts, since it does structural assessments on comprehensive CAD assemblies within minutes. It eradicates geometry preparation and meshing, the two most time-consuming, labor-intensive, and error-prone procedures in structure simulation.

4.2 SIMSOLID Traction Analysis

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

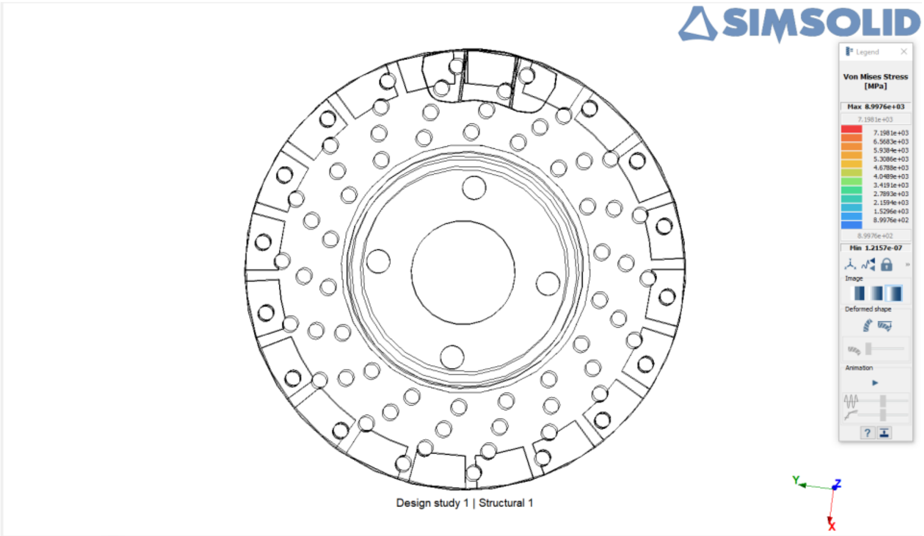

Figure 4.1 Solid brake pad traction test

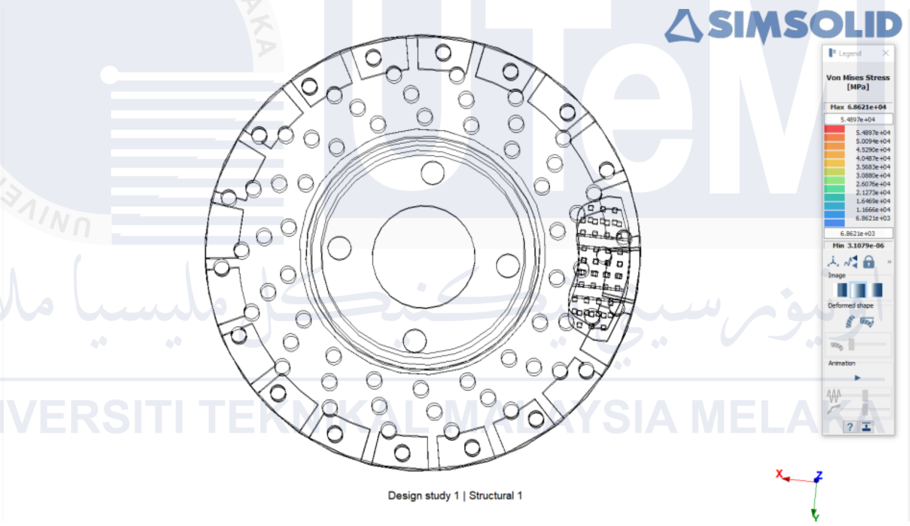

Figure 4.2 Square-pocketed brake pad pressure test

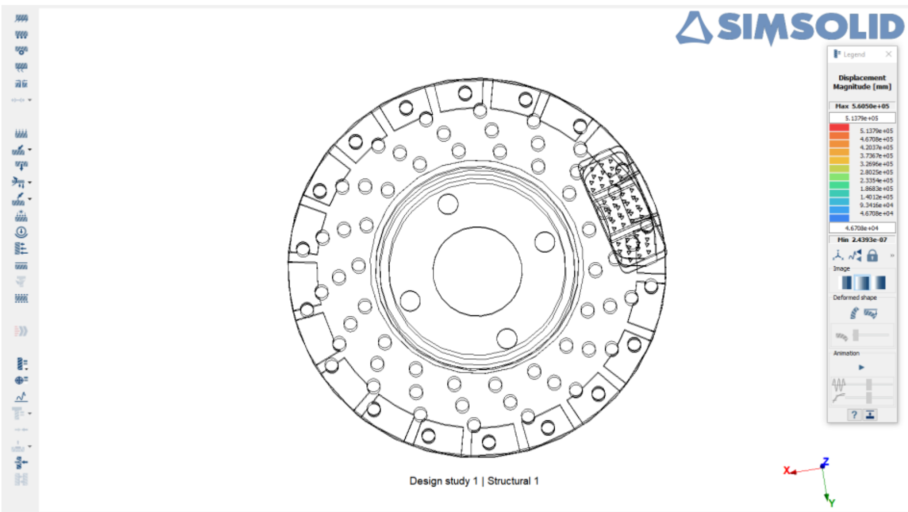

Figure 4.3 Triangle-pocketed brake pad traction test

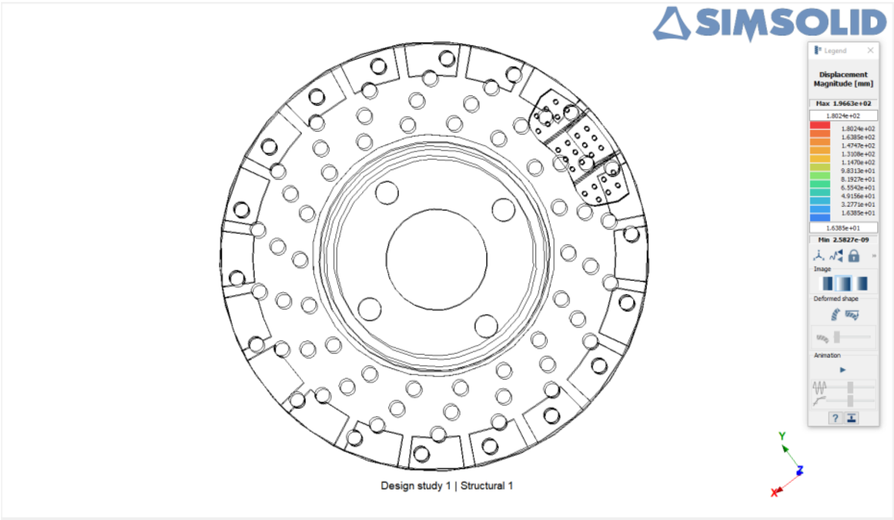

Figure 4.4 Circle-pocketed brake pad traction test

Table 4.2 Results of traction test

Pocket geometry	Normal Traction (MPa)
Solid	5.9963 e+00
Square	3.5087 e+00
Triangle	3.0520 e+00
Circle	3.4591 e+00

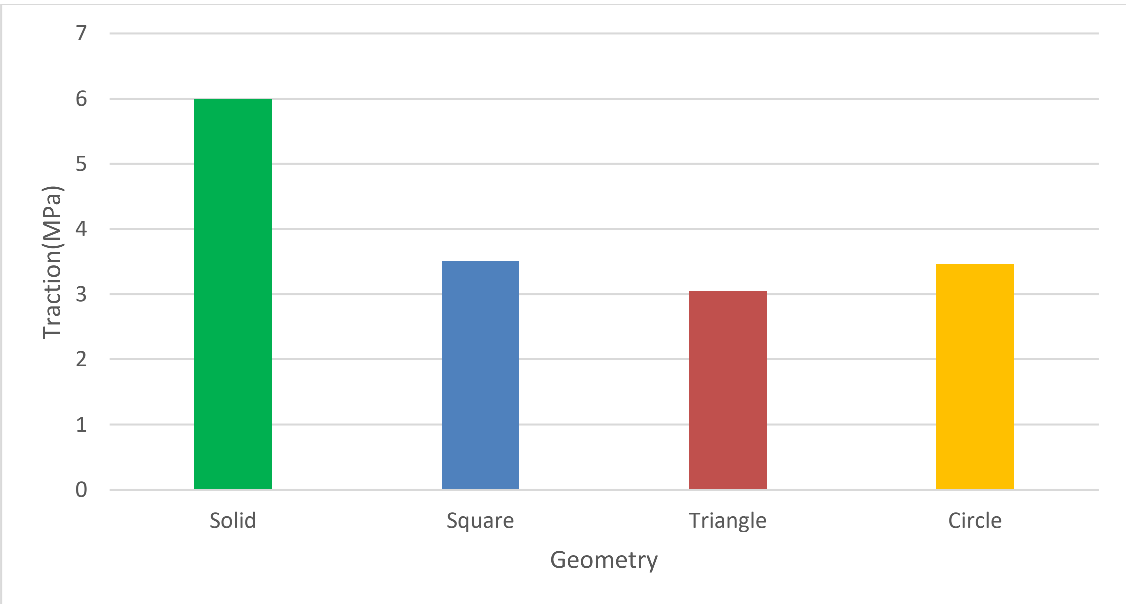

Figure 4.5 Traction test comparison

The chart indicates that solid geometry attains the highest normal traction (5.9963 MPa) owing to complete contact devoid of any voids, facilitating optimal load distribution. Among pocketed geometries, the square configuration (3.5087 MPa) provides superior traction relative to the triangle (3.0520 MPa) and circle (3.4591 MPa), due to its greater contact area retention. The triangle exhibits the least traction owing to its acute edges and limited contact area, but the circle's rounded edges provide a more uniform distribution of stress, yielding somewhat greater traction than the triangle.

4.3 Structural Non-Linear (SIMSOLID)

This creates a system that allows components to separate completely or partially from one other. When this transpires, forces are sent solely through the segment of the link that remains connected. A friction coefficient establishes the threshold for adhesion and sliding. A score of 0.0 indicates complete sliding, whereas a value of 1.0 signifies total bonding. The friction levels vary from 0.1 to 0.2. To ascertain the value of interest in nonlinear analytical processes, the solver must iterate. This will require more time than anticipated, so ensure the analysis is coherent from a physical perspective. Nylon 12 was chosen as the simulation material notwithstanding all the simulations. A brake disc, constructed from steel, was an extra component incorporated into the simulation. The incorporation of the brake disc is essential, as the pads need reinforcement for all exerted stresses. A force of 500 Newtons was exerted on the brake pad surface as the brake disc spun at 35.5 radians per second in this simulation.

4.3.1 Displacement Magnitude

Displacement analysis is an engineering discipline that concentrates on determining the displacement field within a structure subjected to external forces. Each point in the structure relocates when a solid undergoes deformation due to external force. The highest displacement was represented by red, and the minimum displacement was denoted by blue.

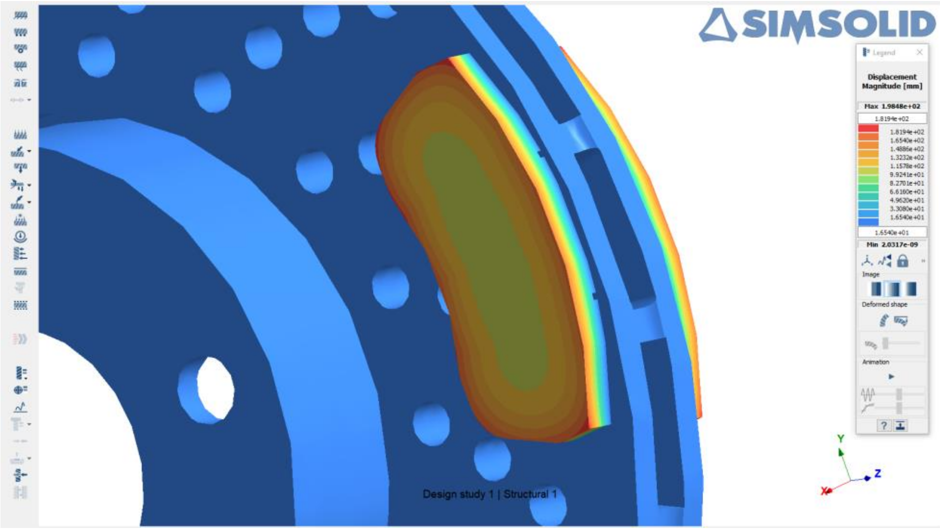

Figure 4.6 Solid pattern displacement magnitude

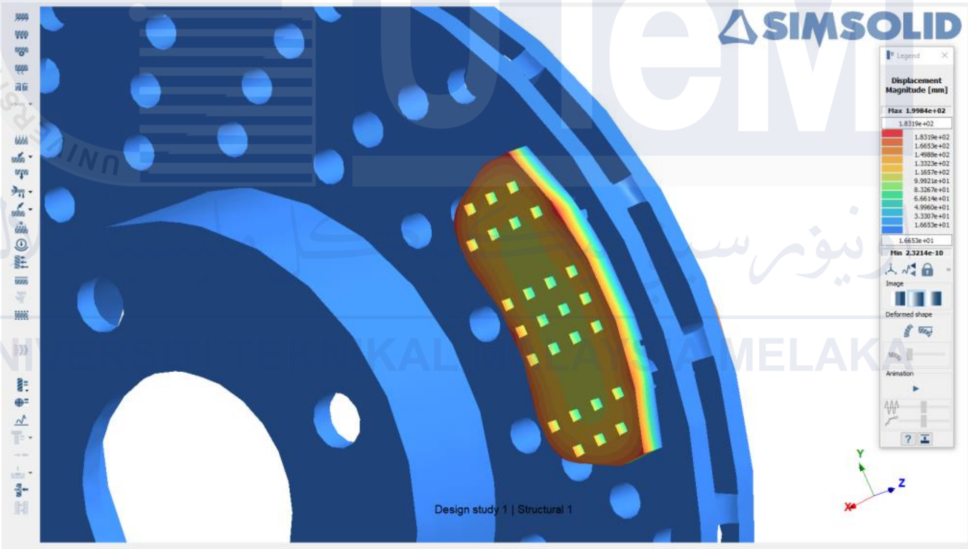

Figure 4.7 Square pattern displacement magnitude

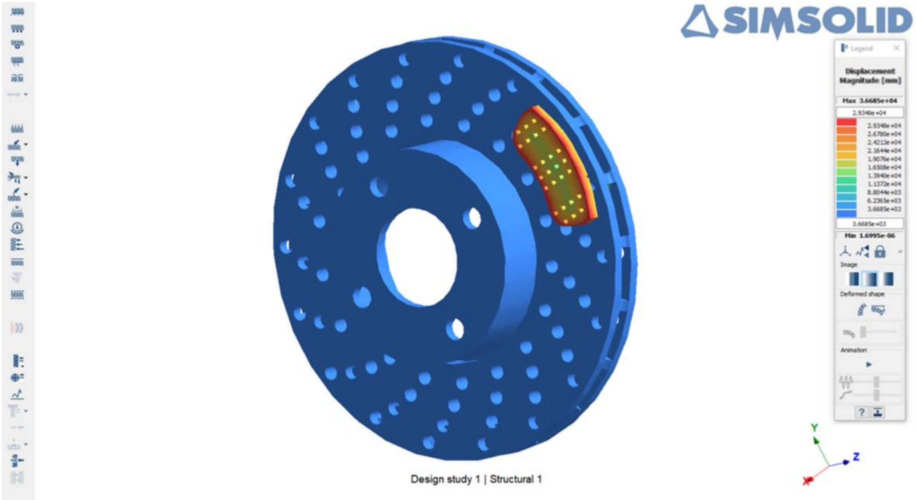

Figure 4.8 Triangle pattern displacement magnitude

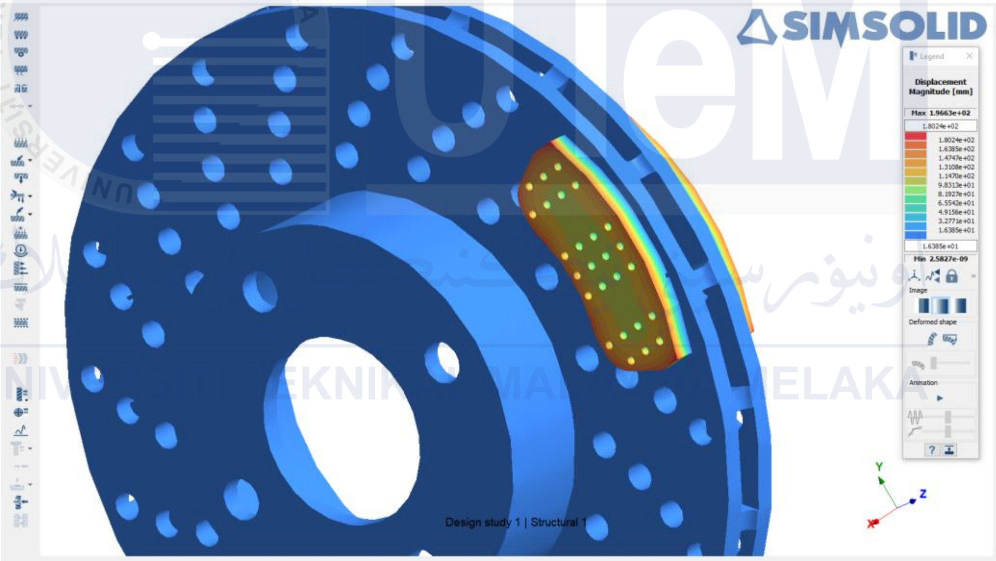

Figure 4.9 Circle pattern displacement magnitude

The highest displacement, shown by red hue, occurs on the outside edge of the backing plate. The solid geometry has a more pronounced red spot compared to other geometries; nevertheless, this does not imply that the displacement of solid geometry is higher than that of other geometries. The results of all displacement simulations indicate that circular geometry exhibits a greater degree of displacement, suggesting a larger propensity for failure, whereas solid geometry has a lower propensity for failure due to its minimal displacement. The solid geometry exhibits the lowest maximum value, but the triangular pattern displays the lowest minimum value. The greatest quantity ranges from 2.934e02 to 1.802e02, with an average maximum displacement magnitude of 1.467e02.

Table 4.3 Results of magnitude displacement test

POCKET GEOMETRY	MAGNITUDE DISPLACEMENT (MM)
SOLID	1.819 E+02
SQUARE	1.831 E+02
TRIANGLE	2.934 E+02
CIRCLE	1.802 E+02

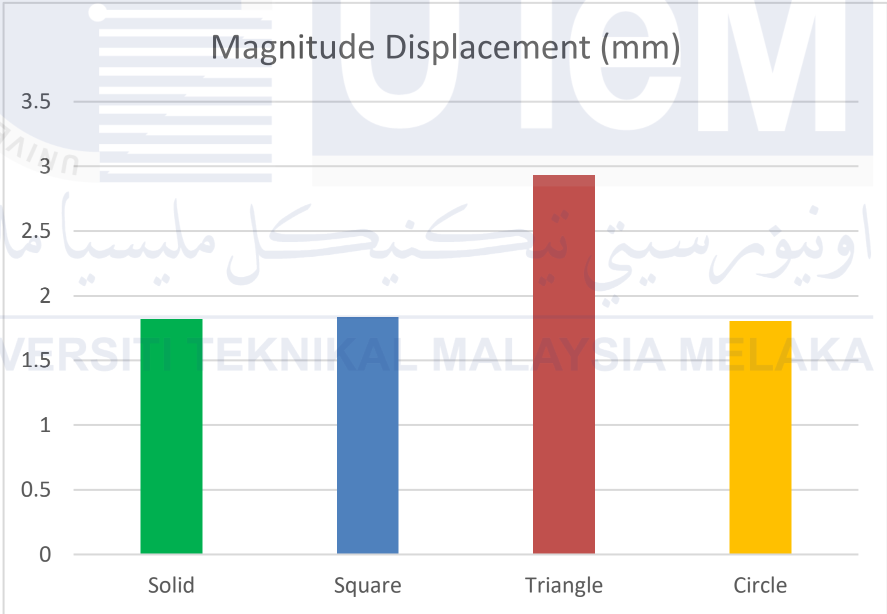

Figure 4.10 Magnitude displacement comparison

The table demonstrates that the circular geometry exhibits the lowest displacement magnitude (180.2 mm), closely succeeded by the solid geometry (181.9 mm), indicating superior stability and little deformation. The square geometry (183.1 mm) exhibits somewhat greater displacement, whilst the triangle geometry demonstrates the maximum displacement (293.4 mm), indicating diminished structural stability because to its acute edges and irregular load distribution.

4.3.2 Von Misses Stress

The Von Mises Stress is a scalar quantity used to assess if the stress in a material surpasses the yield strength or results in failure. These criteria are mostly utilized for ductile materials, including metals. The von Mises yield criteria states that a material yields when its von Mises stress under an applied load equals or exceeds its yield strength as determined by uniaxial tension.

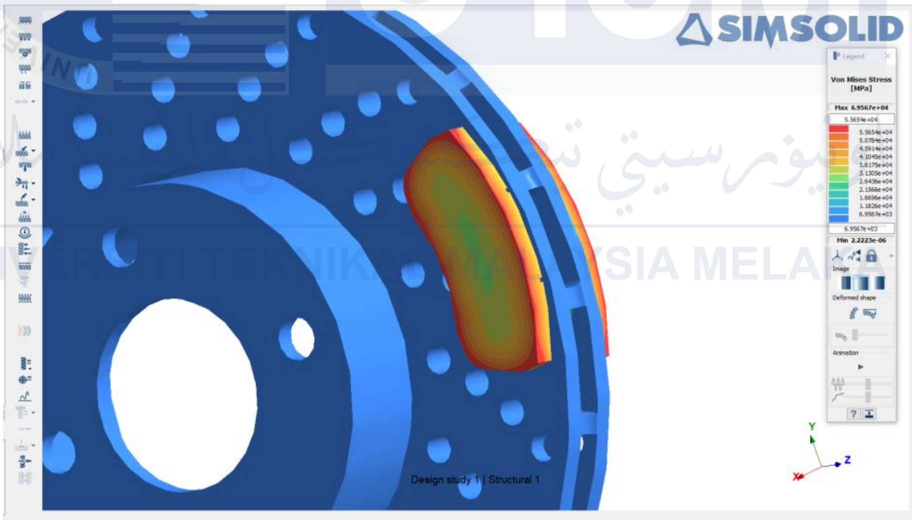

Figure 4.11 Solid pattern Von Mises Stress

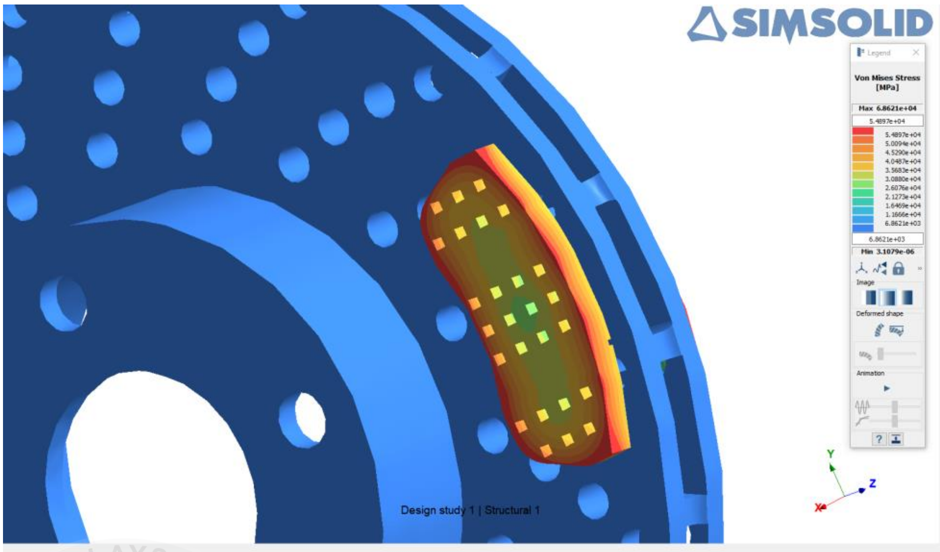

Figure 4.12 Square pattern Von Mises Stress

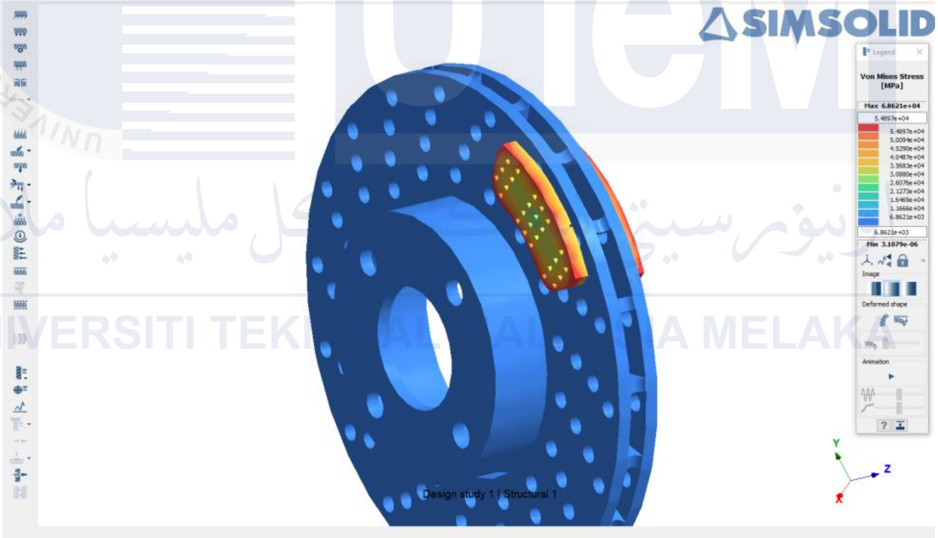

Figure 4.13 Triangle pattern Von Misses Stress

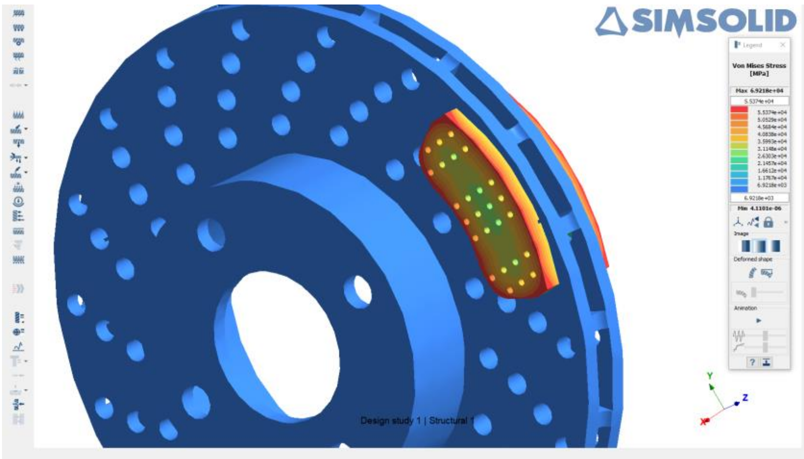

Figure 4.14 Circle pattern Von Misses Stress

The simulation findings for von Mises stress were inconsistent with the displacement magnitude. The data clearly reveals this disparity, since the regions highlighted in red—signifying the peak von Mises stress—were situated on the brake disc instead of the brake pad. The majority of the impacted regions had green and blue tones, indicating moderate to low von Mises stress levels. Table 4.4 indicates that the rectangular design had the highest von Mises stress, quantified in megapascals, with an average maximum von Mises stress of 5.5654 MPa. Conversely, the solid shape exhibited the minimal von Mises stress, signifying a reduced probability of failure or yielding under applied pressures.

Table 4.4 Results of Von Misses Stress test

PATTERN	VON MISSES STRESS (MPA)
SOLID	5.5654 E+04
SQUARE	5.4897 E+04
TRIANGLE	5.5494 E+04
CIRCLE	5.5374 E+04

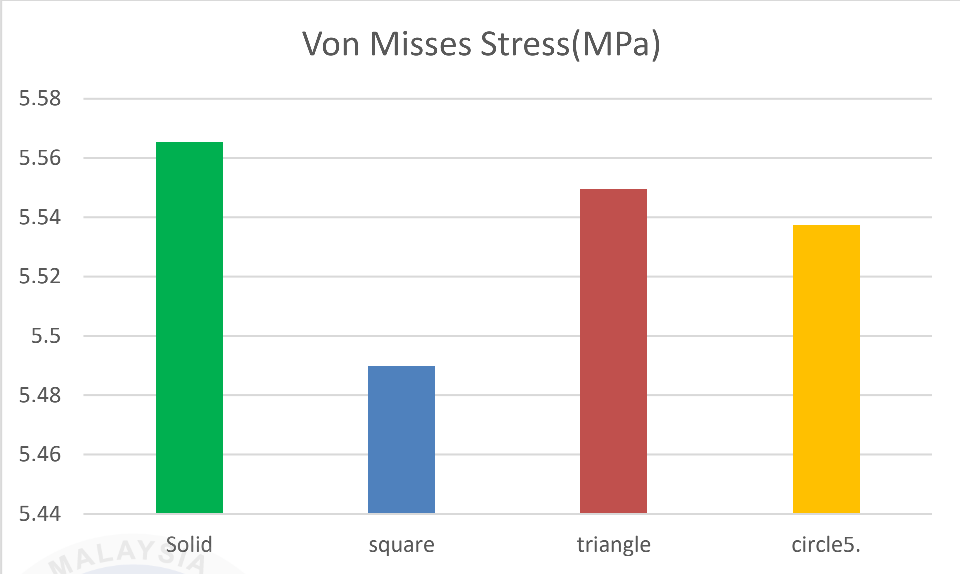

Figure 4.15 Von Misses Stress comparison

The table presents the outcomes of the Von Mises stress test for various geometries. The solid geometry exhibited the maximum stress (55654 MPa), succeeded by the triangle (55494 MPa) and circle (55374 MPa), which had somewhat lower stress values, suggesting superior stress distribution. The square shape had the lowest stress (54897 MPa), indicating it may manage stress more efficiently due to its structural properties.

4.3.3 Max Shear Stress

Ductile materials often fail or yield when their maximum shear stress meets or surpasses the shear stress at the yield point established by a uniaxial tensile test. The stress distribution visualization shows that red spots signify greatest shear stress, indicating a higher likelihood of failure, whilst blue areas denote minimal shear stress.

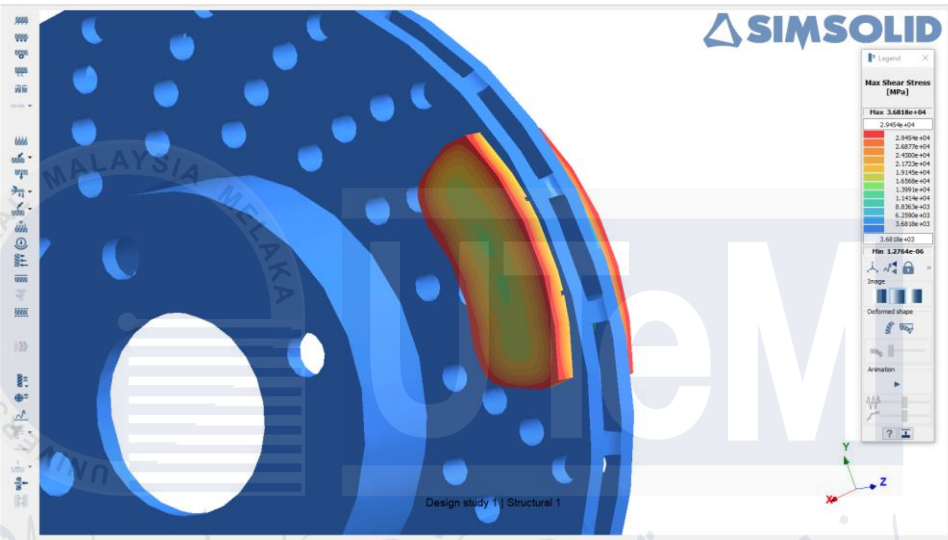

Figure 4.16 Solid pattern shear stress

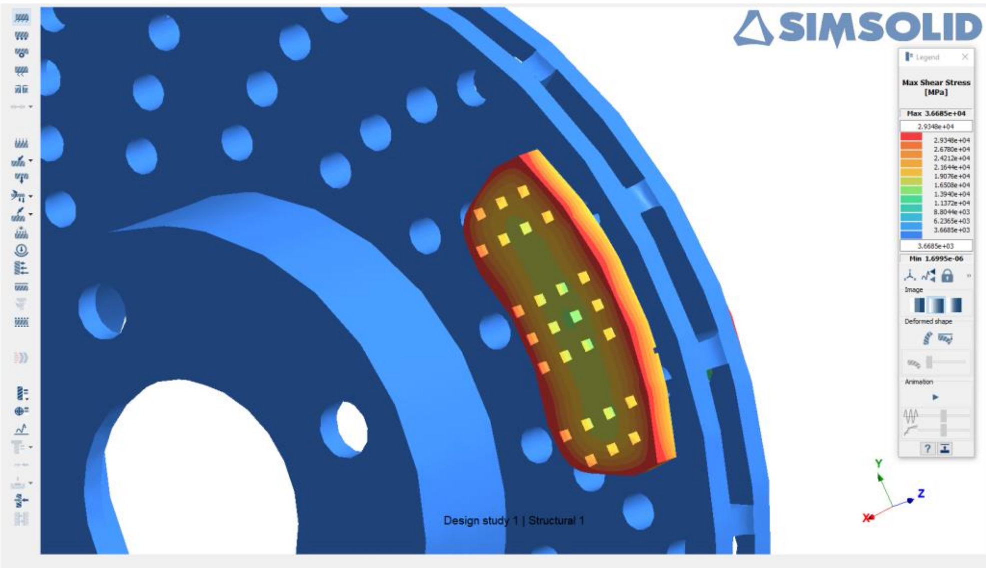

Figure 4.17 Square pattern shear stress

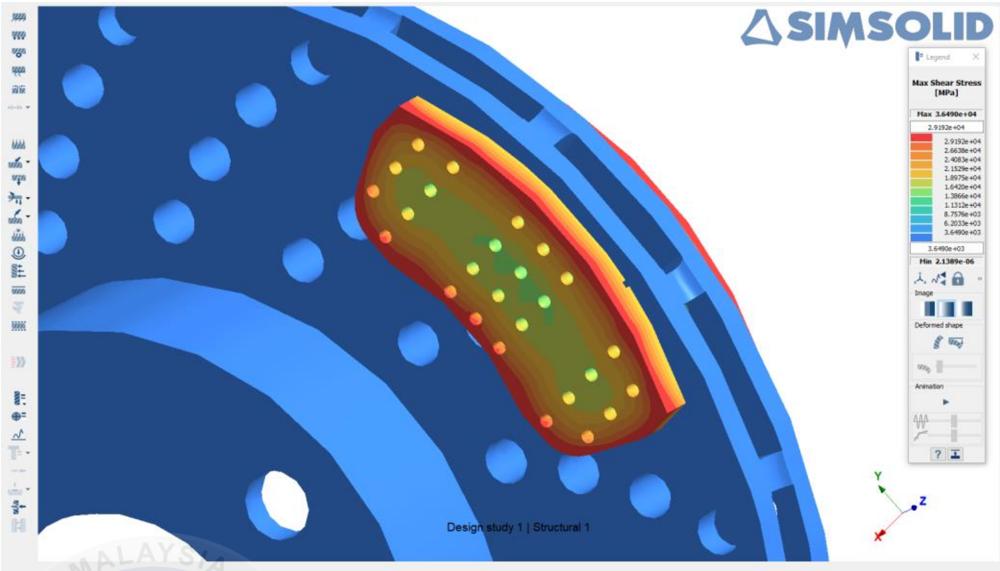

Figure 4.18 Circle pattern shear stress

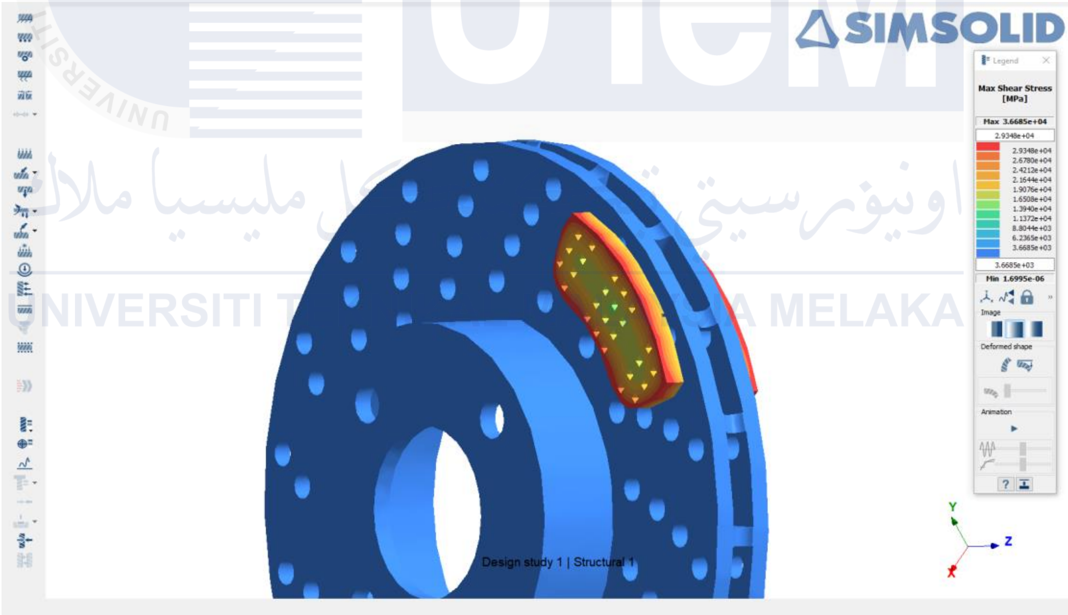

Figure 4.19 Triangle pattern shear stress

In this simulation, the highest shear stress was shown by areas colored red. As in the prior simulation, the most intense red regions were situated on the brake disc rather than the brake pad. The simulation indicated that the revolving brake disc is the most impacted region, producing maximum shear stress exceeding that of the brake pad. The brake pad predominantly displayed green and blue hues; signifying reduced shear levels. Figure 4.15 illustrates that the highest shear stress value is 2.945 e+04MPa on the solid geometry, whereas the solid geometry recorded the minimum value. The mean maximum shear stress for all geometries is 2.932 e+04MPa. The solid geometry is more prone to failure, as it demonstrated the greatest maximum shear stress value, signifying an increased likelihood of failure under applied pressures.

Table 4.5 Result of Max shear stress test

PATTERN	MAX SHEAR STRESS (MPA)
SOLID	2.945 E+04
SQUARE	2.934 E+04
TRIANGLE	2.930 E+04
CIRCLE	2.919 E+04

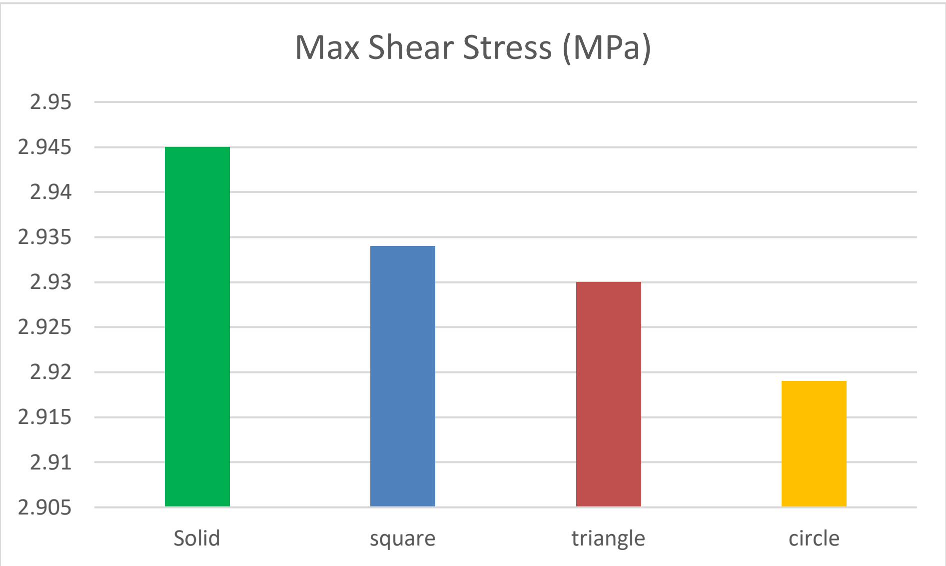

Figure 4.20 Max shear stress comparison

The solid pattern exhibited the highest shear stress (29,450 MPa) owing to its continuous material structure, providing optimal strength but missing weight efficiency. The square design (29,340 MPa) lowered stress somewhat, facilitating consistent load distribution but posing possible stress concentrations at the corners. The triangular design (29,300 MPa) optimised stress and weight economy by using the structural integrity of triangular forms. The circular design, exhibiting the lowest shear stress (29,190 MPa), reduced stress concentrations due to its smooth, uniform geometry, enhancing durability while compromising surface contact and load-bearing capability.

4.4 Prototype and Actual Product Comparison

Yamaha LC135 Apido brake pad

Figure 4.21 Actual brake pad

4.4.1 Product comparison

Figure 4.22 Solid geometry brake pad

Figure 4.23 Square geometry brake pad

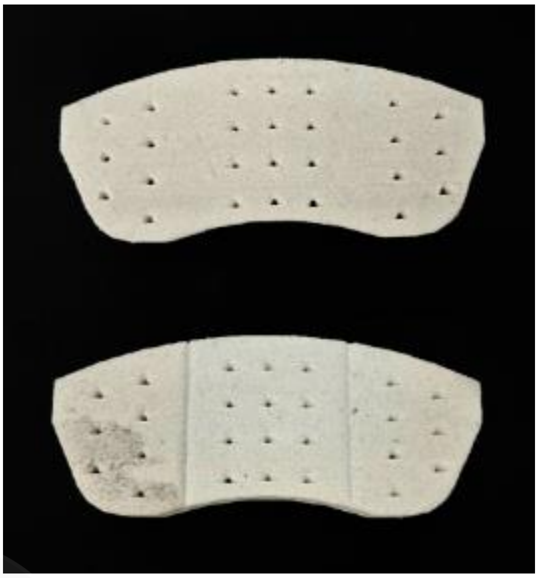

Figure 4.24 Triangle geometry brake pad

Figure 4.25 Circle geometry brake pad

4.4.2 Product Specifications

The dimensions of the brake pad were obtained from accurate measurements of a Yamaha LC135 Apido brake pad. These data served as a benchmark to guarantee compatibility with current braking systems while enhancing performance. The length, height, and breadth represent the requisite dimensions for optimal friction and wear distribution. The groove and pocket depths were engineered to optimize heat dissipation and facilitate debris removal, hence enhancing performance and prolonging the brake pad's lifespan. The geometric diameter and quantity were derived from the original brake pad, assuring structural integrity while preserving cost-effectiveness and usefulness.

Table 4.6 Product Dimensions

PARAMETER	VALUE
LENGTH	86.3 mm
HEIGHT	36.9 mm
WIDTH	8.5 mm
GROOVE DEPTH	1.2 mm
POCKET DEPTH	8.5 mm
GEOMETRY DIAMETER	3 mm
GEOMETRY QUANTITY	26

The material characteristics were carefully chosen to guarantee the brake pad's performance and longevity. Nylon 12 was selected for its superior mechanical qualities, encompassing high elastic modulus, tensile strength, and low density, which facilitate lightweight and efficient designs. The thermal expansion coefficient and compressive yield strength provide stability under fluctuating temperatures and pressures during braking. These properties combined render Nylon 12 an appropriate material for brake pads in lightweight industrial applications.

Table 4.7 Material Properties of Nylon 12

Parameter	Value
Elasticity modulus	1860 MPa
Poisson’s ratio	0.40

Density	1020 kg/m^3
Ultimate tensile stress	50.00 MPa
Tensile yield stress	52.00 MPa
Compressive yield stress	45.00 MPa
Thermal expansion coefficient	1.00×10^{-5} °C^{-1}

4.5 Product Readiness

Product readiness is a crucial element in the manufacturing process of brake pads. Some applications may function best under particular conditions, necessitating the establishment of criteria for distinguishing and evaluating distinct items. A performance scale from 1 to 5 was employed to assess printed brake pads, where 1 signifies poor performance and 5 denotes great performance.

Figure 4.21 illustrates that the solid shape of the brake pad accurately reflects real brake pad designs. Among the geometries evaluated, solid geometry consistently prevailed in the majority of simulations. Nevertheless, it attained a performance score of 2 under standard traction conditions, signifying that other geometries demonstrated similar performance in these scenarios.

The square geometry exhibited exceptional performance, attaining superior results in many tests, indicating that it is the most efficient geometry relative to the others. The rectangle shape demonstrated subpar performance across three criteria, rendering it the least appropriate geometry for practical use.

Sample	Displacement Magnitude	Von Misses Stress	Max Shear Stress	Normal Traction
Solid	5	5	5	2
Triangle	3	3	3	5
Square	4	4	4	3
Circle	1	2	2	4

Figure 4.26 Product performance

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

Figure 4.27 Guidelines for product readiness

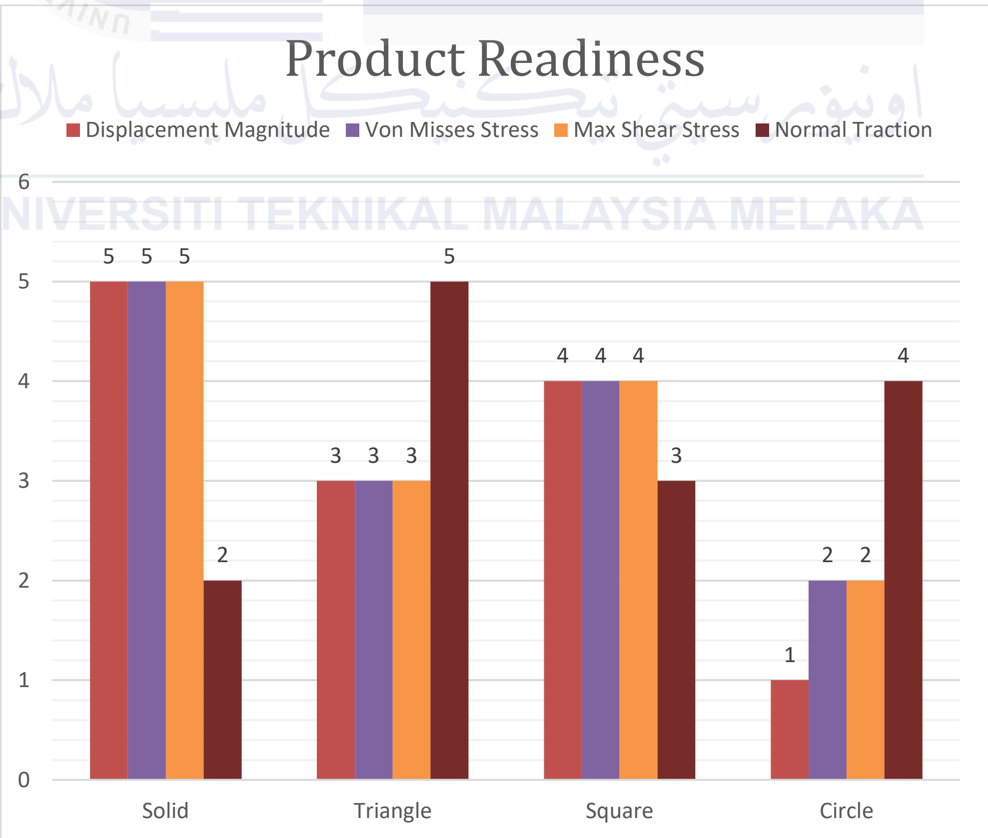

Figure 4.28 Product Rating

The Square geometry demonstrates the best overall performance due to its balanced characteristics across all evaluation criteria. It achieves high scores in Displacement Magnitude, Von Mises Stress, and Max Shear Stress (all rated 4), indicating excellent structural reliability and stability under applied loads. While its Normal Traction score (3) is moderate, it strikes a balance between friction and wear, ensuring effective braking without compromising durability. Unlike the Solid geometry, which excels in structural performance but has poor traction (score of 2), the Square geometry offers a superior combination of strength and braking efficiency. Similarly, it outperforms the Triangle and Circle geometries, which show uneven results across the parameters, with structural weaknesses outweighing their traction benefits. Therefore, the Square geometry is the most efficient and well-rounded choice.

4.5.1 Product Potential Application

The analysis conducted in this project demonstrates that incorporating different geometric patterns into brake pad designs can significantly enhance performance metrics, including structural strength and friction efficiency. These improvements, compared to traditional solid brake pad geometries, highlight the potential for cost reduction in manufacturing through optimized material usage and customized dimensions.

At an early stage, this innovation can be applied to small vehicles operating at low speeds, such as motorized wheelchairs or scooters, where the demands on braking systems are moderate. Additionally, this method of applying geometric patterns to brake pad surfaces can extend to industries focused on braking mechanisms, including bicycles, lightweight electric vehicles, and compact industrial machinery.

Furthermore, the findings of this project could serve as a foundation for scaling up the technology to heavier vehicles, provided further research is conducted to validate performance under higher loads and speeds. With the integration of 3D printing and advanced material technologies, this approach could revolutionize the production of brake pads, promoting efficiency and sustainability in automotive manufacturing.

4.5.2 Product Improvement

This product may enhance its design by including more geometric patterns, such as hexagonal patterns. Hexagonal patterns are considered superior geometrically than other shapes or patterns. For further enhancement, the printing technique of this product may also be upgraded utilizing the SLM printing process. The design of brake pads is less complex compared to other mechanical components, which is why this product is suitable for implementation using SLM printing methods.

Moreover, this project may be enhanced by applying this strategy to many brake pads models. A substantial amount of data was collected and analyzed, providing more information for comparing various brake pad types and determining if this procedure is applicable to all brake pad models or only to certain ones.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

This chapter summed up the project's results and proposed recommendations for further research. Comprehensive study on the optimal shape of brake pads has been undertaken in both analysis and production to ascertain the most suitable sample selection. The conclusion part encompasses a synopsis of the research and a summary of the findings. The recommendations section contains suggestions for further research and improvement of this project.

5.1 Conclusion

The primary objective of this research is to design and simulate a brake pad with optimal shape. This objective was achieved by creating and constructing a model of brake pad samples using CAD software. The optimal geometric configurations have been determined, selecting four types: solid, triangular, square, and circular geometries. The findings indicate that the incorporation of geometries on the surface of the samples influences alterations in parameter structure.

The second aim was achieved when the four samples were printed utilizing the SLS machine. The flow chart indicates that certain geometry brake pads were printed, but not in the anticipated optimal condition. To achieve this, the sample must undergo a redesign process, culminating in the optimization of the printed parameter sample. This sample is unsuitable for actual use as it is composed of nylon, which significantly differs from genuine brake pads. Despite such circumstances, it provides a clear understanding of how geometry influences braking performance when the geometric pattern is applied to the surface of the brake pad.

5.2 Recommendations of future development

This project may continually change with the available data; here are some suggestions for its future development.

1. Conducting the real physical test toward the SLS sample throughout any machine or can be tested as real brake pad.
2. Focus on conducting durability test by perform a test to ensure the exact lifespan of the brake pads.
3. Exploring the use of new materials compatible with the same fabrication method.

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