DESIGN AND ANALYSIS OF DIFFERENT DESIGN SPOKE STRUCTURE OF AIRLESS TYRE AND CONVENTIONAL TYRE

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B092010410

BACHELOR OF MECHANICAL ENGINEERING TECHNOLOGY (AUTOMOTIVE TECHNOLOGY) WITH HONOURS

2024

Faculty of Mechanical Technology and Engineering

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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 Technology and Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2024

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

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TAJUK: **DESIGN AND ANALYSIS OF DIFFERENT DESIGN SPOKE STRUCTURE OF AIRLESS TYRE AND CONVENTIONAL TYRE**

SESI PENGAJIAN: **2023-2024 Semester 1**

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DEDICATION

This project is dedicated to the tire industry pioneers and visionaries who have revolutionized the way we move. Their tireless dedication and relentless pursuit of excellence have transformed the world of mobility. With deep gratitude, we honour the tire innovators who have pushed the boundaries of technology, creating safer, more efficient, and sustainable transportation solutions. May their groundbreaking contributions inspire future generations to continue pushing the limits of tire engineering, shaping a future where mobility knows no bounds.

ABSTRACT

Optimizing performance, durability, and comfort poses considerable issues in the design and analysis of spoke structures for both airless and traditional tires. Although airless tires have benefits like resilience to punctures and less need for maintenance, the optimal design and arrangement of the spoke structure are still undetermined. This research seeks to rectify the lack of thorough studies that compare the performance of airless tires with various spoke systems to that of regular pneumatic tires. The project aims to develop several spoke configurations for airless tires, examine their non-linear characteristics, and compare them to traditional tires. The scope of the project includes the specification of two designs for spoke structures, the creation of two airless tires and one conventional tire using SolidWorks software, the selection of appropriate materials and their qualities, and the execution of a comparative study using SimSolid software. The methodology uses sophisticated mathematical methods, such as finite element analysis and simulation techniques, to forecast the mechanical characteristics of spoke structures. The objective of the study is to determine the benefits and obstacles associated with airless tires in comparison to traditional ones. The conclusion will offer valuable insights on the optimal spoke structure design for airless tires, taking into account factors such as performance, cost-effectiveness, and practicality. This research enhances the comprehension and enhancement of airless tire design, offering vital insights for future progress in tire technology.

ABSTRAK

Mengoptimumkan prestasi, ketahanan, dan keselesaan mencetuskan isu-isu besar dalam reka bentuk dan analisis struktur rangka untuk tayar yang tidak memerlukan udara dan tayar tradisional. Walaupun tayar yang tidak memerlukan udara mempunyai kelebihan seperti keupayaan menahan pancitan dan kurangnya keperluan penyelenggaraan, reka bentuk dan susunan optimum struktur rangka masih belum dapat ditentukan. Kajian ini bertujuan untuk menangani kekurangan kajian menyeluruh yang membandingkan prestasi tayar yang tidak memerlukan udara dengan pelbagai sistem rangka berbicara dengan tayar pneumatik tradisional. Projek ini bertujuan untuk membangunkan beberapa konfigurasi rangka berbicara untuk tayar yang tidak memerlukan udara, mengkaji ciri-ciri bukan linear mereka, dan membandingkannya dengan tayar tradisional. Skop projek termasuk penentuan dua reka bentuk untuk struktur rangka, penciptaan dua tayar yang tidak memerlukan udara dan satu tayar konvensional menggunakan perisian SolidWorks, pemilihan bahan yang sesuai dan sifat-sifat mereka, dan pelaksanaan kajian perbandingan menggunakan perisian SimSolid. Metodologi menggunakan kaedah matematik yang canggih, seperti analisis elemen terhingga dan teknik simulasi, untuk meramalkan ciri-ciri mekanikal struktur rangka. Objektif kajian adalah untuk menentukan manfaat dan rintangan yang berkaitan dengan tayar yang tidak memerlukan udara berbanding dengan tayar tradisional. Kesimpulannya akan memberikan pandangan berharga tentang reka bentuk struktur rangka yang optimum untuk tayar yang tidak memerlukan udara, dengan mengambil kira faktor seperti prestasi, kecekapan kos, dan kebolehan praktikal. Kajian ini meningkatkan pemahaman dan penambahbaikan reka bentuk tayar yang tidak memerlukan udara, memberikan pandangan penting untuk kemajuan masa depan dalam teknologi tayar.

ACKNOWLEDGEMENTS

I would like to express my deepest gratitude and appreciation to Universiti Teknikal Malaysia Melaka (UTeM) for providing me with the opportunity to pursue my education and undertake this research project. The resources, facilities, and support provided by the university have been instrumental in the successful completion of this work.

I am extremely thankful to my supervisor, Mohd Hafizi bin Abdul Rahman, for his invaluable guidance, expertise, and continuous support throughout this journey. His knowledge and insights have been instrumental in shaping the direction of this research and enhancing its quality. I am grateful for his patience, encouragement, and willingness to share his expertise, which have been crucial in overcoming challenges and ensuring the successful completion of this thesis.

I would also like to extend my appreciation to the faculty members of the Department of Engineering for their valuable contributions, insightful discussions, and constructive feedback. Their expertise and guidance have played a significant role in enhancing the quality and depth of this research.

Furthermore, I would like to express my sincere gratitude to my family and friends for their unwavering support, understanding, and encouragement throughout this academic journey. Their love, motivation, and belief in my abilities have been a constant source of inspiration.

Lastly, I would like to acknowledge all the individuals who have directly or indirectly contributed to this research project. Your contributions, whether through discussions, feedback, or assistance, have been invaluable. Thank you all for your support, guidance, and encouragement. This achievement would not have been possible without each and every one of you.

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LIST OF SYMBOLS AND ABBREVIATIONS

D,d	-	Diameter
FEA	-	Finite Element Analysis
P	-	Passenger
LT	-	Light Truck Tire
ST	-	Trailer Tire
SBR	-	Styrene-butadiene rubber
2D	-	Two-dimensional
NPT	-	Non-pneumatic Tire
CFD	-	Computational Fluid Dynamic
UPTIS	-	Unique Puncture-Proof Tyre System
PU	-	Polyurethane
mm	-	Millimeter
MPa	-	Megapascal

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CHAPTER 1

INTRODUCTION

1.1 Background

Historically, the creation of conventional tires was remarkably aided by a few businesses and innovators in the period of 19th century, In particular Charles Goodyear, and John Boyd Dunlop, among the rest. In 1888, Dunlop invented the practical conventional tire which led to the development of current-day tire companies like Bridgestone, Goodyear, Continental, Michelin, Yokohama, and Pirelli. All the way to the middle of the 20th century, bias-ply tires were the most common type of tire on the market, and they were famed for their firmness and hardiness. Furthermore, they had layers of cord cloth that were intertwined at a variety of angles. Bias-ply tires had a significant load-bearing capacity, but they were not very fuel-efficient and did not provide a particularly comfortable ride.

In the year of 1940s and 1950s, Michelin was the first company to introduce radial-ply tires into the tire industry, which also caused fundamental change. Correlated to bias-ply tires, radial-ply tires accommodated cords that ran at an angle of 90 degrees to the direction of travel. Appropriately, the radial-ply tires offered super grip, increased fuel efficiency, and intensify ride comfort. For this reason, Radial-ply tires gained instant popularity around the world and became the industry standard for most passenger vehicles. Similarly, tubeless tires were first available about the middle of the 1950s by eliminating the requirement for inner tubes. So that, tubeless tires provided a few advantages, increase in vehicle safety, weight reduction, enhanced heat dissipation, and reduced rolling resistance. Through the years, tire technology has continued to progress, resulting in advancements in tread patterns. Figure 1.1 shows a conventional tire.

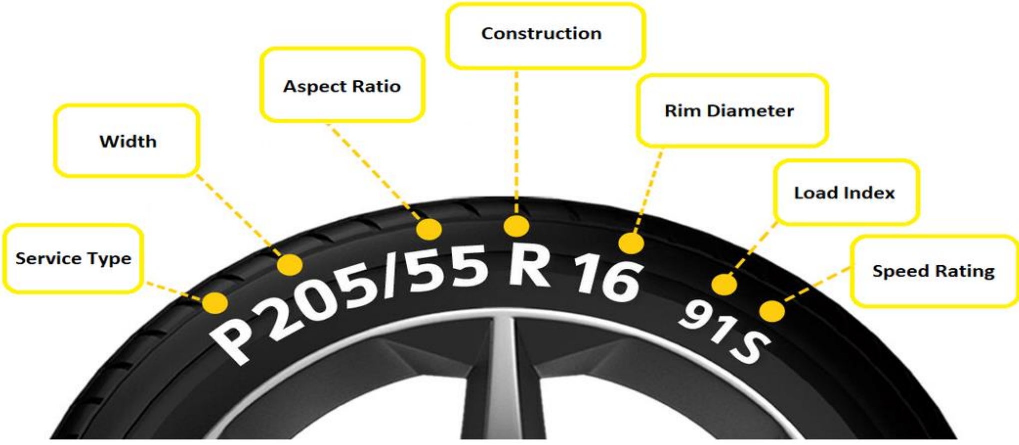

Figure 1.1 Shows a conventional tire with tire designation (Pauwelussen, 2015)

The "Seiberling Non-Skid" tire, invented by F.A. Seiberling in the early 1900s, was a significant development in tire technology at that time. While the tire still had a solid rubber core, it incorporated a tread pattern that greatly enhanced puncture resistance compared to earlier tire designs. Although not completely airless, the Seiberling Non-Skid tire represented a significant improvement in durability and reliability.

Fast forward to 2005, Michelin introduced a groundbreaking innovation in tire design known as the "tweel." The term "tweel" is a combination of the words "tyre" and "wheel." The tweel revolutionized the concept of a tire by introducing a solid outer tread band that was connected to a series of flexible spokes. These spokes served a dual purpose of supporting the rider's weight and absorbing shocks from the road surface. By eliminating the need for air-filled chambers, the tweel offered several advantages such as reduced maintenance, increased resistance to punctures, and improved ride comfort. The innovative design of the tweel opened new possibilities for tire technology, paving the way for further advancements in the airless tire concept. Figure 1.2 shows Michelin X Tweel airless tire.

Figure 1.2 Shows an example of airless tire (Deng, Wang, Shen, Gong, & Xiao, 2022)

Overall, both the Seiberling Non-Skid tire and the tweel represent significant milestones in tire innovation. They demonstrate a continuous effort to enhance tire performance, durability, and safety, with the tweel introducing a groundbreaking concept that challenged the traditional air-filled tire design. These advancements in tire technology have contributed to the development of more reliable and efficient tire options for various applications, pushing the boundaries of what was once considered possible in the world of tires.

1.2 Problem Statement

The design and analysis of spoke structures for airless tires and conventional tires pose tremendous demanding situations in attaining most effective overall performance, durability, and comfort. Although airless tires have proven capability benefits together with puncture resistance and decreased maintenance, the most reliable design and configuration of the spoke structure continue to be unsure. Additionally, a comprehensive comparison between airless tires and traditional pneumatic tires is required to assess their respective performance characteristics.

That is why, there is a need to review and improve the design of various spoke structures for airless tires to increase load carrying capacity, ensure structural integrity, and improve overall performance. This includes determining the correct geometry, material selection, and manufacturing processes to achieve the desired characteristics. Considering all these factors, it is essential to identify the most suitable spoke structure design for airless tires and the selected design is based on performance, cost-effectiveness, A balance must be struck between it and practicality.

Even more important, that there is an insufficiency of complete studies that examine and compare the performance of airless tires with different spoke systems to standard pneumatic tires. The overall performance parameters, including durability, rolling resistance, comfort, and cargo-carrying ability, want to be assessed and compared to set up the advantages and obstacles of airless tires in relation to their conventional counterparts. For this reason, there is a need to utilize advanced analytical tools, consisting of finite element analysis (FEA) and simulation techniques, to investigate and are expecting the mechanical conduct and performance of different spoke structures. Experimental testing, inclusive of laboratory tests and area trials, is needed to validate the analytical findings and examine the actual-world overall performance of airless tires and conventional tires.

1.3 Research Objective

The main aim of this research is to investigate the design principle of spoke structure of airless tire and to make a comparison between airless tire and conventional tire. Specifically, the objectives are as follows:

a) To design the different spoke structure of airless tire.

b) To analyze the non-linear behavior of different spoke structure.

1.4 Scope of Research

The scope of this research are as follows:

a) Specify two spoke structure design.

b) Design two airless tire and one conventional tire by using SolidWorks.

c) Determine material and properties for the design respectively.

d) Conduct a comparative analysis between airless tires and conventional tires to decide the advantages and barriers of every type by using SimSolid.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This literature review affords a top-level view of current research and trends concerning the design and analysis of spoke structures for airless and conventional tires. This article investigates studies and courses that target design and analysis ideas, overall performance assessment, spoke design, and evaluation of airless and conventional tires.

2.2 Conventional Tire

Conventional tires rely on aerodynamics for support and cushioning, which helps with shock absorption and improved rideability. Proper tire pressure is essential for optimal tire performance, including traction, handling, fuel economy, and tread. When trodden to a certain depth or when signs of wear, tear, or aging appear, traditional tire maintenance usually requires regular inspections, cycles, and replacements. Over the years, traditional tires have been completely manufactured and optimized to provide a balance of performance, comfort, and reliability for different vehicles and road conditions. According to (Gent, 2006), tires are highly developed structural composites, and their performance can be designed to match the ride, handling, and traction standards of the vehicle manufacturers, in addition to the quality and performance demands of the consumer. When traveling one mile, the tires on a mid-sized car complete around 800 revolutions. Therefore, over 50,000 miles, every component of the tire goes through more than 40 million loading and unloading cycles, which is a remarkable demand for endurance (Gent, 2006).

2.3 Type of Tire Construction

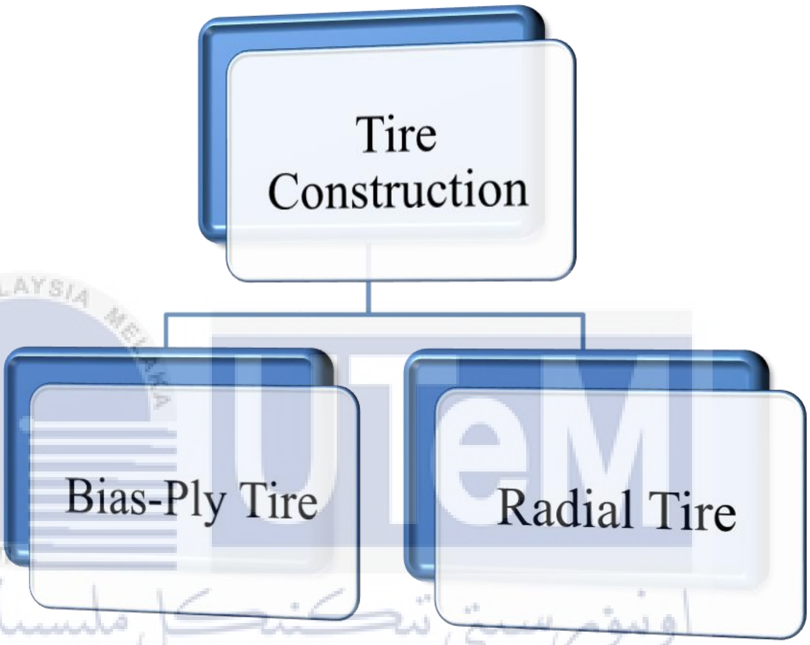

Figure 2.1 Type of Tire Construction (Pauwelussen, 2015)

Like other vehicle components, tire selection is important to maximize performance and ensure longevity. The best option reduces operating and maintenance costs in addition to enabling you to maximize the performance of your vehicle. Passenger car tires are metal-rubber bands around the wheels. Based on their design, automotive tires are classified as bias or radial Figure 2.1. To understand the difference between these tires, you need to examine their features, advantages, and disadvantages (Pauwelussen, 2015).

2.3.1 Bias-Ply Tire

Typically, bias-ply tyres are made of nylon fibres that extend from bead to bead, creating a uniform surface footprint with each successive fibre mounted at an angle to the previous one, so that the crisscross pattern is created, and additional layers are added, increasing the strength of the material. This layering process makes a fungus more environmentally resistant and durable. Bias-ply tyres with reinforced belts are said to be bias-belted. Bias-ply tyres are generally distinguished by their convex tread profile.

Based on (Pauwelussen, 2015), Figure 2.2 shows both sides and tread of bias-ply tyres are equally strong, thanks to their design. Because the tyre itself cleans easily and the compounds tend to be softer to improve grip, bias-ply tyres are more resistant to corpse shifting and provide unmatched road performance on Increase the available area of contact. Sidewall lugs can extend towards the shoulder more because bias-ply side walls carry part of the weight. Ply tyres tend to be smaller than their full-size counterparts if it is the radial that has the greatest flexibility in the tread, providing a smooth ride.

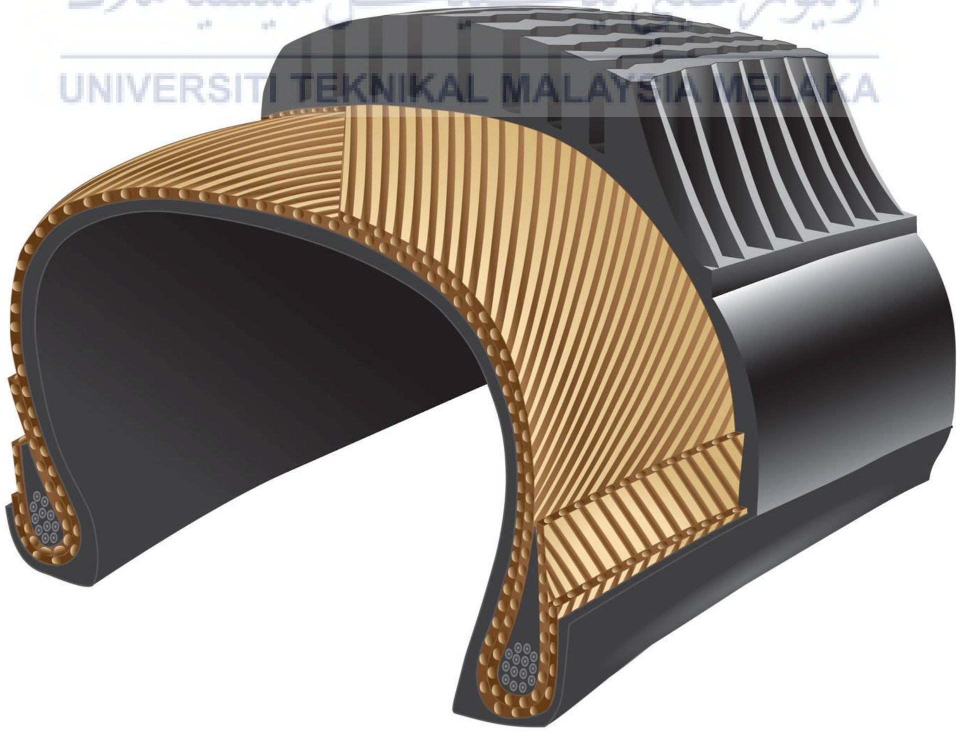

Figure 2.2 Cutaway view of a typical bias-ply tire (Pauwelussen, 2015)

2.3.1.1 Advantage and Disadvantage of Bias-Ply Tire

Table 2.1 Advantage and Disadvantage of Bias-Ply Tire (Pauwelussen, 2015)

ADVANTAGE	DISADVANTAGE
This design approach enhances driving comfort by allowing drivers to drive smoothly on uneven road surfaces. Bias construction tyres can also withstand higher loads, which is why heavy machinery finds them so useful. These tyres also have the advantage of being relatively easy to maintain and less susceptible to damage.	On the downside, biased-build tyres have less grip at higher speeds and, at the same time, are more susceptible to overheating. Due to their low rolling resistance, the wear rate of these tyres has increased, and they also use more fuel than radial tyres.

2.3.2 Radial Tire

Radial tyres are a popular option for collector enthusiasts who intend to drive their vintage vehicles. The modern design's excellent ride, wet-weather traction, and tread life make it extremely practical for most individuals. The advantages come from the construction of the tyre, which has ply-straight threads on the bead. This curvature of the blades allows for a more flexible arrangement to suit the road surface and the ability of the tyres to slide over bumps and cracks. This makes for a pleasant driving experience, even on bumpy highways, so a bias-ply tyre will have a rolling feel.

Even with the same size, radial tyres are generally wider than bias-ply tyres. For example, a 6.70-15 tyre (common on passenger cars from the late 1940s to the mid-1950s) is compatible with a 205/75R15 P-metric radial tyre. The radial equivalent, however, has a top step that is more than an inch wide. This increased contact surface increases traction and stability, while the curved shoulder increases traction in extreme cornering situations. Radial tyres also have tread sipping, which helps drain water and increase rainy traction. Recently, Coker Tyres found a solution to the longstanding debate between bias and ply radial tyres for collector cars (Pauwelussen, 2015).

Figure 2.3 Cutaway view of typical Radial Tire (Pauwelussen, 2015)

2.3.2.1 Advantage and Disadvantage of Radial Tire

Table 2.2 Advantage and Disadvantage of Radial Tire (Pauwelussen, 2015)

ADVANTAGE	DISADVANTAGE
These tyres have wider, smaller treads. It also claims to have minimum rolling resistance, reducing fuel consumption and improving efficiency. Additionally, the radial tyres provide excellent traction and comfort at high speeds. Steel wire used in tyre manufacturing prevents contact between tyres, increasing thermal resistance or reducing heat buildup. Steel belts for the same tyre provide resistance as the tear is greater.	Steel belt construction provides a stiff ride at low speeds on rough roads, especially on steep roads. Additionally, a stiff tread increases tyre noise, and a collision with an obstacle can damage the surface, thus reducing overall ride quality.

2.4 Types Of Tires

Generally, you don't care if the tyre is bias-ply or radial. You probably already know you need a passenger car, light truck, trailer, or spare tyre. There may be interest in the differences between all-season, summer, and winter tyres, as well as the mass production of these three categories. Figure 2.4 shows main type of tire (Pauwelussen, 2015).

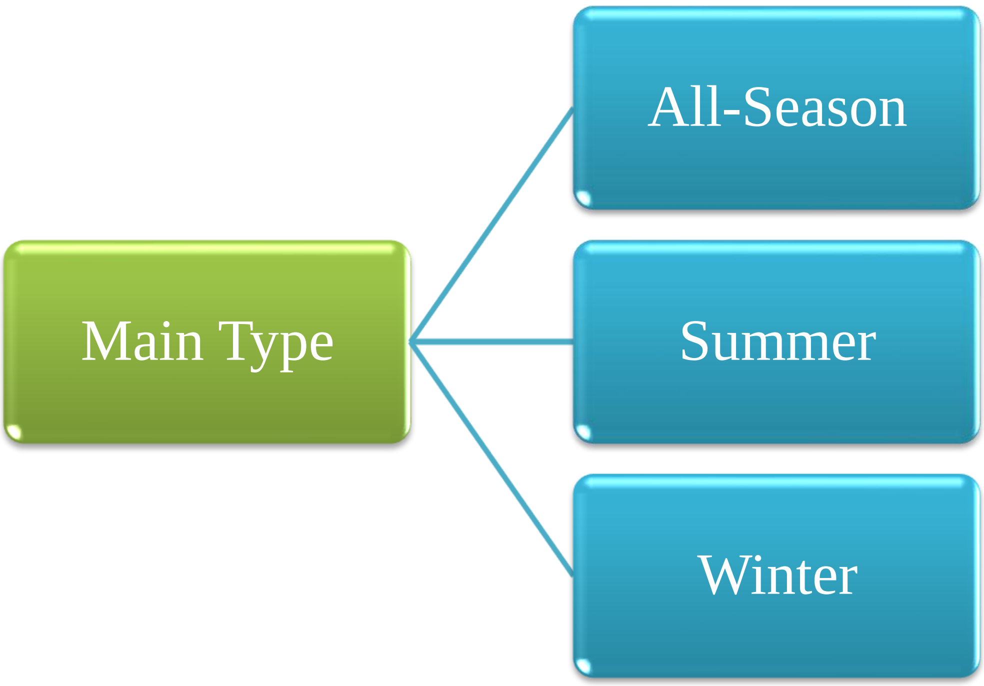

Figure 2.4 Main type of Tires (Pauwelussen, 2015)

Common variations of the main types:

a) Touring

b) Performance

c) Passenger

d) All-Terrain

e) Off-Road

2.4.1 All-Season Tires

All-terrain tires, also known as multi-use tires, are common equipment in many cars, trucks, and SUVs. These tires are designed for year-round use in tropical climates. However, it can withstand extreme winter heat, cold, and even some snow. It is not recommended for all-terrain snow tires because the rubber is not designed to withstand temperatures near or below freezing. Winter tires are recommended for winter conditions in extreme weather conditions, which generally provide temperatures below freezing during the winter months.

While all-terrain tires can survive warm winter days without causing problems, their design isn’t designed to compromise the great benefits of warm days, like most things trying to do everything right. As a result, dedicated winter tires perform best in the winter, while summer tires perform best when temperatures are well above freezing (Pauwelussen, 2015). Figure 2.5 shows an example of all-season tire.

Figure 2.5 MICHELIN CrossClimate2 All-Season Tire (Pauwelussen, 2015)

2.4.2 Summer Tires

Summer tires work best in hot conditions. It is designed for use at temperatures well above zero. It should not be used in snow or ice and should not be worn in the winter.

For most of the year, summer tires perform better than regular tires because they don't account for snow, and materials that don't require cold adjustments are preferred.

Benefits include greater traction in hot and humid conditions and a longer ride life. In harsh winter weather conditions, it is ideal for changing tires at the end of winter and is a good year-round choice in warmer climates with exceptionally cold temperatures. Rubber makes up most high-performance street tires. Summer tires can optimize their tread pattern and rubber compound for greater traction and tire life without sacrificing winter performance (Pauwelussen, 2015). Figure 2.6 shows an example of summer tire.

Figure 2.6 Michelin Pilot Sport 4 S Summer Tire (Pauwelussen J.P., 2015)

2.4.3 Winter Tire

Winter tires are specifically designed to perform well in below-freezing temperatures and provide excellent traction on snowy and icy roads. Optimizing tread patterns and rubber compounds aims to improve traction performance in cold weather and the ability to handle winter snow and slush. Winter tires often have sips, which are narrow tubes that increase drag in extreme cold. The rubber used in the product is designed to remain flexible even at low temperatures, thus increasing the grip and handling capabilities.

Winter tires are not recommended for use in non-winter seasons and may cause adverse effects. The gripping capacity of the tires is greatly reduced in rainy conditions, which is lower than for all-season or summer tires, and in addition, the rubber compound is too soft for hot temperatures. Soft drugs are not very durable. The ability of the tread block to be too flexible can cause easy tire wear (Pauwelussen, 2015). Figure 2.7 shows an example of winter tire.

Figure 2.7 Michelin X-Ice Xi3 Winter Tire (Pauwelussen, 2015)

2.4.4 Touring Tire

Touring tires are designed with specific characteristics that make them suitable for the intended application. These characteristics include quietness, comfort, performance in wet and dry conditions, and longevity. Due to its immense popularity, the magazine design can be found in all three tire styles. According to the user, touring tires are designed to balance all suitability factors. A regular touring tire should be able to perform multiple tasks. Issue tires are a versatile product designed to excel in all industry categories. According to the report, these individuals have a unique ability to succeed in almost any situation (Pauwelussen, 2015). Figure 2.8 shows an example of touring tire.

Figure 2.8 DieHard Silver Touring All-Season P225/60R16 97T Tire (Pauwelussen, 2015)

2.4.5 Performance Tire

Performance tires place less emphasis on the durability of a race tire and less priority on handling and traction quality. The article claims that the tires are designed to withstand high speeds and produce high scores, much like VR does. Winter tires and all-terrain tires are the two most common tires available on the market. The tire industry divides performance tires into four categories: normal performance, performance, performance, and performance. Tires place less emphasis on the durability of race tires and prioritize increased handling and traction. The case suggests that the tires are designed to withstand high speeds and have higher scores, such as VR tires. Winter tires and all-terrain tires are the two most common tires available on the market. The tire industry divides performance tires into four categories: normal performance, performance, ultra-high performance, and super-performance.

Standard performance tires are designed to balance tread life with increased handling and traction. Among the tires, it is considered the least complicated. The emphasis is on improving performance characteristics through pavement rather than rubber compounds. Tires designed for normal performance will be offered in two distinct styles: winter and all-season. As you move up to Max Performance tires, there is a trade-off between tread life, handling, and grip. As tire technology improves, the tread becomes more advanced, and the rubber compounds become softer. However, this comes at the expense of durability, as these tires wear out faster than their predecessors. According to the user statement, Max Performance tires are characterized by shorter tread life but offer better grip compared to other street-legal tires. This type of tire is used for occasional track events; however, it's not specifically designed as a track tire (Pauwelussen, 2015). Figure 2.9 shows an example of performance tire.

Figure 2.9 Nitto NT05 Max Performance Tire (Pauwelussen, 2015)

2.4.6 Passenger Tire

Passenger tires prioritize various features such as ride quality, comfort, noise reduction, fuel efficiency, and longevity. Tire performance is satisfactory, but they are not as refined as touring or functional tires. High-quality passenger tires are designed to do their job well and minimize any negative impact on the driving experience. Generally, do not require efficient power, so they are often equipped with low-performance tires (Pauwelussen, 2015). Figure 2.10 shows an example of passenger tire.

Figure 2.10 Goodyear Eagle Enforcer Winter Winter 275/55R20 113V Passenger Tire (Pauwelussen, 2015)

2.4.7 All-Terrain Tire

The all-terrain tires are designed to be versatile and suitable for both on- and off-road driving. However, it needs to be specially developed for road use. Trucks are more often built with off-road tires, but they can also be used for passenger vehicles that frequently operate on lower roads. All-terrain tires are perfect for individuals who frequently drive on dirt roads or travel slowly on roads. The tire design is more open, providing excellent grip on rough terrain but they can still perform well forever.

These tires have less impact on snowy roads than winter or regular tires. Compared to other all-terrain winter tires, their effectiveness on snow roads is limited, with more proficiency on snowy streets. Pulling rubber treads are used in all soils. The rubber is generally not designed for good use in the cold temperatures experienced in the winter. The rubber compounds used in this tire are not well suited for chill weather because they are specially formulated to withstand rough path such as sharp rocks, trees. The hard rubber in this tire system is designed to last longer compared to other types of tires. In colder temperatures, the elasticity and traction capacity of this tires are greatly reduced (Pauwelussen, 2015). Figure 2.11 shows an example of all-terrain tire.

Figure 2.11 All-Terrain Tire (Pauwelussen, 2015)

2.4.8 Off-Road Tire

The primary purpose of road tires is to use off-road tires; however, some of them are so versatile that they can be used on the road even at high speeds on highways. Road tires are best suited for areas where paved roads are scarce. All-terrain tires can be used to increase safety and durability while driving, so replacing them would be a good idea if you drive on rough terrain a lot (Pauwelussen, 2015). Figure 2.12 shows an example of off-road tire.

Figure 2.12 Off-Road Tire (Pauwelussen, 2015)

2.5 Tire Type Codes

According to article by (Gent, 2006), 'Pneumatic Tire', a tire code is a standardized system for describing the characteristics of a tire, including size and other relevant information. Figure 2.13 Tire codes begin with letters, indicating official tires. The tire code next to your tire provides four wide, uniform tire sizes. The two most important vehicles to consider for your daily driver are the passenger (P) and the light truck (LT).

Figure 2.13 Pin-point location of Tire Code (Gent, 2006)

2.5.1 Passenger Tire (P)

Passenger tires, which are the most common type of tire used in the automotive industry, are the mostly used in performance tires in a variety of vehicles. All-terrain tires are designed to meet standard driving requirements with excellent performance and safety. Commuter tires, used on more attractive vehicles, to provide a combination of comfort, traction, and fuel efficiency designed to meet the needs of vehicles. Commuter tires aim to drive smoothly and peacefully, handle reliably, and have decent traction in a variety of different terrain and weather conditions. Because of their flexibility and ubiquity, they are the first choice of most car owners who place a premium on the quality of overall driving experience (Gent, 2006).

2.5.2 Light Truck Tire (LT)

Small truck tires are purpose-built to accommodate small trucks. These vehicles include pickups, regular full-size vans, and crossovers. These tires are designed to accommodate the extra weight required by such vehicles and provide the increased power required to accommodate the lightweight truck tires. They have exceptional grip, stability, and off-road ability due to their complex structure and complex tread structure. These characteristics make light weight truck tires suitable for a variety of terrain and driving conditions. Designed to meet the requirements of towing, in addition to providing reliable performance for off-road travel, the lightweight truck tires, especially for these projects, often have reinforced sections to prevent damage to barriers, pits, and other obstacles. This ensures longer tire life and adds protection. Light weight truck tires are the best choice for drivers looking for a combination of durability, trailer towing capacity, and versatility due to their ability to handle the weight and demands of larger vehicles for the purpose of dealing with (Gent, 2006).

2.5.3 Trailer Tire (ST)

Tires are designed to be used in passenger vehicles and are designed very differently than those used on passenger cars. Passenger tires are specifically designed to withstand heavy loads and have an edge to improve traction, unlike passenger car tires that prioritize handling and performance. Compared to passenger car tires, they are used much less frequently, but they excel in their ability to provide controlled travel at low speeds, whether straight or in circles. For transportation, use human tires to ensure safe and efficient delivery of the vehicle products that will suit specific requirements while also preserving the driver's ability to hold and remain stable throughout the journey (Gent, 2006).

2.6 Tire Designation

A tire rating system is a standardized method of classifying and identifying tires based on their specific characteristics and specifications. Tire size, load carrying capacity, speed rating, and other things are important. The tire nomenclature system is a useful tool for various stakeholders, including consumers, tire manufacturers, and automotive engineers, to make informed decisions when selecting tires for specific vehicle types and applications. Tires name is a combination of letters and symbols that refer to tires. Figure 2.14 provides accurate information about Specific information about the tire is provided to the user, including tire width, section, construction, rim diameter, weight, and speed. The tire designation "205/55R16 91V" is identified with specific information related to the tire type. The first number, 205, represents the width of the tire in millimetres. The second number is the tire's aspect ratio of 55, which is the side height of the tire as a percentage of its width. The "R" indicates the tire's radius is forming. Number 16 indicates the rim diameter in inches to which the tire is designed to fit. 91 The weight index indicates the maximum weight of the tire. Finally, the V-speed indicates the tire's maximum acceleration.

Based on (Gent, 2006), the ability to understand tire data is essential to ensuring that the right tires are chosen and that they match the vehicle specifications. The article emphasizes the importance of ensuring safety, performance, and efficiency while driving plants. Tire names are a useful tool for individuals to determine the size and type of tires required for their vehicles. This allows for optimal traction, handling, and overall performance. Tire manufacturers assign tire names according to industry standards and regulations. The use of labels serves the purpose of creating a shared vocabulary and encouraging successful communication between manufacturers, dealers, and customers.

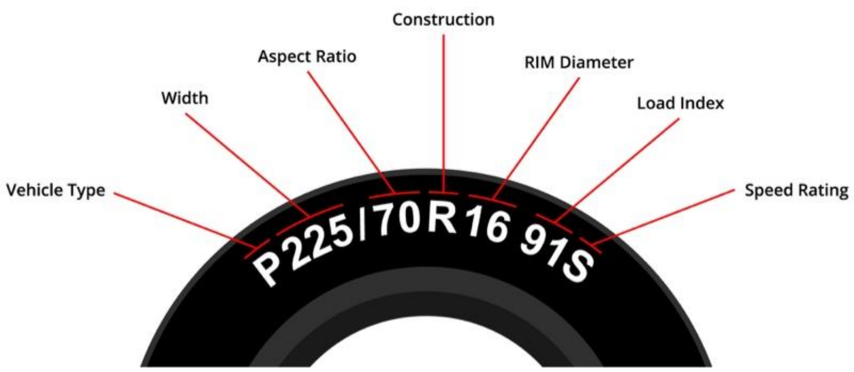

Figure 2.14 Show Tire Designation (Gent, 2006)

2.6.1 Tire Width

In Figure 2.15 the user asks for a method to measure the width of a tire, specifically if it is done in millimetres from one wall to the other, with the tire thickness being three digits, with the first digit indicating the width of the tire. The given example of tire size, P215/65 R15, shows a tire width of 215 millimetres (Gent, 2006).

Figure 2.15 Pin-pointing width (Gent, 2006)

2.6.2 Aspect Ratio

In Figure 2.16 the diameter, width, and height dimensions of the tire are what we mean when we talk about tire wing dimensions, so that's what we'll focus on here. They can be assigned a two-digit number that appears with a slash applied to it. This number depends on the type of user. Tire Size According to P215/65 R15, the number 65 means that the tire height is equal to 65% of the tire width. is the ratio of the two numbers. The tire width and wall height are directly proportional to each other. In practice, the tire height increases to match the tire height (Gent, 2006).

Figure 2.16 Shows Aspect Ratio of a Tire (Gent, 2006)

2.6.3 Construction

The presence of the letter "R" on the size of the tire indicates that the tire is of radial design in Figure 2.17. Steel tubes, arranged perpendicular to the vehicle and extending from one bead to the next, are connected by several layers of fabric to a radial tire. This system allows the tubes to flow radially throughout the tire, from the centre of the tread to its side walls. Radial tires have many advantages over bias-ply tires, including increased tread life, improved traction, and better handling. Radial tires are also durable. Due to the design radius of the tire, it can distribute the forces encountered while driving more efficiently, resulting in a sleek and stable ride in addition to improving the tire's rolling resistance and fuel consumption. Radial tires have established themselves as an industry standard in the tire industry due to their high performance and utility in a wide range of vehicle types and driving conditions (Gent, 2006).

Figure 2.17 Shows Construction of a Tire (Gent, 2006)

2.6.4 Wheel Diameter

(Gent, 2006) have mention that, if the tire size is P215/65 R15, it means that it is intended for use with a wheel size of 15 in. The first value, 215, indicates the width of the tire in millimetres when mounted on a set rim size. The second figure shows 65 sections, showing the wall height as a ratio of tire width. In this case, the wall height equals 65% of the tire width. As just mentioned, the letter "R" on the side of the tire indicates radial construction. Lastly, the number 15 indicates the wheel size in inches that the tire is intended to be mounted on Figure 2.18. As a result, the P215/65 R15 size is intended for tires with 15-inch wheels. It is important to check that wheel size and tire size match each other to ensure proper alignment, smooth operation, and safe driving conditions.

Figure 2.18 Shows Wheel Diameter of a Tire (Gent, 2006)

2.6.5 Load Index

The term "tire weight capacity" refers to the maximum weight that a properly inflated tire can carry without deterioration. These important parameters are usually presented in tire weight specification charts or reports, which describe each tire size's maximum weight in pounds and kilograms. Weight in addition to considering various factors such as tire size, configuration, and functions, the report may also include information on the tire's maximum lateral load, which is obtained by looking at the sidewall of the tire. Knowing tire loads is important to ensure proper performance and prevent overloads, which reduce tire performance, increase the chances of tire failure, and compromise handling function and the application of brakes. In addition, tire weight information can also be included in the report. This allows users to analyse how tire weight affects the vehicle's power and fuel efficiency. Drivers can make informed decisions about tire selection and maintenance when considering tire load and weight. This improves driving ability and increases road safety (Gent, 2006).

2.6.6 Speed Rating

Tire speed refers to the highest speed a tire can achieve when operating under ideal conditions. In this case, the tire's H-speed rating indicates that it is designed to withstand speeds up to 210 kilometres per hour (130 mph), more than two speeds. It is standard practice to ensure adequate safety and reliability. Manufacturers like Goodyear emphasize the importance of driving safely by obeying legal speed limits without exceeding them at any time. The report also includes information on tire speed, which represents typical tire speeds. This is an indicator of the average speed of the tires. This information can help evaluate the performance and durability of a tire under normal driving conditions. Drivers can maintain safe driving habits, prevent tire overheating, and maximize tire life and performance by tracking tire speed records and measuring average tire speed (Gent, 2006).

2.7 Airless Tire

This includes pneumatic tires, also known as pneumatic or non-inflating tires. These tires are an alternative to pneumatic tires that have been in use for many years. The report highlights the advantages of pneumatic tires over conventional tires. While conventional tires rely on air pressure to carry a vehicle’s weight and provide flexibility, conventional tires are specifically designed to eliminate the possibility of tire wear to add profitability in terms of durability, maintenance, and performance. has gained considerable attention and interest in recent years with new materials and designs that have allowed the system to maintain integrity and support without the need for air pressure.

Bridgestone's "airless" or pneumatic tires designed for the passenger car market have generated much interest among motorists. Prototypes of the tires are now in development. However, the prospects for this upgraded tire look promising. Bridgestone’s airless tire technology features a unique spoke system designed to bear the weight of the vehicle in Figure 2.19. This system eliminates the need to fill the tires regularly with air. (Sandberg, 2020) mentioned that the second generation of airless concepts that are not pneumatic tires was unveiled by Bridgestone in 2013. The load-carrying capacity of the tires had increased, and an environmentally friendly design that provided drivability improved efficiency. Further development is also needed prior to the production of airless tires for customers. The report highlights two key challenges that need to be addressed in the development process. The first challenge is avoiding debris lodging in the spokes. The second challenge is to ensure that the load is evenly distributed and spread consistently. According to many observers, there are a variety of reasons why airless tires are still a decade or so away. Continued growth in the automotive industry has called for innovation. As a result, pneumatic tires emerged as a possible solution. Consumers and the auto industry are expected to welcome the development.

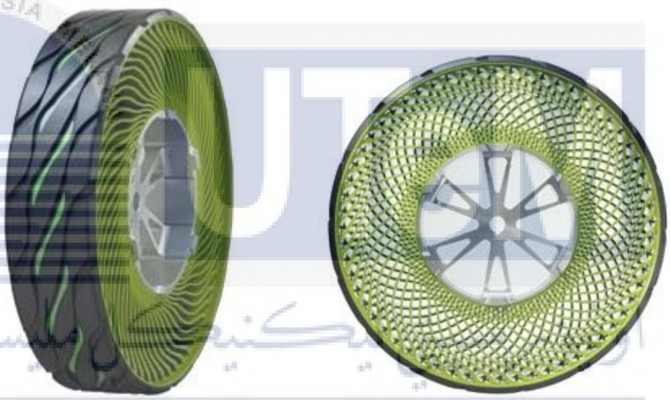

Figure 2.19 Show an Airless Tire (Sandberg, 2020)

2.8 Benefits of Airless Tire

Table 2.3 Benefits of an Airless Tire (Sandberg, 2020)

Benefits	Explanation
Puncture-Proof	The advantages of anti-locking tires become apparent when a flat tire is encountered at an uncomfortable distance. Airless tires are made from special materials, making them more susceptible to punctures and requiring less

	maintenance. Preventing the deflation of these tires will significantly reduce the number of accidents and ultimately save lives. This tire will have improved traction on the road due to its heavier weight and stiffness. It was suggested that improved steering grip could contribute to improved vehicle control.
Enhanced Durability	As the user observed, the anti-lock tires exhibit great durability, indicating long-term durability and cost savings with frequent replacement. According to the user statement, it was suggested that a particular option would save significant time and effort. In September 2017, Toyo Tire & Rubber Company Limited launched airless tires with a 700% increase in efficiency.
Environment-Friendly	The tires under consideration are all made from recyclable materials, which sets them apart from conventional tires. The tires in question are less slippery, reducing carbon emissions. The positive impact on the environment and future generations is staggering.

2.9 Scope of the Airless Tires Market

Table 2.4 Scope of Airless Tire **(Sandberg, 2020)**

REPORT COVERAGE	**DETAILS**
Market Size in 2020	USD 48.6 Million
Growth Rate from 2023 to 2030	5.2%
Revenue Projection by 2030	USD 80.52 Million
Largest Market	North America
Fastest Growing Market	Asia Pacific
Base Year	2022
Forecast Period	2023 to 2030
Companies Mentioned	Trelleborg, Continental AG, Michelin, Toyo Tire Corporation, Hankook Tire & Technology Co. Ltd, Sumitomo Rubber Industries Ltd., The Goodyear Tire & Rubber Company, The Yokohama Rubber Co. Ltd, Bridgestone Corporation, Ameritire Corporation

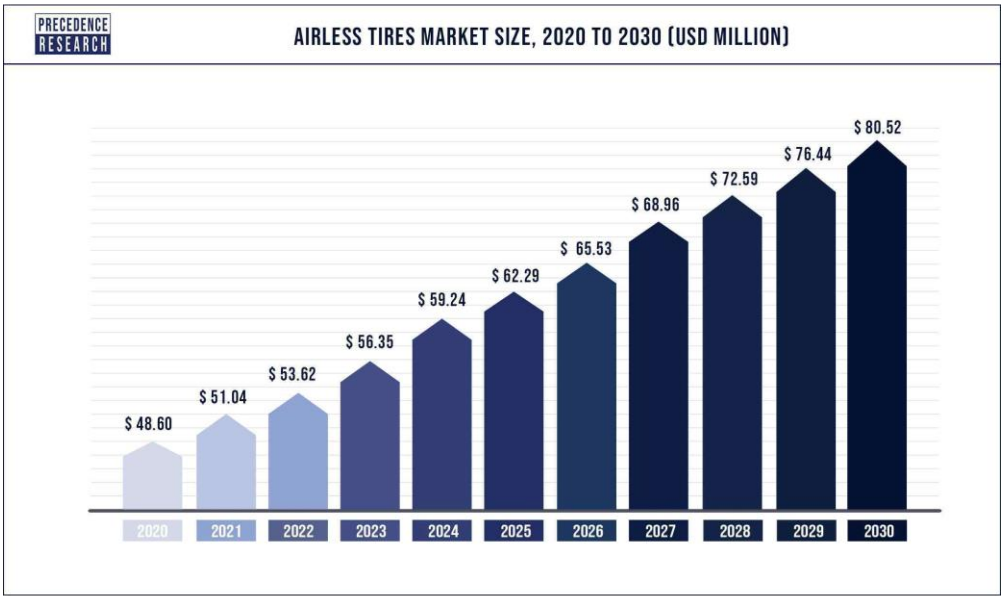

Figure 2.20 Statistic of Airless Tire Market (Sandberg, 2020)

2.10 Airless Tire Product

In 2022, the radial tire segment recorded the highest revenue on a product basis. According to the report, the radial tire has multiple blades from the flower to the tread. According to the (Sandberg, 2020), the seams can be adjusted to have a nearly straight and continuous step centreline between them in addition to placing the belt exactly under the step. According to the user statement, the grid gives the tire strength and shape.

According to the forecast, the bias tire segment is expected to offer the most promising opportunity over the forecast period. The nylon belt in the bias tire can be reported to have formed an angle of 30 to 45 degrees to the tread line. The rubber bundle is the edge connecting the tire. According to the user statement, tire bias offers a few benefits, including improved rideability on uneven terrain and increased sidewall resistance (Sandberg, 2020).

2.11 Airless Tire Material

According to (Deng, Wang, Shen, Gong, & Xiao, 2022) in the 'A comprehensive review on non-pneumatic tyre' research, pneumatic tires can be classified into three categories based on their intended use. These categories are tread compounds, framework materials. The main ingredients in tread are rubber polymers, fillers, and additives. Notes: Matrix's tread compound is made from polymers, with both natural and synthetic rubber as the primary materials. The main properties of pavement composites, such as tensile strength, elongation, tear strength, and elasticity, are determined by rubber polymers. User Statement A filler is a type of reinforcing material that can impart specific rubber properties. A variety of additives are needed to determine tire strength, tire resistance, corrosion, toll resistance, corrosion, etc. Pneumatic tires are made of nylon, steel wire, and other orthopaedic materials to provide the tread with great strength and stability. According to the report, the tires are made from a new polymer, not an inflatable coat.

Direct influence of tire support materials the following report provides a summary of research developments in anaerobic tire materials, with a focus on rubber polymers, fillers, and excipients. Recent research from scientific groups worldwide has attempted to test and improve airless tire systems. The development of a high-performance compound is expected to improve the performance of airless tires (Sandberg, 2020).

2.11.1 Rubber Polymer

The tread compound consists of a rubber polymer matrix comprising more than 50% of the compound. According to the user statement, the rubber polymers determine the basic properties of the tread compound. Rubber can be classified based on its origin and can be either natural or synthetic. Natural rubber is claimed to be a self-reinforcing material exhibiting high mechanical properties and satisfactory strength. The product in question exhibits several drawbacks, including, but not limited to, low viscosity and oil sensitivity. The use of natural rubber as a tread compound often requires processing techniques including epoxidation, vulcanization, carbon sink filling, and the use of other rubber and plastic materials. A substance called synthetic rubber is a polymer exhibiting high strength. Among them, styrene-butadiene synthetic rubber is the most extensive. Due to its remarkable ability to resist damage and shrink in wet environments, this alloy is commonly used in the application step of tires. In Figure 2.21 Styrene-butadiene rubber exhibits high heat generation and hysteretic losses (Deng, Wang, Shen, Gong, & Xiao, 2022).

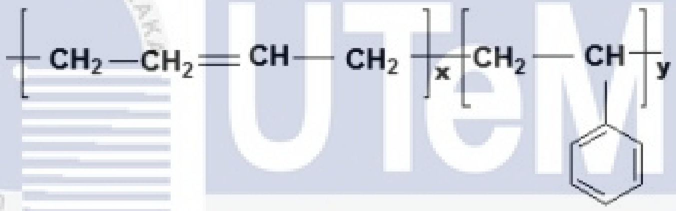

Figure 2.21 Chemical Structure of Styrene-butadiene rubber (SBR) (Deng, Wang, Shen, Gong, & Xiao, 2022)

According to available data, in Figure 2.22 cis polybutadiene is the second largest general synthetic rubber that is commonly utilized. This rubber can provide rubber composites with excellent wear resistance, low-temperature resistance, yield resistance, and impact elasticity; hence, it is a critical rubber matrix. Rubber research has always considered the measurement of mechanical properties of rubber polymers as a crucial aspect. Importance of Testing Rubber-Based Materials under Dynamic Conditions (Deng, Wang, Shen, Gong, & Xiao, 2022).

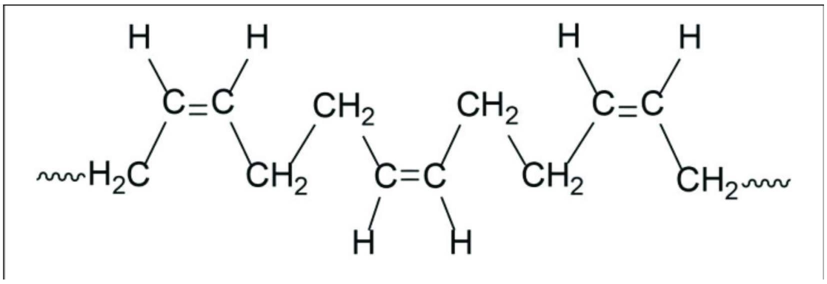

Figure 2.22 Chemical Structure of cis-polybutadiene (Deng, Wang, Shen, Gong, & Xiao, 2022)

2.11.2 Aramid and Aramid pulp

The material aramid in Figure 2.23, or aromatic polyamide, consists of an amide bond directly attached to two aromatic rings and is composed of at least 85% fibrous material. According to the user's statement, aramid is the most suitable material for conventional pneumatic tires. According to the study, aramid pulp is mainly used in anaerobic tires. The report states that aramid compounds are a product commonly obtained from primary aramid fibres through the processing of primary fibres. It is claimed that aramid pulp has unique characteristics inherent in aramid, including, but not limited to, high scale, high strength, good thermal stability, chemical stability, dimensional stability, and hardness (Deng, Wang, Shen, Gong, & Xiao, 2022).

Figure 2.23 Shows Aramid pulp (Deng, Wang, Shen, Gong, & Xiao, 2022)

2.11.3 Carbon Nanotube

The materials in question are carbon nanotubes in Figure 2.24, which are nanomaterials with a crystalline tubular structure. The diameter of these tubes is very small only a few nanometres. There is a hollow triangular arrangement of carbon atoms near the two ends. In recent years, carbon nanotubes have received increasing attention in the field of materials due to their high thermal properties, strength, and electrical conductivity. In addition, they exhibit excellent electrical and thermal conductivity. The production and direct fabrication of carbon nanotubes present significant challenges for anaerobic tires. Easily fabricating composite materials by incorporating carbon nanotubes among other materials has been a focus of research efforts. The cost of using carbon nanotubes as tire reinforcement is extraordinarily high due to their difficulty in manufacturing. The report compares the economic and business aspects of carbon fibres and carbon nanotubes in rubber blends. It says carbon fibres cost less than carbon nanotubes, but their efficiency in rubber compounds is lower than carbon nanotubes (Deng, Wang, Shen, Gong, & Xiao, 2022).

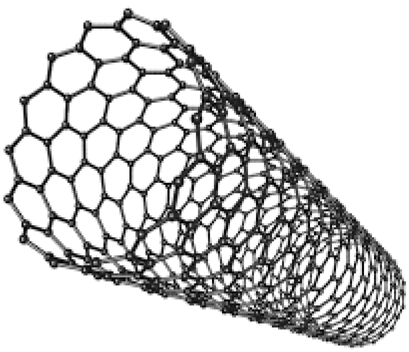

Figure 2.24 Show Carbon nanotube (Deng, Wang, Shen, Gong, & Xiao, 2022)

2.11.4 Two-Dimensional Material

Two-dimensional or purely 2D structures can range in size from a single atom to a very large number of atoms. Graphene in Figure 2.25, boron nitride, molybdenum disulfide shows in Figure 2.26, layered silicates, and layered bimetallic hydroxides are taken as examples of common bimetallic materials that are determined to be highly effective in reducing fabric degradation and shrinkage (Deng, Wang, Shen, Gong, & Xiao, 2022).

From the available data, graphene is could be to be the thinnest of all bimodal materials. The data showed that this material exhibits the highest properties, including thermoelectric conductivity. Graphene is a versatile material used in new power vehicles, electronics, thermal systems, energy storage, and environmental protection.

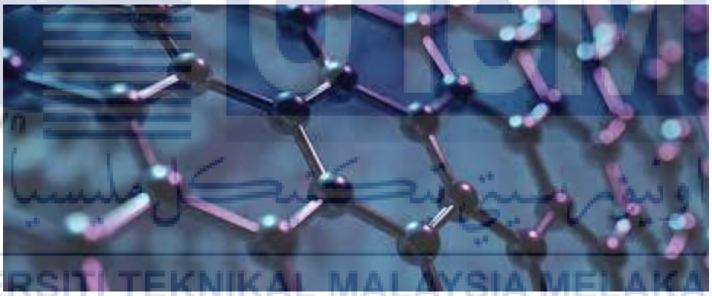

Figure 2.25 Show Chemical Structure of Graphene (Deng, Wang, Shen, Gong, & Xiao, 2022)

The element boron nitride has a double structure that allows boron and nitrogen atoms to form honeycombs. The material in question exhibits exceptional thermal stability and acts as an excellent thermal conductor for rubber materials. Molybdenum disulfide is a two-dimensional material consisting of a central molybdenum atom sandwiched between two sulphur atoms, one on top and one on the bottom. The material in question exhibits an incredibly low coefficient of friction and acts as a tire-strengthening and highly effective -rust treatment (Deng, Wang, Shen, Gong, & Xiao, 2022) .

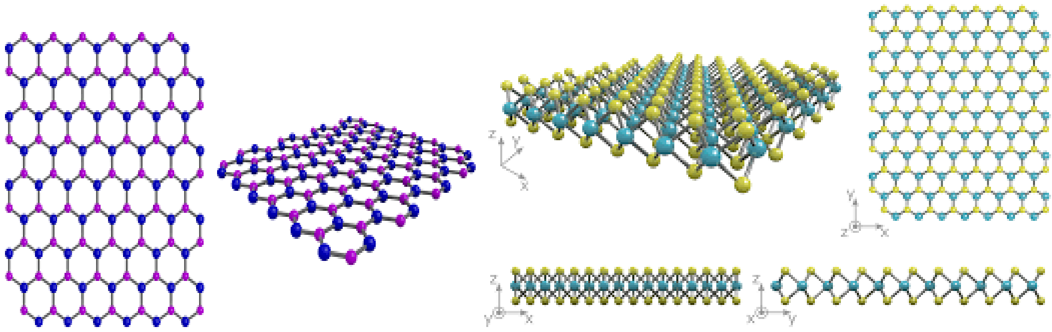

Figure 2.26 Chemical Structure of Boron Nitride and Molybdenum Disulphide (Deng, Wang, Shen, Gong, & Xiao, 2022)

2.12 Polyurethane (PU) Manufacturing

The production of airless tires relies on the production of polyurethane, which is the main raw material. Polyurethane, a polymer that can be used in a variety of environments, such as airless tire spokes, is found. Polyurethane formulation is a user-defined process. This compound is a polyol isocyanate. Extruding or pouring mixtures into molds made specifically for this purpose produces tire components. In addition to curing and solidification processes, polyurethane parts undergo various finishing processes, including trimming and coating with protective coatings. The lightweight, durable, flexible material of polyurethane contributes significantly to air tire strength, performance, and longevity (Abishek & Kumar, 2020). The prepolymer consists of not one but two distinct components, denoted by the term's polyol and diisocyanate. According to some claims, polyesters and polyether are the two main types of polyols, whereas toluene diisocyanate and methylene diphenyl diisocyanate are the two main types of diisocyanatos that undergo an exothermic reaction when polyols are mixed with diisocyanatos. The user reports that the temperature of the prepolymer in its liquid state is approximately sixty degrees Celsius. Polyurethane can be produced by using a solvent, primarily butadiene, in the prepolymer at forty degrees Celsius. After exposure to the environment for approximately four hours at ambient temperature, the polyurethane will become stiffer (Abishek & Kumar, 2020). Figure 2.27 show procedure of PU making.

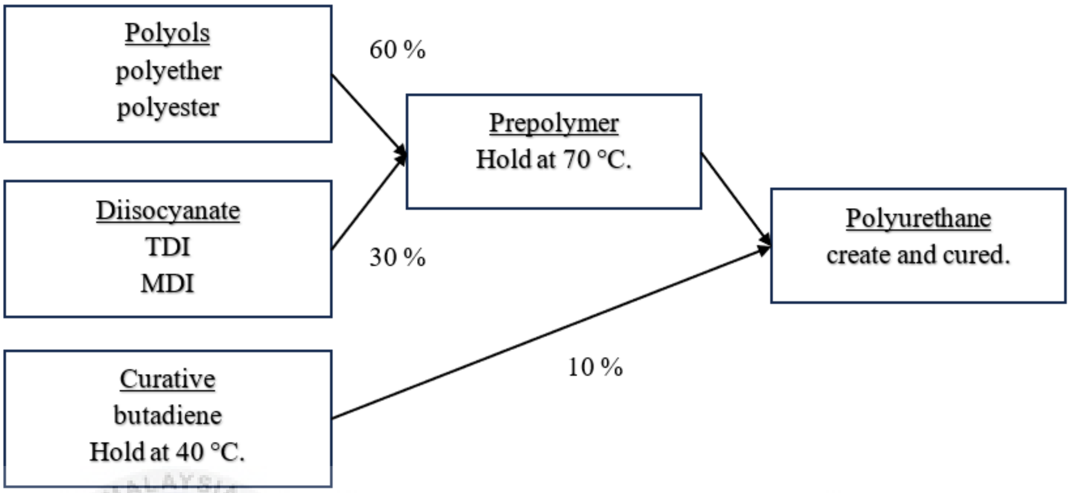

Figure 2.27 PU Block Diagram (Abishek & Kumar, 2020)

2.13 Spoke Structure

The spoke system is an integral part of a pneumatic tire, as it acts as an air-filled alternative to that found in conventional tires. The system distributes weight, absorbs shock, and improves efficiency. Honeycomb, ribbed, lattice, and webbed spoke configurations have been developed. It can be reported that the spoke design has a significant effect on weight distribution, handling, traction, and braking performance. The product in question plays a role in increasing tire longevity and reducing maintenance requirements by preventing deflection and inflation. They offer better reliability and longer durability when compared to pneumatic tires. If the tire industry is shown to be enjoying a more sustainable future thanks to continuous improvements in spoke design, these improvements improve efficiency and versatility, contributing to the sustainable future. According to (Praburam, 2020) in the journal article ‘Static analysis of different spoke structure of airless and conventional tyre', The design and manufacturing related issues of airless tyre are recent areas of the research. Many academicians and industrialist are working on development of new materials and 3D printing methods for airless tyre. The objective of this paper is to conduct finite element analysis of airless tyre with different spoke structures and different 3D printing materials. The spoke structures considered for this study are honeycomb, diamond and triangular.

2.13.1 Tweel

Michelin introduced Tweel in 2005 in Figure 2.28. The main features of tires are tire treads, polyurethane (PU) fibres, shear pads, tread rubber, and that many PU fibres are soft and brittle. It was installed to maintain contact between the tread and the wheel. According to users, spokes undergo elastic deformation when crossing obstacles, allowing them to absorb impact forces and reduce the weight of shock absorbers and suspension. Due to these advantages, scholars have conducted various studies. A study by the Korea Institute of Science and Technology has applied a structural topology optimization method to improve the stiffness of tweel tires (Deng, Wang, Shen, Gong, & Xiao, 2022).

Figure 2.28 Tweel Designed Tire (Deng, Wang, Shen, Gong, & Xiao, 2022)

2.13.2 Gyroblade

Sumitomo Rubber Industries developed the Gyroblade tire in 2015 Figure 2.29. The tire is designed with six arrow-shaped resin spokes placed around the rim for support. The tire is designed in such a way that the weight is efficiently dispersed, ensuring equal distribution. According to the user statement, Gyroblade tires have more lateral stiffness compared to pneumatic tires. This characteristic can reduce tire twist during steering, ultimately improving handling (Deng, Wang, Shen, Gong, & Xiao, 2022).

Figure 2.29 Gyroblade Structure (Deng, Wang, Shen, Gong, & Xiao, 2022)

2.13.3 Mechanically Elastic Tire

Mechanically rigid tires were developed by Zhao. The report describes mechanically elastic tires differently than regular airless tires in Figure 2.30. These tires are manufactured primarily from steel materials and feature flexible tire bodies, hinge units, and suspension hubs. According to the user statement, the hinge unit works to connect the flexible tire body to the suspension hub with pin bolts, and according to an observation made while driving, it was found that if bent under load, it would cause damage to the hinge. This deformation causes vibration, and then a spring at the bottom of the hinge shrinks (Deng, Wang, Shen, Gong, & Xiao, 2022).

Figure 2.30 Mechanically Elastic Tire (Deng, Wang, Shen, Gong, & Xiao, 2022)

2.13.4 Honeycomb

According to ray theory, honeycomb engineers developed efficient flight systems for square honeycombs. These developments are often referred to as the theory of cellular processes. The figure above shows six types of honeycomb fibres considered for NPT. The cellular spoke system uses a regular honeycomb and an auxetic honeycomb with a negative effective Poisson ratio. According to the user, there are two types of honeycomb systems: regular and auxetic. There are three types of regular honey: A, B, and C. On the other hand, auxetic honey is also classified into three types, namely D, E, and F. Among the six studied in Figure 2.31, each is equipped with 20-mm working tires. The resulting power displacement plots were examined to check the hypotheses (Abishek & Kumar, 2020).

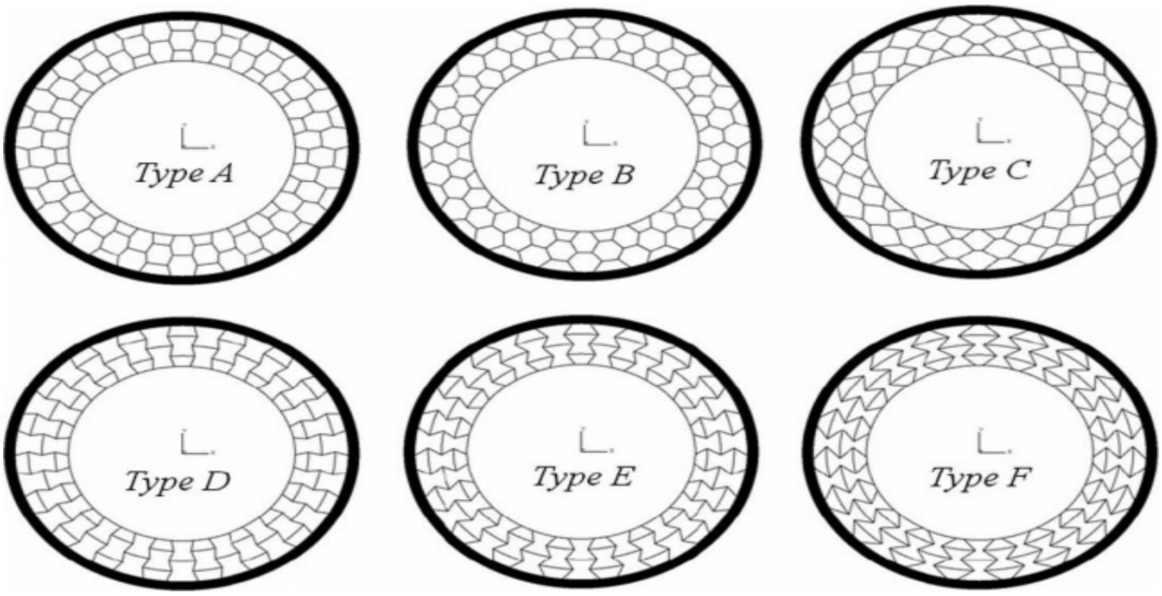

Figure 2.31 Types of Honeycomb Design (Abishek & Kumar, 2020)

2.13.5 Second Generation Air-Free Airless Tire

In 2013, Bridgestone introduced a new line of pneumatic tires in Figure 2.32. According to the user statement, pneumatic tires consist of three components: a rubber tread, thermoplastic resin supporters, and a rigid hub. According to the specifications, the wheel support consists of horizontal lines on the inner and outer surfaces. These lines are arranged at a 45-degree angle relative to the centre of the wheel. According to the source, the tire exhibits excellent renewable performance, ease of rolling, and ensures safety and environmental protection. According to the user statement, it is now indicated that the maximum tire speed is 60 km/h. The technology has been seen in small vehicles like golf carts (Deng, Wang, Shen, Gong, & Xiao, 2022).

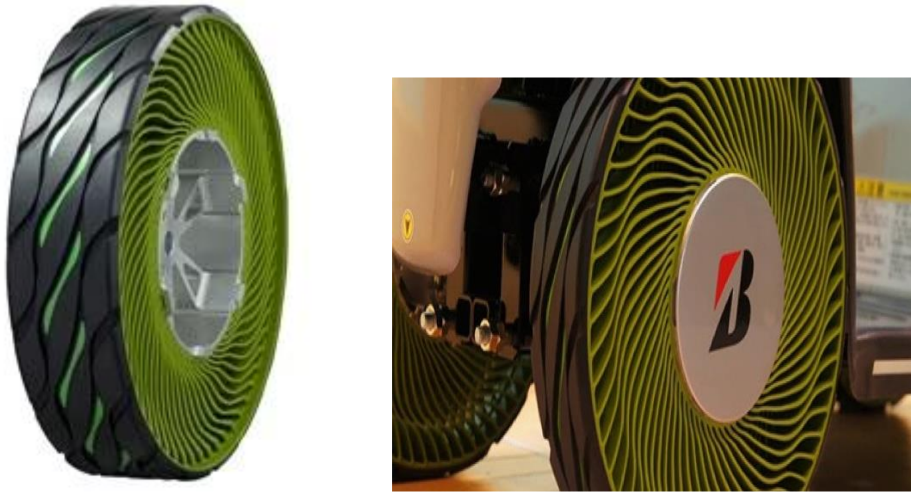

Figure 2.32 Show Bridgestone Second Generation Air-Free Airless Tire and Application in Gold Cart (Deng, Wang, Shen, Gong, & Xiao, 2022)

2.13.6 TurfCommand

Goodyear has officially debuted the airless TurfCommand tire for the Outlaw XP series of lawnmowers in Figure 2.33. The post was attached to the hub using thermoplastic spokes to create a balance of rigidity and flexibility. According to the user statement, the TurfCommand tire is designed to absorb impact through deformation but maintain sufficient bearing capacity (Deng, Wang, Shen, Gong, & Xiao, 2022).

Figure 2.33 Turf Command Airless Tire (Deng, Wang, Shen, Gong, & Xiao, 2022)

2.13.7 Lunar Rover Tire

A joint effort between Goodyear and the National Aeronautics and Space Administration resulted in the development of a forged, pneumatic tire designed specifically for the lunar rover Figure 2.34. As the operator noted, moonplane tires are made of steel. Its body pipes are wrapped in helical steel. protection requirements, durability, excellent grip over rock, and the tire in question exhibits high strength and can adapt to environments with large temperature changes. Two important issues have been identified regarding the technology used in the Lunar Module. The vehicle reportedly suffers from handling problems due to the insufficient lateral stability of the tire, which is due to its radial distribution. This is the first observed problem. The report revealed that the vehicle's inadequate cushioning and vibration damping performance are due to an uneven tire contact point (Deng, Wang, Shen, Gong, & Xiao, 2022).

Figure 2.34 Lunar Rover Tire (Deng, Wang, Shen, Gong, & Xiao, 2022)

2.13.8 I-Fex

Hankook recently released i-Fex Figure 2.35, an airtight tire with a hub and spoke made of PU synthetic material. The sides of the tire are mesh. According to the user's statement, the use of uniformly distributed mini-shock absorbers in the tires was found to be an effective solution to resolve vibration and noise issues. According to the study by (Deng, Wang, Shen, Gong, & Xiao, 2022), the quality of this tire was found to be adequately lower than conventional pneumatic tires.

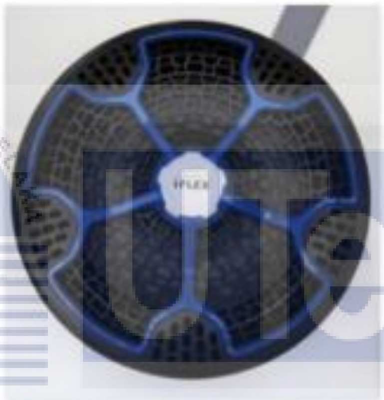

Figure 2.35 i-Fex Tire (Deng, Wang, Shen, Gong, & Xiao, 2022)

2.13.9 Tiltread and Motiv

In 2013, Hankook developed two concept airless tires, the Tiltred and Motiv Figure 2.36. According to the user statement, the tiltred tire is made up of three separate components and is driven by three separate mechanisms. The size of the tires can be adjusted based on the user's input to suit road conditions. According to the user statement, Tiltread could continuously operate at different speeds for each of the three segments, rotating the tire with optimum grip. The motive tread is a PU block with a flexible lumen, allowing free movement and adjustment of different internal landscapes. This arrangement enables the step to achieve optimum efficiency (Deng, Wang, Shen, Gong, & Xiao, 2022).

Figure 2.36 Tiltread and Motiv Tires (Deng, Wang, Shen, Gong, & Xiao, 2022)

2.13.10 Maxpolo

British tire manufacturer Kumho Tyres created the MaxPolo Figure 2.37, a conceptual airless tire. According to the user statement, the tire can self-adjust and adapt to various adverse weather conditions, such as wet and snowy conditions, etc. The product in question is a drainage tube for traveling on wet roads. Depending on what the operator sees, tire pitch and height reduce the chances of snow or ice accumulating (Deng, Wang, Shen, Gong, & Xiao, 2022).

Figure 2.37 Maxpolo Airless Tire (Deng, Wang, Shen, Gong, & Xiao, 2022)

2.13.11 Smasher

Kumho Tire and Ssangyong Motor Company developed the anaerobic tire and produced the Smasher, an anaerobic tire Figure 2.38. Tires must be suitable for use in all severe weather conditions. According to the operator, the tire has traction plates that can help the car navigate bumpy surfaces. The product features swing-like running gear designed to hit uneven ground and help steer vehicles in difficult terrain (Deng, Wang, Shen, Gong, & Xiao, 2022).

Figure 2.38 Smasher Tire (Deng, Wang, Shen, Gong, & Xiao, 2022)

2.13.12 Dandelion

The Korean company Nexen Tire has recently unveiled a new tire called Dandelion Figure 2.39. These tires are unique in that they are not airtight and are uniquely designed like flowers. The tire consists of 72 cylinders that protrude from the ball, giving it a unique look. According to the user statement, each cylinder is reported to have an up and down capacity independent of road conditions. According to the data, the design of the tires allows them to be used on terrain that is hard and uneven (Deng, Wang, Shen, Gong, & Xiao, 2022).

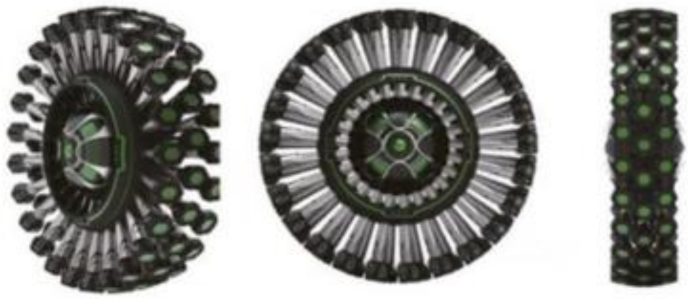

Figure 2.39 Dandelion Tires (Deng, Wang, Shen, Gong, & Xiao, 2022)

2.13.13 ReCharge

The year 2020 saw the release of a new tyre by Goodyear, which was named reCharge in Figure 2.40. The tyre is composed of spokes that are constructed from high-strength fibre materials, and a tread that is made from biomaterials. According to the user's statement, the reCharge tyre appears to be a more durable option compared to traditional non-pneumatic tyres. Furthermore, it has been observed that the tire can experience total deterioration. According to the user's statement, the tyre's tread can be replaced by inserting a distinct capsule into its middle section. According to the user's statement, the capsule is designed to contain a liquid tread formula that can be customized to suit specific needs. This formula is responsible for providing the tread with self-generation properties. According to the user's statement, the reCharge tyre could be modified to suit various weather and road conditions, as well as the driver's individual driving preferences. According to an official announcement, the tyre is currently in the design stage. Despite this, the features have been confirmed (Deng, Wang, Shen, Gong, & Xiao, 2022).

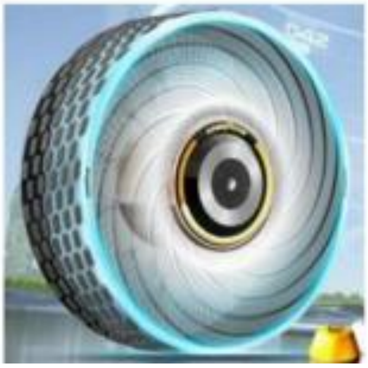

Figure 2.40 reCharge Tire (Deng, Wang, Shen, Gong, & Xiao, 2022)

2.13.14 Comparison of Main Spoke Structure

In the comparison of main spoke structures, several designs are considered, including Tweel, Honeycomb, Lunar Rover, Recharge, and Tiltread. Each structure possesses unique structural features. The Tweel incorporates an annular shear zone, providing high grip and low rolling resistance. It also exhibits low noise levels and excellent shock absorption. On the other hand, the Honeycomb structure features flexible polyurethane spokes arranged in a honeycomb-like pattern. This design ensures uniform mass distribution, large bearing capacity, and effective shock absorption. The Lunar Rover spoke structure utilizes a spiral steel wire mesh arrangement, offering high strength and low noise characteristics. The Recharge structure boasts adjustable tread, allowing it to adapt to various terrains and providing energy conservation and environmental benefits. Lastly, the Tiltread structure comprises three independent parts, offering good adaptability, high grip, and excellent shock absorption (Deng, Wang, Shen, Gong, & Xiao, 2022).

The advantages of these spoke structures further differentiate them. The Tweel provides high grip, low rolling resistance, low noise levels, abrasion resistance, and good shock absorption. The Honeycomb structure exhibits uniform mass distribution, large bearing capacity, good shock absorption, high strength, and low noise levels. The Lunar

Rover structure can adapt to harsh environments, showcasing high strength and resilience. The Recharge structure stands out for its customization options, energy conservation, environmental friendliness, and intelligent features. Lastly, the Tiltread structure offers good adaptability, high grip, and excellent performance on various surfaces. Each spoke structure presents its own set of advantages, catering to specific needs and requirements in different applications in Table 2.5 (Deng, Wang, Shen, Gong, & Xiao, 2022).

Table 2.5 Comparison of Main Spoke Structure (Deng, Wang, Shen, Gong, & Xiao, 2022)

Spoke Type	Structural Feature	Advantages	Disadvantages	Application
Tweel	Annular shear zone, Flexible polyurethane spokes	High grip, Low rolling Resistance, Low noise, Abrasion resistance, Good shock absorption	Unclear fire and bullet proof performance	Lunar rover
Honeycomb	Honeycomb-like spokes	Uniform mass Distribution, Large bearing capacity, Good shock absorption, High strength, Low noise	Easy to insert sundries, Stress concentration	Armored Vehicle
Lunar Rover	Spiral steel wire mesh structure	Can adapt to harsh Environment, High strength	Poor handling stability, Poor vibration damping	Lunar Rover
recharge	Adjustable tread	Can be customized, Energy conservation	Complex structure, High cost	Car

		and environmental protection, intelligence		
Tiltread	Three independent parts	Good adaptability, High grip	Complex structure High cost	Car

2.14 Finite Element Analysis

FEA is a computational technique used in engineering and the sciences to analyse and predict the behaviour of complex systems. It entails decomposing a complex structure or system into smaller, simpler elements known as finite elements and simulating their behaviour under different loading and boundary conditions using mathematical equations. FEA provides engineers with valuable insight into the performance, strength, and safety of various structures and components by numerically solving these equations.

In numerous industries, including aerospace, automotive, civil engineering, and mechanical engineering, FEA has become an indispensable instrument. It permits engineers to simulate and analyse the response of structures and systems to various forces, including mechanical loading, thermal effects, fluid flow, and electromagnetic fields. Engineers can examine stress distribution, deformation, vibration modes, and other factors that affect the performance and dependability of their designs using finite element analysis (FEA) (Zienkiewicz & Taylor, 2005).

(Zienkiewicz & Taylor, 2005) in the journal article titled ‘The finite element method for solid and structural mechanics mentioned that FEA's capacity to optimise designs and reduce the need for costly tangible prototypes is one of its primary advantages. By virtually testing various design iterations and evaluating their performance, engineers can identify problem areas, make design modifications, and improve the efficacy of products or structures.

2.14.1 Application of FEA in Engineering

Finite Element Analysis (FEA) are widely utilized in diverse engineering fields to model and evaluate intricate systems and structures. This report outlines some of the typical uses of the Finite Element Analysis (FEA) in the field of engineering. For an example, a developed the airless and air tyre by considering the rubber as the material and conducted the FEA with static compressive load (Praburam, 2020).

Based on the 'study on key mechanical properties of the flexible spoke non-pneumatic tire considering thermo-mechanical coupling' by (Fu, Liang, Chen, Wang, & Xiao, 2022), ABAQUS software, the material setting, assembly setting, meshing, interaction setting, analysis step setting and load setting of the flexible spoke non-pneumatic tire are carried out, to construct the static mechanic's numerical analysis model and dynamic mechanic's numerical analysis model of the flexible spoke non-pneumatic tire.

2.14.1.1 Structural Analysis

In structural engineering, finite element analysis (FEA) is a crucial instrument for evaluating the performance of structures under various loads. Engineers can predict tension distribution, deformation, and failure modes by dividing structures into smaller, discrete elements. The analysis of stress distribution identifies areas of high stress concentration that can contribute to structural failure. An analysis of deformation predicts how a structure will deform under various loads, ensuring its shape and functionality. FEA also aids in identifying failure modes and contributing factors, allowing engineers to design structures that can withstand extreme conditions. FEA also helps optimize structural designs, explore different scenarios, and evaluate the effects of design changes on performance, providing valuable insights into complex systems and helping engineers make informed decisions. Overall, FEA is essential for designing safe and reliable structures, optimizing designs, and ensuring compliance with industry standards (Chopra, 1995).

For an example, the honeycomb spokes with a high cell angle magnitude experience low local stress, which is satisfactory for the fatigue resistant spoke design (Abishek & Kumar, 2020). The Honeycomb spoke types C and F are good for fatigue resistance. Type C spokes are the best of the honeycomb spokes studied in terms of thickness. All honeycombed NPTs reach the speaker when the section width is 100 mm. Since nonlinear load-bearing behaviour is a function of vertical displacement, the load with a given vertical displacement can be used as a reference value. The effective force-deflection curve shows nonlinear behaviour associated with the combined nonlinear effects of materials and geometry, especially hyper-elastic material behaviour and large deflection and buckling of cell walls that spawn spokes, respectively.

2.14.1.2 Heat Transfer and Thermal Analysis

The report discusses the application of finite element analysis (FEA) in heat transfer studies. The processes studied include conduction, convection, and radiation. It also highlights the application of these techniques in the analysis of systems such as heat exchangers, electronics, and power equipment. The article emphasizes the role of a technology or product in optimizing heat management and ensuring proper heat transfer (Fu, Liang, Chen, Wang, & Xiao, 2022).

Based on an article by (Fu, Liang, Chen, Wang, & Xiao, 2022), in the rolling process of the flexible spoke non-pneumatic tire, the viscoelastic properties of PU material will cause the strain to lag behind HETVAL was used to define the internal heat source.

After the simulation, the steady-state temperature field distribution of the flexible spoke non-pneumatic tire under different operating conditions is obtained and compared with the prototype test results. The distribution law of the steady-state temperature field under different operating conditions.

2.14.1.3 Computational Fluid Dynamics

Fluid dynamics analysis using computational fluid dynamics (CFD) provides detailed flow behaviour simulations and analyses flow behaviour in a wide range of applications. FEA methods provide engineers with very helpful insights into pressure distributions, velocity profiles, and turbulence characteristics. These characteristics help engineers understand the efficiency and performance of engineering tasks. For an example, wind power, hydropower, and heating, ventilation, and air conditioning (HVAC). Engineers are able to gain a deeper understanding of fluid behaviour, enabling more educated design decisions, improving system performance, and even identifying potential fluid-related problems that flow from them (Versteeg & Malalasekara, 2007).

2.14.1.4 Composite Materials

The Analysing composite materials, which are utilised in industries such as aerospace, automotive, and sports, requires the application of FEA techniques, which are necessary for this. They make it possible to conduct an in-depth investigation of the stress distribution as well as the failure modes and deformation properties. Engineers can detect locations with a high concentration of stress, forecast what failure modes will occur, and optimise the design of composite structures to ensure safety and reliability. Additionally, FEA clarifies how materials behave during manufacturing processes, which enables the prediction of residual stresses, distortions, and other process factors. The use of FEA in the analysis of composite materials results in improvements to the product's design, performance, and durability, as well as its conformance to industry requirements (Hyer, 2018).

2.14.1.5 Linear Static Analysis

User-stated linear static analysis is an analytical method that assumes a linear relationship between applied power and output. Its practical application is related to design issues where the stresses involved are in the linear elastic range of the material. Comparatively, it is cheaper to apply a linear static analysis several times before a follow-up non-linear analysis is complete as a preliminary approximation (Praburam, 2020).

According to the user's statement, a nonlinear analysis is a type of analysis that involves a nonlinear relationship between applied forces and displacements. The report highlights that nonlinear effects can arise from various sources, including geometrical nonlinearity (such as large deformations), material nonlinearity (such as elasto-plastic materials), and contact. The observed effects lead to a stiffness matrix that exhibits non-constancy throughout the load application. The statement contrasts the current analysis approach with the linear static analysis method, where the stiffness matrix remains unchanged. It is necessary to utilize an alternative solving approach and corresponding solver for the nonlinear analysis (Karp, 2021).

The utilization of modern analysis software has enabled the acquisition of solutions to nonlinear problems. The validity of these analyses requires a certain level of expertise, and it is possible for them to be inaccurate without proper skill. It is recommended that appropriate model and solution parameters be specified with care. The importance of comprehending the problem, recognizing the significance of the parameters involved, and implementing a well-structured and rational strategy to achieve a favourable outcome. According to the user's statement, the nonlinearity observed in the system can be traced back to various properties such as materials, geometry, nonlinear loading, and constraints (Praburam, 2020).

2.14.2 Type of Finite Element Analysis (FEA) software

ANSYS Computational Software is a widely accepted FEA package that provides advanced features for systems analysis. The software provides a wide selection of tools for engineers to perform linear and nonlinear static analysis, dynamic analysis, and fatigue analysis. ANSYS Mechanical software uses powerful solver technology, provides efficient meshing algorithms, and provides Finite Element Analysis (FEA) for accurate and efficient simulations. ANSYS Mechanical is widely used in a variety of industries, including automotive, aerospace, and civil engineering, due to its versatile capabilities and user-friendly interface (Moaveni, 2019).

Integrated into the SOLIDWORKS CAD platform, SOLIDWORKS Simulation is a user-friendly FEA tool that provides analytical tools for design, temperature, and flow analysis. It simplifies the simulation process and provides valuable insights into optimised products, thereby facilitating iterative product enhancements. SimSolid, a revolutionary FEA software, revolutionises design analysis by employing a meshless, direct modelling approach, accurately analysing large aggregates and nonlinear materials, and providing an intuitive workflow.

The instances are a mere fraction of the numerous FEA software options that engineers have at their disposal presently. It is important to note that each software possesses unique strengths and features that are tailored to meet specific requirements and application areas. The development of FEA software is a crucial factor in the advancement of engineering design and analysis capabilities. It allows engineers to address complex and challenging problems with greater ease (I & N, 2020).

2.15 Previous Research

Throughout the research, a wealth of information and knowledge was gathered from other previous studies to obtain more information on the topic, establish a solid research foundation, compare the findings of previous research with the findings of this work, and validate the work can be compared to identify similarities, differences, and areas for further research. References:

2.15.1 Influence of Non-Pneumatic Tire Structure on its Operational Properties

Non-pneumatic tires (NPTs) are a new type of safety tire designed to be as durable as pneumatic tires. The absence of compressed air to provide adequate traction and directionality is the main advantage of NPT. Proper products and it is supported by the geometry, which provides the characteristics of pneumatic tires. Simple spokes and closed honeycomb structures are the most common types of permanent structures. NPT properties—radial stiffness, unit pressure in the contact band, and parameters of the area of contact of the undeformed surface—influence the geometry, thickness, and material of the component. The paper uses the FEM NPT model (NPT_0), which was confirmed using experimental NPT analysis results. The NPT_0 model with additional variables (structure and geometry of the radial spokes) was used for the analysis. Seven new systems supporting system geometry were selected for simulation testing. Numerical experiments determined the parameters of the radial stiffness, the unit pressure in the contact strip, and the region in contact with the hard surface and found that the radial stiffness decreased and the contact path lengthened with increasing spoke curvature (Hryciów, Jackowski, & Żmuda, 2020).

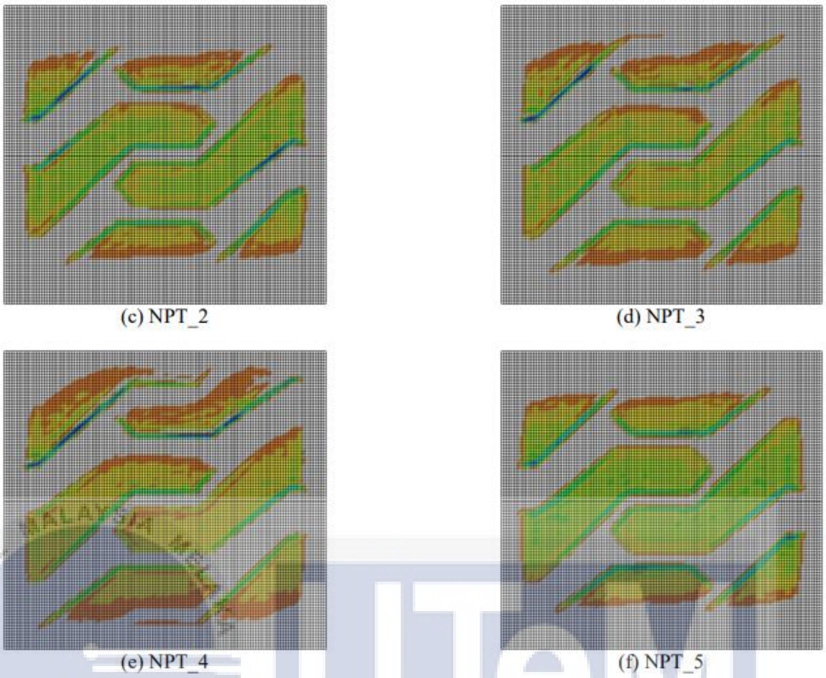

Figure 2.41 Unit pressure distribution in the contact patch of the NPT models on a non-deformable surface (Hryciów, Jackowski, & Żmuda, 2020)

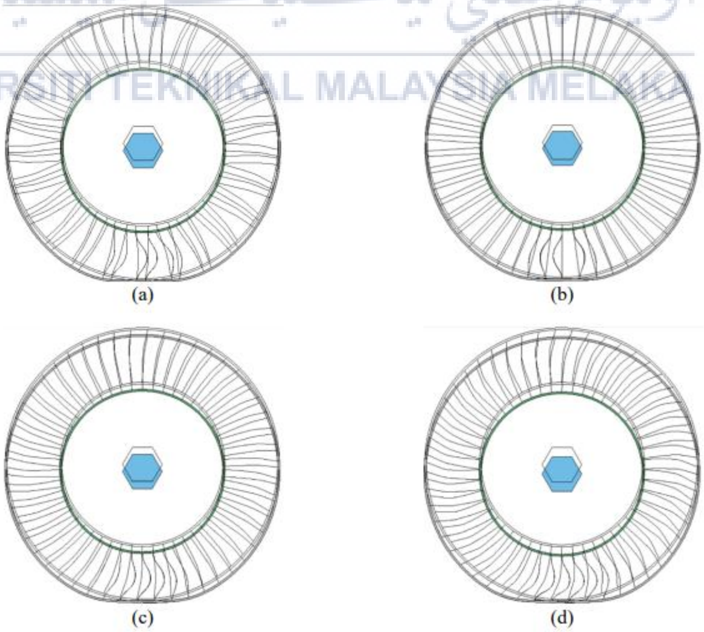

Figure 2.42 Spoke deformation under a 20 kN normal force: (a) NPT_0, (b) NPT_1, (c) NPT_2, (d) NPT_3 (Hryciów, Jackowski, & Żmuda, 2020)

2.15.2 A comprehensive review on non-pneumatic tire research

Conventional pneumatic tires have safety concerns that deflated tires can eliminate. Thus, it is supposed to make driving much safer. Therefore, this technology has received much attention in the last few years. This paper discusses the status and changing nature of pneumatic tire research. First, the basic concept of airless tires is introduced, and the manufacturing process is explained in detail. Then, the progress of the research on the physical properties of deflated tire parts is summarized. The results of the investigations on the mechanical properties of anaerobic tires are summarized in terms of vertical mechanics, curved mechanics, peripheral mechanics, soil, vibration, and fatigue properties, and the advantages and disadvantages of wheels on the airless surface have been observed. Three common tire manufacturing processes are described, and their efficacy studied. Intelligent materials and systems can be used to make airless tires lighter, more practical, and smarter. The final section of this paper discusses the technical issues to be addressed in the study of airless tires and the expected growth trends (Deng, Wang, Shen, Gong, & Xiao, 2022).

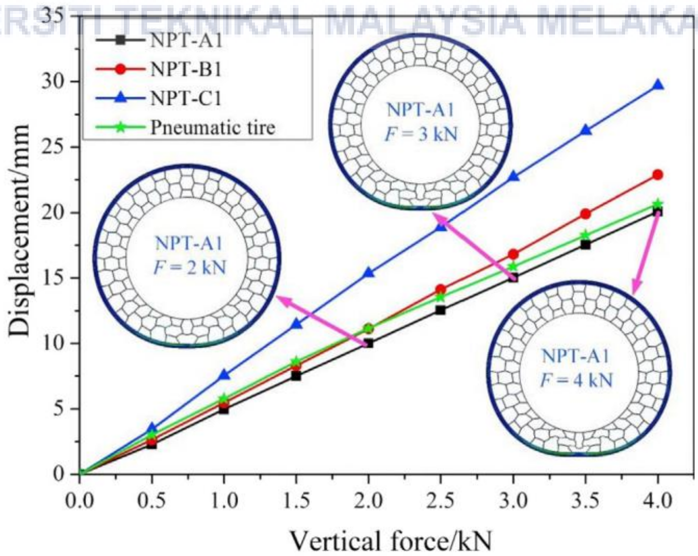

Figure 2.43 Rolling resistance of non-pneumatic tyres under different vertical forces (Deng, Wang, Shen, Gong, & Xiao, 2022)

2.15.3 Effect of spoke design and material nonlinearity on non-pneumatic tire stiffness and durability performance.

Traditional non-pneumatic tyres are popular due to their advantages of no run-flat, no need for air maintenance, minimal rolling resistance, and enhanced passenger comfort due to their superior shock absorption. It has various applications in military vehicles, earthmovers, lunar rovers, and stair-climbing vehicles, among others. Recently, non-pneumatic UPTIS (Unique Puncture-Proof Tyre System) tyres for passenger vehicles were introduced. This study compares three distinct design configurations: tweel, honeycomb, and the newly developed UPTIS. Applying five distinct nonlinear polyurethane (PU) material properties to the spokes has also demonstrated the nonlinearity of PU materials. Using ANSYS 16.0's three-dimensional FEM simulations, a combined analysis of the nonlinearity of the PU material and spoke design configuration on the overall tyre stiffness and spoke damage prediction is conducted. It has been observed that the Mooney-Rilin 5-parameter model best captures the nonlinearity of all five studied PU materials. The effect of material nonlinearity on different spoke designs has been investigated. In terms of cycling comfort, tyre stiffness, and tyre longevity, the optimal combination of spoke design and the use of nonlinear materials has been suggested (Dhrangdhariya, Maiti, & Rai, 2021).

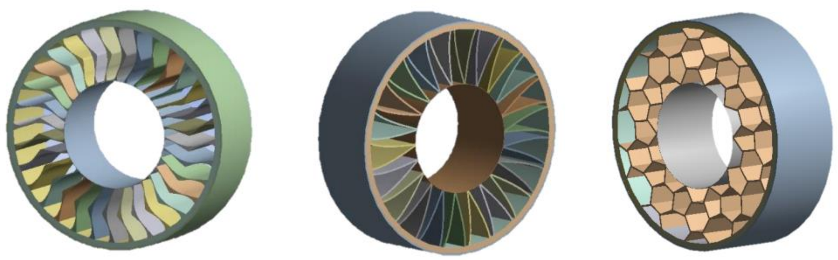

Figure 2.44 CAD model of UPTIS, Tweel, and Honeycomb (Dhrangdhariya, Maiti, & Rai, 2021)

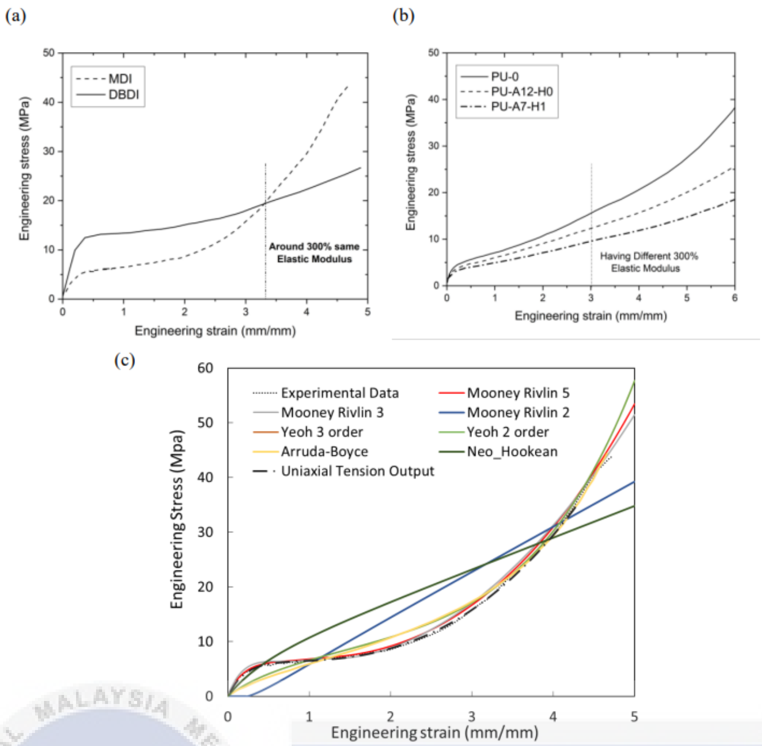

Figure 2.45 Show (a,b) 5 different nonlinear PU material property stress strain Curve (c) MDI Curve fitting (Dhrangdhariya, Maiti, & Rai, 2021)

2.15.4 Design and analysis of non-pneumatic tire

A non-pneumatic tyre (NPT) is a type of tyre that does not use air pressure to sustain the load. Even though solid rubber tyres exist, they lack sufficient compliance and will not provide a comfortable ride on standard vehicles. The NPT discussed here is primarily composed of three sections. A rigid core, flexible spokes capable of supporting vertical loads, rubberized shear band reinforcement, and tread that contacts the surface. By altering the dimensions or materials used to manufacture NPT, its properties, such as contact pressure, rolling resistance, and load carrying capacity, can be modified. Multiple studies are being conducted around the world to make NPT a viable alternative to conventional pneumatic tyres. This paper provides a comprehensive summary of the research conducted to develop and enhance NPT (Mohan, 2017).

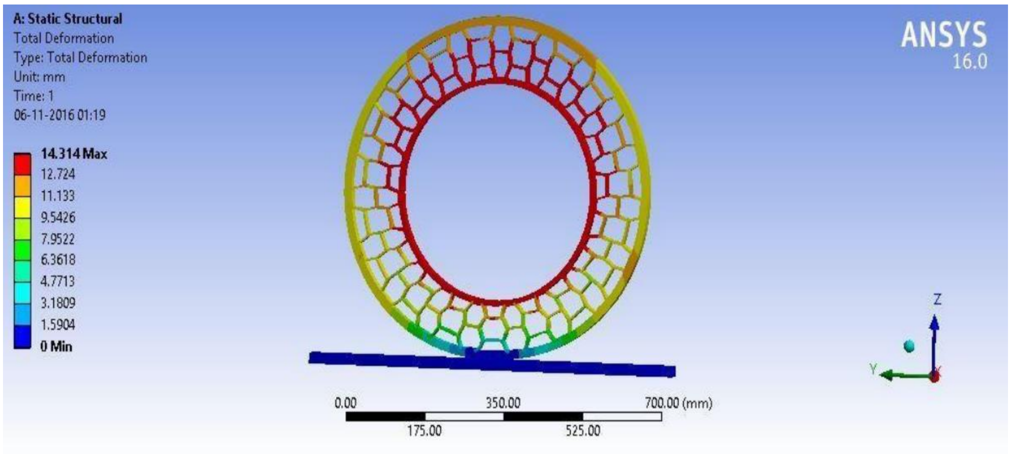

Figure 2.46 Shows Ansys test of deformation (Mohan, 2017)

2.16 Summary

This report provides a comprehensive literature review of various aspects of the topic of interest. The study includes an introduction, common tires, tire manufacturers, tire types, tire type rules, tire definition, advantages of airless tires, airless tire market, airless tire commodity, vehicle type, regional airless tire applications, and structural analysis.

a. It starts with an introduction and discusses conventional tire types.

b. Differentiate tire construction types, such as bias-ply and radial tires, are explained along with their advantages and disadvantages.

c. The review explores different types of tires, including all-season, summer, winter, touring, performance, passenger, all-terrain, and off-road tires.

d. Various airless tire products and materials used, such as rubber polymers, aramid, aramid pulp, carbon nanotubes, and two-dimensional materials, are discussed.

e. The spoke structure of tires is explored, including specific examples like Tweel, Gyroblade, mechanically elastic tires, honeycomb structures, and second-generation air-free airless tires.

CHAPTER 3

METHODOLOGY

3.1 Introduction

In the methodology section of the project, "Design and Analysis of Different Design Spoke Structures of Airless Tires and Conventional Tires" outlines the methods and techniques for achieving the objectives of the project. This section explains how the research process was developed and how the study was conducted.

3.2 Overall Process

Entitled "Design and Analysis of Different Design Spoke Structures for Airless Tire and Conventional Tires," the work follows a structured approach that includes a literature review, CAD modelling, FEM simulations, and possible experimental verification. Based on this information, detailed CAD models of various spoke structures are developed considering factors such as size, shape, and material properties, and subsequently, the design performance of the developed spoke structure is analysed through FEA simulations. The results are compared and evaluated using parameters such as load bearing, stress distribution, and structural capacity. The project seeks to contribute to the advancement of tire technology and improve the performance and safety of airless and conventional tires through improved tire remanufacturing.

3.3 Project Process (Gantt Chart)

NO	TASK	WEEK														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Identify problem statement															
2	Identify objectives of project															
3	Identify scopes of project															
4	Conduct research for Literature Review															
5	Develop process flow chart															
6	Determine spoke structure for airless tire															
7	Determine dimension for the tires															
8	Determine material selection for the tire															
9	Design model using Solidworks															
10	Analyse model using SimSolid															
11	Compare results of different spoke structure with conventional tire															

Table 3.1 Shows Gantt Chart

3.4 Flow Chart

Charts and diagrams were required during the entire course of the project. Clarification is required regarding the planning of the flowchart, and it is recommended that a flowchart be provided to illustrate the process. According to the user's statement, the diverse behaviours of the flow diagram are directly related to each stage of the diagram. The depiction of the sequences and linkages of the stages is presented using rows and arrows.

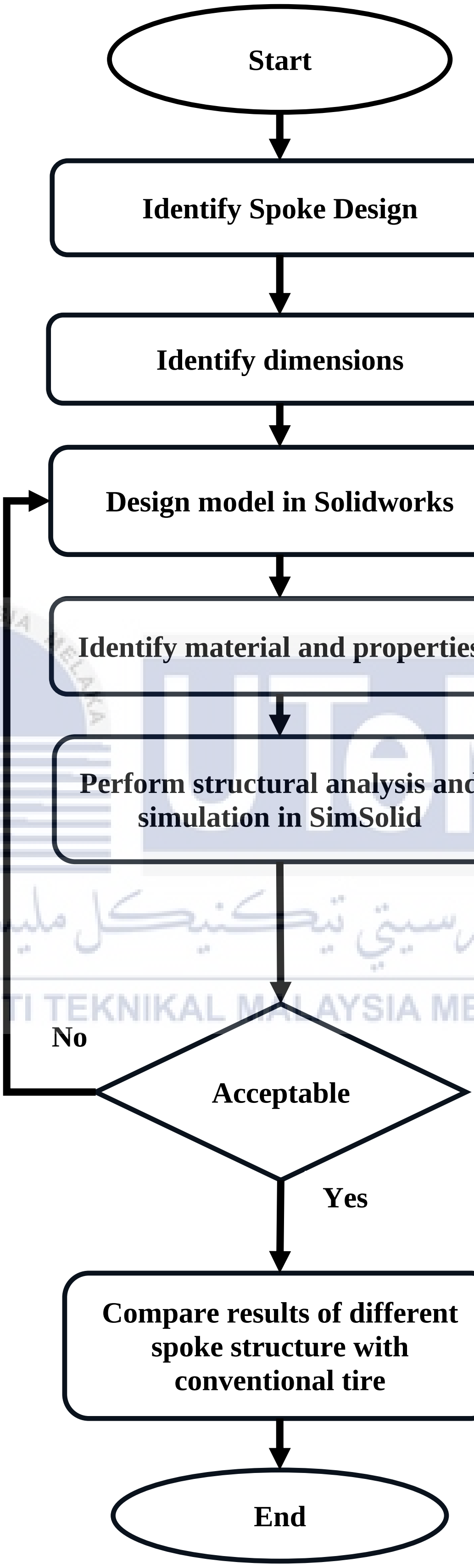

Figure 3.1 Flowchart for the project

3.5 Dimension

Dimension is essential in the design process because it provides a detailed and accurate representation of the final design. By incorporating measurements into the layout, it provides a demonstration of the shape, length, and proportionality of the various components, ensuring that the final product meets all of the necessary requirements and fulfils all of its intended functions.

3.5.1 Main Hub with Rim

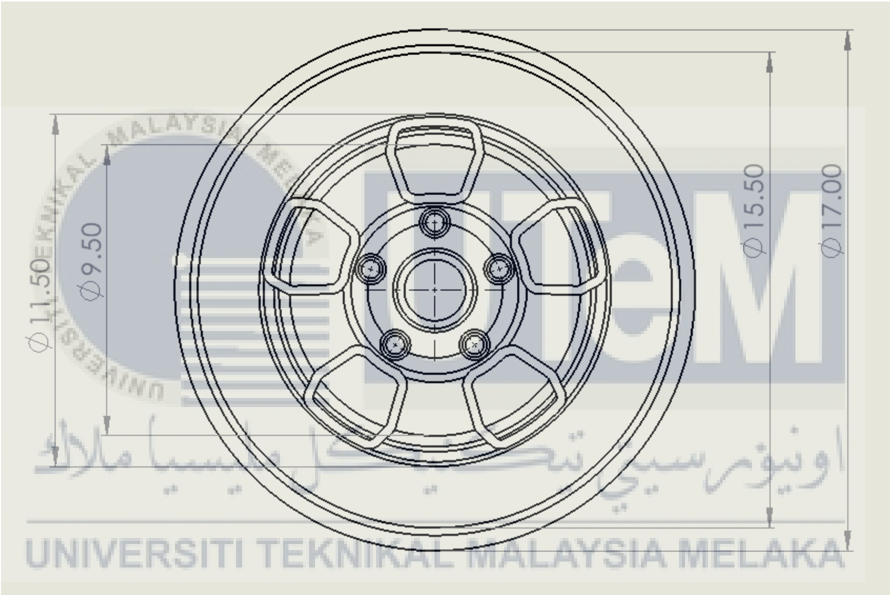

Figure 3.2 Shows the dimension of the Main Hub with Rim

The CAD model titled "Main Hub with Rim" created with SOLIDWORKS software is an integral part of this project, as it functions as the basis for both the airless tire spoke designs and the conventional tire. The dimensions of this model are essential for compatibility, fitment, and overall performance. The outer dimension of the tire is 17 inches, which defines its overall measurement and determines its compatibility with the rim. The inner diameter of the tire is 15.50 inches, which corresponds to the circular opening through which the tire attaches to the rim, ensuring a secure and proper fit. The outer diameter of the hub is 11.50 inches, which indicates the measurement of the central portion that connects the hub to the axle. The inner diameter of the hub is 9.50 inches, allowing for a precise alignment on the axle and preserving stability. By precisely defining these dimensions, the Main Hub with Rim model lays the groundwork for designing and analysing various spoke structures for airless tires and conventional tires, allowing exhaustive exploration and evaluation of the impact of various design configurations on overall tire performance.

Table 3.2 Shows dimension of Tire and Hub

	Tire	Hub
Inner Diameter (inch)	15.5 inches	9.50 inches
Outer Diameter (inch)	17 inches	11.5 inches

3.6 Design

Using SolidWorks software, design plays a crucial role in the creation of two airless tires and one conventional tire. The design process includes the creation of comprehensive tire models and configurations, with a particular emphasis on the spoke structures. Two distinct spoke designs are considered for airless tires: the tweel (triangular) structure and the honeycomb structure. The triangular spoke arrangement of the Tweel design provides tire strength and stability while minimizing tire weight. The honeycomb structure, on the other hand, employs a hexagonal pattern and offers a balance between strength, flexibility, and weight distribution. Both designs seek to address the shortcomings of conventional tires, such as their susceptibility to punctures and need for routine maintenance. Consideration is also given to the conventional tire design, which includes traditional spoke patterns for comparison and reference. The objective of the design process is to optimize spoke structures for enhanced performance, durability, and overall efficiency, taking into consideration load-bearing capacity, stress distribution, and manufacturing feasibility. Utilizing SolidWorks software enables precise modelling, analysis, and visualization during the design phase, allowing for iterative refinements and the development of innovative tire designs that improve safety and performance.

3.6.1 Main Hub with Rim

In SolidWorks, the design process begins with the creation of the "Main Hub with Rim" model. After drawing a 6-inch circle, the "Boss Extrude" command is used to extrude it, thereby creating the bolt circle feature. The "Circular Pattern" command is then applied to the bolt section to generate six evenly spaced openings. Other commands, such as "Cut Revolve" and "Fillet," are used to refine the model further by adding the necessary cuts and fillets for the desired features. To produce symmetrical components, the "Mirror" command is used.

In the second phase, the rim's flange is created using commands such as "Cut Extrude" to create precise cuttings or profiles, "Shell" to create thickness or hollow sections, and "Chamfer" to add bevelled edges. These commands assist in conforming the rim to the design specifications. Utilising the "Boss Extrude" command, the initial profile of the rim is created. The "Circular Pattern" command is then applied to the selected extruded boss element. Five instances of the circular pattern are evenly spaced at 360 degrees. This enables the replication of the extruded boss component around the rim, assuring uniformity and preserving the intended design.

Lastly, the outer dimension (17 inches) and inner diameter (15.50 inches) of the tyre are taken into account to ensure a suitable fit between the rim and tyre. To establish the precise dimensions for the hub's attachment to the axle, the outer diameter of the hub (11.50 inches) and the inner diameter of the hub (9.50 inches) are specified.

3.6.2 Tweel (Triangular)

The SolidWorks model of the Tweel demonstrates the complex design process required to create the delicate spoke of the Tweel. To begin, a central axis is sketched, serving as a pivotal point of reference for the subsequent design components. The spoke design is meticulously completed, beginning with the meticulous selection of the inner portion of the flange. The drawing is subsequently converted into a three-dimensional form by employing the "Boss Extrude" function, according to the given measurements and guaranteeing precise alignment with the defined centerline. The tweel structure is formed utilizing the "Circular Sketch Pattern" command, which is essential for attaining the tweel-like configuration of the spokes. The utilization of this circular sketch pattern is highly advantageous in attaining the complex intricacies of the Tweel structure.

In the second step of the design process, an extruded body is generated to establish a solid and secure foundation for the Tweel structure. The manufacturing of this solid component is a crucial step in the whole production process of the Tweel. Upon the successful creation of the solid component, the tweel spoke is connected to the main hub and outer ring using the assembly feature in SolidWorks. This assembly feature ensures the seamless integration of the individual components, ultimately resulting in the completion of the Tweel tire.

The specifications of the tweel structure are precisely defined throughout the design process. Initially, a central line is constructed. Next, two circles are created with sizes of 15.55 inches and 11.50 inches, respectively. This thorough assessment ensures the precise positioning of the tweel spoke component with the outer ring throughout the assembly process. Two lines are extended from the centreline, each with specific specifications. The first line is 1.14 inches in length and forms an angle of 18.05 degrees. The length of the second line is 1.22 inches, and it has an angle of 27.07 degrees. Consequently, these lines are connected at the bottom to create the unique triangular shape that characterizes the tweel. To ensure consistency and keep the ideal design of the tweel, it is essential to establish a pattern of 80 occurrences uniformly spaced at 360 degrees. The rigorous SolidWorks design process produces a flawlessly engineered Tweel model, including a unique triangular spoke pattern that enhances the tire's durability, stability, and optimal weight distribution without the need for traditional air-filled chambers.

3.6.3 Honeycomb

Prior to beginning the sketch, designate the internal section of the flange in the model. Utilize the accompanying illustration as a reference to replicate the honeycomb arrangement. Utilize the circular pattern command to duplicate the design and guarantee that the honeycomb pattern permeates the entire model, thus finalizing the honeycomb structure. Using the mirroring command to achieve symmetry in the honeycomb construction.

Next, generate an extruded body in order to form the solid surface of the honeycomb structure. This extrusion adds depth to the structure and creates a three-dimensional picture. Next, utilize the cut-extrude function to eliminate material and generate holes that align with the honeycomb design specified. The presence of these perforations enhances the lightweight and porous characteristics of the honeycomb construction.

The honeycomb structure was built based on many parameters. It has a hexagonal form. The disparity in length between the horizontal lines at the top and bottom of the hexagon is 0.65 inches and 0.64 inches, respectively. Four lines were slanted at an angle, each measuring 0.42 inches in length. A second hexagon is constructed on the base, and its midpoints are joined to the horizontal lines of the top and bottom. The measurements of these lines are 0.60 units in length. The length of the two slanted lines at the top of the hexagon below is 0.41 inches, while the length of the lines below is 0.42 inches.

In order to fully construct the honeycomb structure, it is necessary to include an extra geometric shape known as the trapezium. The trapezium is positioned between the two parallel horizontal hexagonal lines. The spacing between these lines is 0.41 inches, while the length of both sides of the trapezoid's slanted lines is 0.36 inches. The chosen structures are subsequently arranged in a circular configuration to finalize the honeycomb construction. This arrangement ensures the consistent duplication of honeycomb cells across the whole structure.

Next, an extruded body is created to form a solid surface for the honeycomb structure. The fabrication of this solid component is an essential stage in the overall assembly of the honeycomb. After successfully creating the solid element, the honeycomb spoke is joined with the primary hub and outer ring using the assembly function in SolidWorks. The incorporation of this assembly characteristic guarantees the smooth amalgamation of the separate constituents, finally culminating in the finalization of the Honeycomb tire.

3.6.4 Conventional Tire

Conventional tire design work mainly emphasizes the core and rim of the tire while excluding the outer section of the tire as it is not required for this design. This is done because this design does not require the outer section of the tire. The aim of this work is to produce an accurate and correct model of a typical tire. Important additions to the model include a round bolt rim with five bolt holes. The first step is to draw a 17-inch circle, which is equivalent to measuring an airtight tire. The design of the tire points to this circular element as the focal point.

Using the "Extrude" command, the circle is then extended to a height of 5 inches. This extruded shape forms the primary body of the conventional tyre and provides the foundation for subsequent design modifications. To improve the aesthetics of the tyre and ensure a seamless transition, the "Fillet" command is executed. This command creates an aesthetically pleasing design by rounding off the tyre's sidewalls. In addition, the "Shell" command is used to construct the inner portion of the tyre, which adds the desired thickness and reinforces the tyre's structural integrity.

Designing the tread pattern on the tyre's outer surface is the next crucial phase. The tread pattern is meticulously drawn and applied to the surface of the tyre. This procedure involves selecting the outer surface and employing commands such as "Extrude," "Mirror," "Fillet," and "Circular Pattern" to replicate the desired tread pattern. Once the individual components of the conventional tyre model have been finalised, including the primary hub with rim and the tread pattern, they are integrated using the SolidWorks assembly feature. This assembly ensures that the components are properly aligned and positioned, resulting in a realistic and comprehensive representation of the conventional tyre.

Using SolidWorks software effectively, the design process for the conventional tyre involves creating the primary hub and rim, incorporating the necessary components, and refining the design to produce an accurate and functional model. Contributing to the advancement of tyre design and engineering practises, the resulting model functions as an asset for subsequent analysis and evaluation.

3.7 Material

The production of non-pneumatic tyres involves three primary steps: tread and shear band fabrication, hub fabrication, and polyurethane spoke assembly. In the first stage, the tread is produced using a method comparable to that of conventional pneumatic tyres. Belts are created by rolling rectangular sheets of rubber and steel fibre onto a steel drum to form layers. After removing the excess material, the desired base thickness is attained. The extruded tread is then rolled onto the assembly's top, and the entire assembly is vulcanised.

The second stage involves the production of the hub, which may be a 4-kg steel or aluminium alloy casting. Pouring molten metal into a mould and allowing it to cool results in the production of the hub component. In the third stage, the hub and tread are assembled in a concentric arrangement. Filling a spoke and shear band mould with polyurethane while the assembly rotates ensures appropriate filling in the radial direction. Before the filling procedure, all surfaces in contact with the polyurethane are cleansed and treated with adhesives or mould release agents. The polyurethane pre-polymers and the curing agent are stored separately until they are heated together during the manufacturing process. After the polyurethane has been injected and the assembly has stopped rotating, the entire tyre is deposited in an oven at 100 °C for four hours for final curing. This procedure guarantees that the desirable polyurethane properties are achieved and that all components are firmly joined (Abishek & Kumar, 2020).

Table 3.3 Shows materials used for (Abishek & Kumar, 2020)

Materials	Parts in Airless tire
Rubber	Used as tire tread material. Rectangular sheets are rolled onto a steel cylinder and vulcanized to achieve the desired base thickness.
Steel	Used for the hub casting; approximately 4 kg in weight. As molten metal is poured into a mold, it solidifies to form the centre component. The hub can also be made from an aluminium alloy casting.
Polyurethane	Used for the spokes of the tire. It is filled into a spoke and shear band mold and allowed to cure, ensuring it sufficiently fills the mold in the radial direction. Polyurethane pre-polymers and curative are heated and combined before filling.

3.7.1 Hub

The hub is made from AL 7075-T6, which is a high-strength aluminium alloy. It has a high Young's Modulus, indicating its stiffness and resistance to deformation. The

Poisson's Ratio indicates how the material responds to lateral strains when subjected to axial loads. The yield strength represents the point at which the material begins to deform plastically (Abishek & Kumar, 2020).

3.7.2 Spoke

The spokes are made from polyurethane, which is a flexible and resilient material. It has a relatively low Young's Modulus, indicating its ability to deform under applied loads. The Poisson's Ratio suggests that it exhibits higher lateral strain when subjected to axial loads. The yield strength represents the point at which the material starts to deform permanently (Abishek & Kumar, 2020).

3.7.3 Outer Ring

The outer ring is made from AISI 4340, which is a high-strength, low-alloy steel. It has a high Young's Modulus, indicating its stiffness and resistance to deformation. The Poisson's Ratio suggests a lower lateral strain under axial loads compared to the spoke material. The yield strength represents the point at which the material begins to deform plastically (Abishek & Kumar, 2020).

3.7.4 Thread

The tread is made from rubber, which is a flexible and elastic material. It has a relatively low Young's Modulus, indicating its ability to deform under applied loads. The Poisson's Ratio suggests a higher lateral strain when subjected to axial loads. The yield strength represents the point at which the material starts to deform permanently (Abishek & Kumar, 2020).

3.7.5 Summary of Materials Properties

The material properties that needed to carry out the analysis parts.

Table 3.4 Show the Material Properties (Abishek & Kumar, 2020)

Part	**Hub**	**Spoke**	**Outer Ring**	**Thread**
Material	AL 7075-T6	Polyurethane	AISI 4340	Rubber
Density (P)	2800	1200	7800	1043
Young Modulas E, (MPa)	72000	32	210000	11.9
Poison Ratio,	0.33	0.49	0.29	0.49
Yield Strength (MPa)	500	140	470	16

3.8 Analysis

Using SimSolid, a powerful FEA software, to perform a non-linear analysis on the 2 airless tires and 1 conventional tire. The non-linear analysis involves three key components: geometric analysis, numerical analysis, and contact analysis.

Geometric analysis is an essential aspect of the non-linear analysis, where SimSolid considers the large deformations and material nonlinearity of the tire models. It accurately captures the complex geometrical changes that occur during the analysis, ensuring a realistic representation of the tire's behaviour under various loading conditions. Based on (Mohan, 2017), the movement of NPT was arrested in all directions except the vertical and load varying from 1000N to a maximum of 4000N was applied at the centre of the hub and corresponding total deflection in vertical direction and equivalent stresses developed in spokes were noted. Contact tool is used to get the value of contact pressure generated between the tread and road surface when the load is applied.

The numerical analysis in SimSolid involves solving the governing equations for the tire models using advanced numerical techniques. It considers factors such as stress distribution, strain, and displacement to evaluate the structural performance of the tires accurately. By considering these non-linear effects, the analysis provides a more comprehensive understanding of how the tires respond to different loads and forces. According to (Mathew, 2017), in the journal article, ‘design and static analysis of airless tyre to reduce deformation’, conjointly stress and strain energy distribution developed ought to be analysed. The validation of metallic element prediction against air tire results was undertaken. The distribution of strain energy and deflection below loading was conjointly distributed victimization metallic element analysis. Vertical loading on the wheel through the appliance of a uniformly distributed edge load at the tire-rim contact region. The all tire half square measure mashed by victimization the solid Tetrahedral parts. Tread properties square measure E=30Mpa, density=1300 kg/m3. Each band consider as same material properties, and the wheel load of 1200 N is applied.

Contact analysis is another critical aspect of the non-linear analysis. SimSolid accurately models the interactions between various parts of the tire assembly, including the contact between the tire and the road surface, as well as the interactions between tire components. By considering factors such as friction, pressure distribution, and contact forces, the analysis helps in assessing the tire's performance in terms of stability, grip, and overall contact behaviour. Based on (Mathew, 2017), in the journal article, ‘design and static analysis of airless tyre to reduce deformation ‘road and tread were command contact stipulation not fastened. Vertical loading on the wheel through the applying of a uniformly distributed edge load at the tire-rim contact region. The deflection within the loading direction of the wheel centre and therefore the displacement within the lateral direction.

By using SimSolid for nonlinear analysis gives me valuable insight into the behaviour and performance of airless and conventional tires. This analysis enables a more realistic assessment of tire structure, durability, and tire safety under operating conditions. It also allows to optimize tires, identify potential problems, and make appropriate decisions to ensure overall tire performance.

3.8.1 Meshless

Meshless analysis, also known as mesh-free analysis, is a computational technique for solving complex engineering and physics problems without a predefined mesh structure. To discretize the problem domain, it employs scattered data points, or particles. This method is advantageous for managing problems with complex geometries or large deformations because it naturally handles moving boundaries and discontinuities without remeshing. Meshless analysis offers latitude in node distribution and refinement, enabling greater precision in regions of interest. However, imposing boundary conditions and the computational cost of large-scale problems present obstacles. In general, meshless analysis is a potent alternative to traditional mesh-based methods, providing accurate and efficient simulations for a variety of applications (Karp, 2021).

3.8.2 Non-Linear Setup type

Meshless SimSolid's non-linear configuration can be divided into two categories: material non-linear and geometric non-linear. In nonlinear material analysis, structural effects beyond linear elastic behaviour are considered. This is accomplished by incorporating nonlinear stress-strain curves into the material's properties. SimSolid offers three outputs for every result: elasto-plastic full load, elastic full load, and after discharge. These outputs represent, respectively, the results at full load assuming non-linear behaviour, the results at full load assuming linear behaviour, and the residual results after the burden has been removed. Geometric nonlinear analysis, on the other hand, takes into consideration changes in geometry as the structure deforms. In addition to considering the iterative solution of strain-displacement and equilibrium equations, it permits the specification of follower loads. Standard applications include thin structures, metal sheets, and stability analysis. By displaying a deformed shape plot and selecting the change max deformation option, it is essential to examine deformations at their true scale when performing geometric nonlinear analysis (Karp, 2021).

According to (Ali, Maarij, & Hussai, 2022), The deformation of spokes or the load-carrying ability of NPTs is one of the main parameters in designing NPTs, which can be classified as the centre of aluminium alloy hub displacement value. the deformation contours of all the straight spoke type NPTs under a vertical force of 2500 N. The straight spokes are acting just like columns and because of elastic buckling of spokes the maximum amount of deformation is at the centre of the spokes equal to 12.56 mm and 11.702 mm for both the trapezoid and simple spoke NPTs.

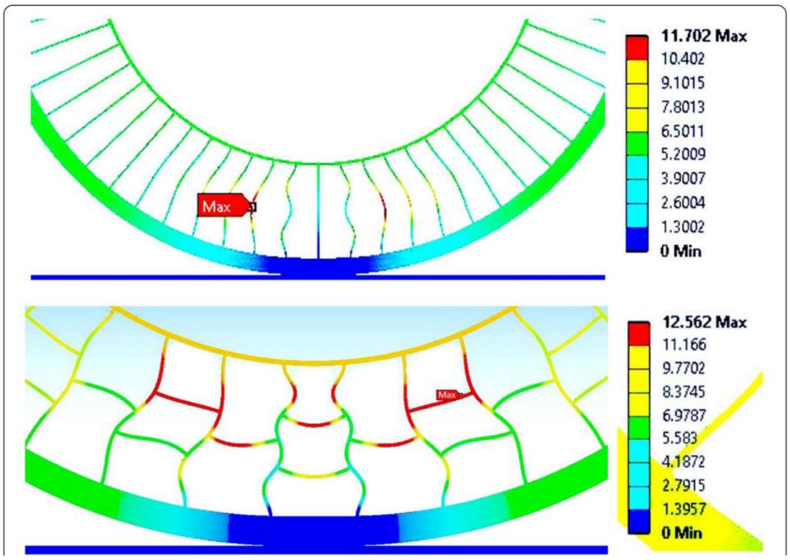

Figure 3.3 Deformation contours at a force of 2500 N (Ali, Maarij, & Hussai, 2022)

3.8.3 Boundary Condition and Loading

The CAD model is imported into SimSolid, and then the material properties for each element of the NPT that was developed are assigned. This allows for static analysis to be performed on the NPTs that were designed. Using bonded constraint, the tread and shear band with rings, the shear band and spokes, and the spokes and aluminium hub were constrained together. The nature of the contact that occurred between the tread and the road surface was characterised as a frictional sort of contact. The movement of the NPT was stopped in all directions except the vertical one, and a load that ranged from 1,000 N to a maximum of 4,000 N was applied in the centre of the hub. The corresponding total deflection in the vertical direction as well as equivalent stresses formed in the spokes were observed. The value of the contact pressure that is formed between the tread and the road surface when the load is applied can be determined with the help of the contact tool (Mohan, 2017).

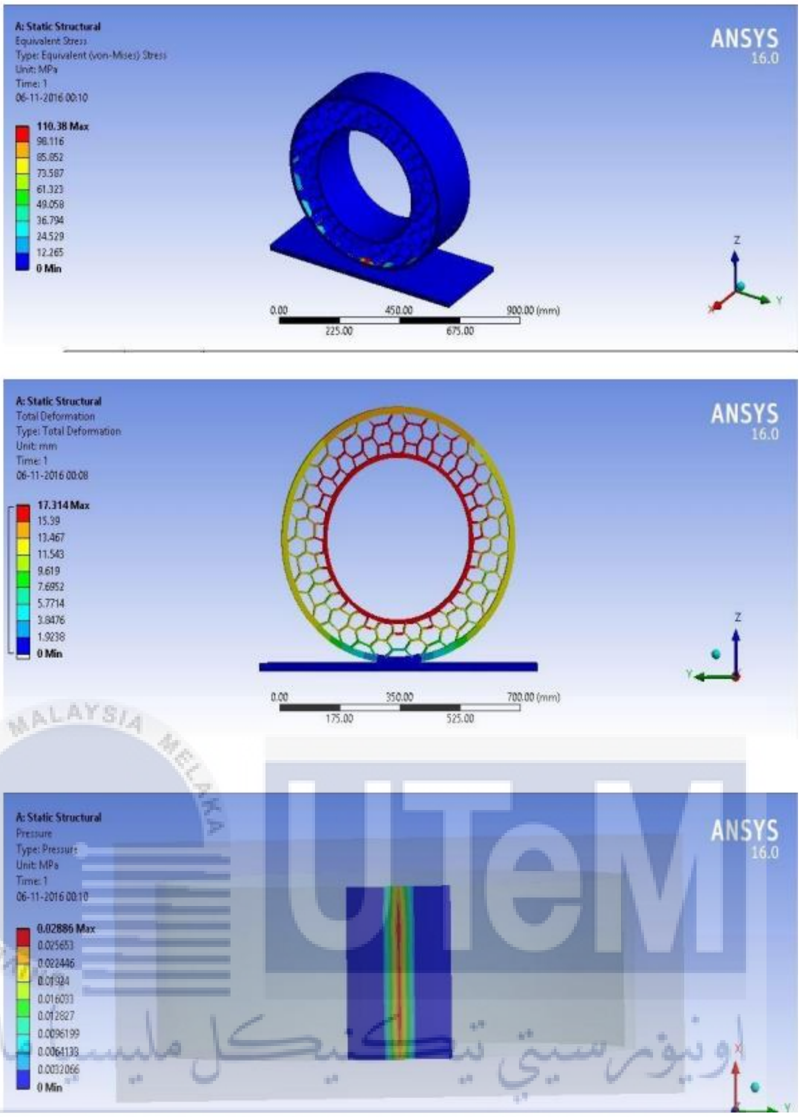

Figure 3.4 Ansys test results for Type B at maximum load showing Von-Mises Equivalent stress, Deformation, and Contact pressure in order (Mohan, 2017)

3.9 Comparison of Airless Tire and Conventional Tire

This table presents a comparison of the analysis results for the maximum deformation, Von Mises stress, and maximum contact pressure of three different tire types: Tweel (Triangular), Honeycomb, and Conventional. The table includes load variations ranging from 1000N to 4000N. Each tire type's corresponding values for maximum deformation (in millimetres), Von Mises stress (in megapascals), and maximum contact pressure (in megapascals) are indicated under their respective columns for each load condition. This table allows for a quick and concise comparison of the performance characteristics of the three tire types under different load scenarios, providing valuable insights for selecting the most suitable tire design based on factors such as deformation, stress distribution, and contact pressure.

Table 3.5 shows the table will use for the future analysis

Load (N)	Type	Maximum Deformation (mm)	Von mises Stress (MPa)	Safety Factor
1000	Tweel (Triangular)			
	Honeycomb			
	Conventional			
2000	Tweel (Triangular)			
	Honeycomb			
	Conventional			
3000	Tweel (Triangular)			
	Honeycomb			

	Conventional			
4000	Tweel (Triangular)			
	Honeycomb			
	Conventional			

3.10 Summary

a) Provides an overview of the methodology chapter.

b) Outlines the general steps and approach followed in the research project.

c) Presents a Gantt chart that illustrates the planned timeline and tasks of the project.

d) Depicts a visual representation of the flow and sequence of activities in the research process.

e) Focuses on the dimensional aspects of the design, particularly related to the main hub with rim.

f) Discusses the specific dimensions and characteristics of the main hub with rim.

g) Provides further details and considerations for the design of the main hub with rim.

h) Discusses the design elements and considerations for the triangular tweel.

i) Explores the design aspects and considerations related to the honeycomb structure.

j) Discusses the design aspects and considerations for the conventional tire.

k) Discusses the specific material properties and considerations for the hub component.

l) Explores the material properties and considerations for the spoke component.

m) Provides a summary of the material properties considered for the different components.

n) Discusses the analysis techniques and approaches used in the project.

CHAPTER 4

RESULT AND DISCUSSION

4.1 Introduction

This report presents the findings and analysis of CAD drawings for three distinct tire designs: Tweel (Triangular), Honeycomb, and Conventional. The results and discussions obtained from the evaluation are also included. Solidworks is the CAD software used for designing and modelling tire structures. The following chapter presents a comprehensive analysis of the results obtained from the CAD drawings. The examination concentrates on different aspects, including design features, structural characteristics, and performance parameters. A detailed analysis of the CAD results will be presented to provide a comprehensive evaluation of the tire designs' strengths, weaknesses, and overall suitability. The discussions will offer significant perspectives on the practicability and efficiency of the tire designs, facilitating the choice of the most appropriate alternative for applications and needs.

4.2 Conceptual design of spoke

The conceptual design of the spoke is a crucial element of the project since it establishes the basic structure for the Tweel and Honeycomb tires. During this stage, the primary emphasis is on generating ideas and creating initial sketches. Important factors like measurements, angles, and material choices are carefully discussed and considered. The design process includes establishing a core concept for the spoke construction, taking into account elements such as durability, efficiency in distributing loads, and overall stability. The conception phase is anticipated to establish the foundation for later detailed design stages, guaranteeing that the spoke is in line with the project's objectives of innovation, structural soundness, and improvement in performance.

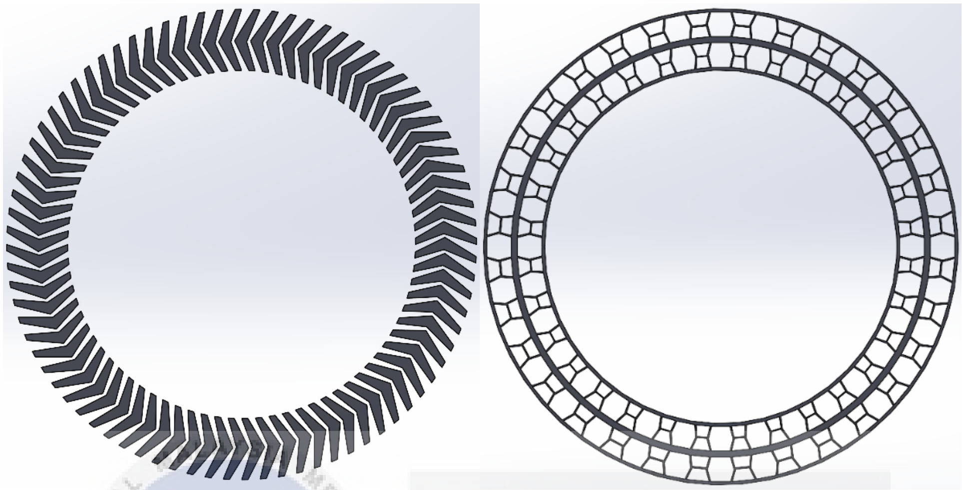

Figure 4.1 Shows the conceptual spoke design of Tweel and Honeycomb

4.2.1 Tweel (Triangular) Tire

The SolidWorks model of the tweel (triangular) undergoes a careful design process, starting with the precise fabrication of the distinctive spoke. This procedure involves meticulously creating the spoke design using the "Boss Extrude" command and forming the whole tweel structure using the essential "Circular Sketch Pattern" command. In the next step, an extruded body is created to form a solid surface. Once this surface is successfully generated, it is smoothly included into the main hub and outer ring using SolidWorks' assembly function, thereby finishing the Tweel tire. The design parameters, thoroughly detailed with factors such as circle diameters and angular measurements, guarantee an accurate fit during assembly. By incorporating a pattern consisting of 80 occurrences, the Tweel model achieves a consistent and homogeneous structure. This pattern, characterized by triangular spokes, promotes stability and evenly distributes the stress, eliminating the necessity for conventional air-filled chambers.

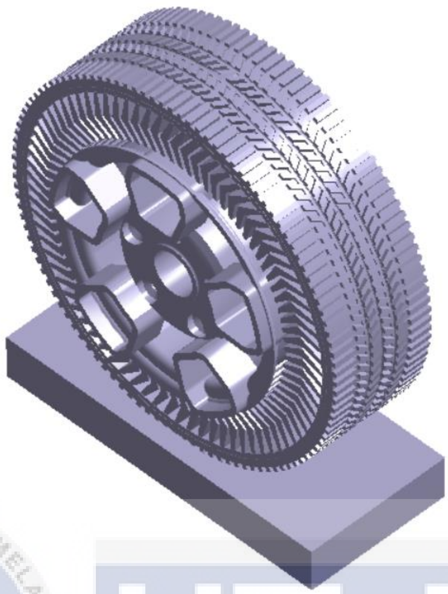

Figure 4.2 Shows the Tweel tire in SimSolid

4.2.1.1 Analysis of Tweel tire

The Tweel tire's structural non-linear analysis, carried out using SimSolid software, provides vital insights into its performance when subjected to different stresses. The research, conducted throughout a load range of 1000N to 4000N, demonstrates the tire's reaction to varying amounts of stress and displacements. The maximum Von Mises stress with a force of 1000 N is 25.35 MPa. This stress is accompanied by a displacement magnitude of 0.48925 mm, which leads to a factor of safety of 18.5. At a load of 2000 N, the stress increases to 53.99 MPa, the displacement increases to 1.0194 mm, and the factor of safety reduces to 8.7. Increasing the load to 3000N results in a stress of 78.68 MPa, a displacement of 1.749 mm, and a factor of safety of 6. The maximum applied force of 4000N results in a stress of 105.01 MPa, a displacement of 2.113 mm, and a factor of safety of 4.5. These results demonstrate a direct correlation between the amount of force applied and the resulting stress or displacement. This highlights the need for these analyses to comprehend the structural limitations of the Tweel tire and guide its improvement for increased safety and performance.

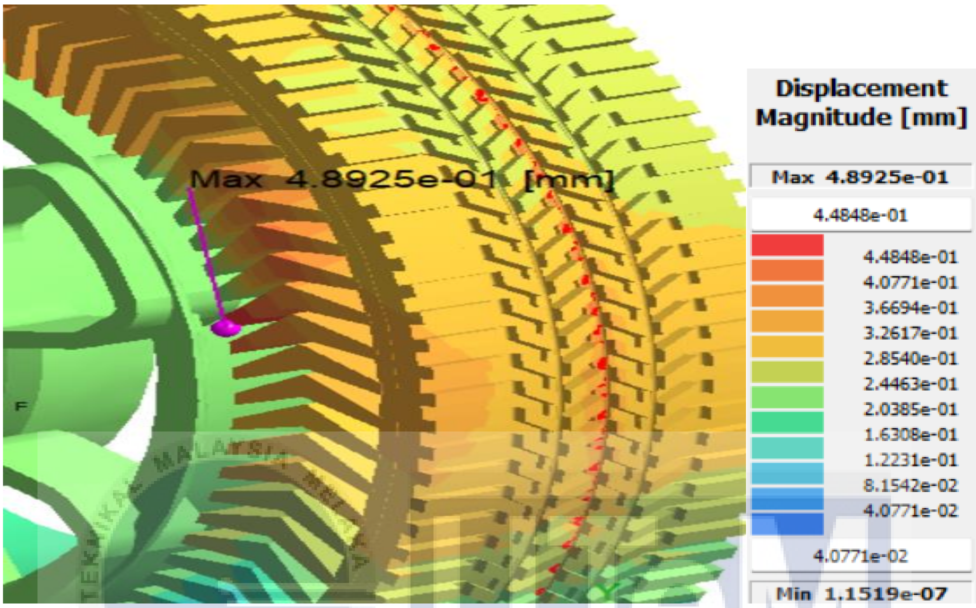

Figure 4.3 Shows the maximum Displacement Magnitude at 1000N

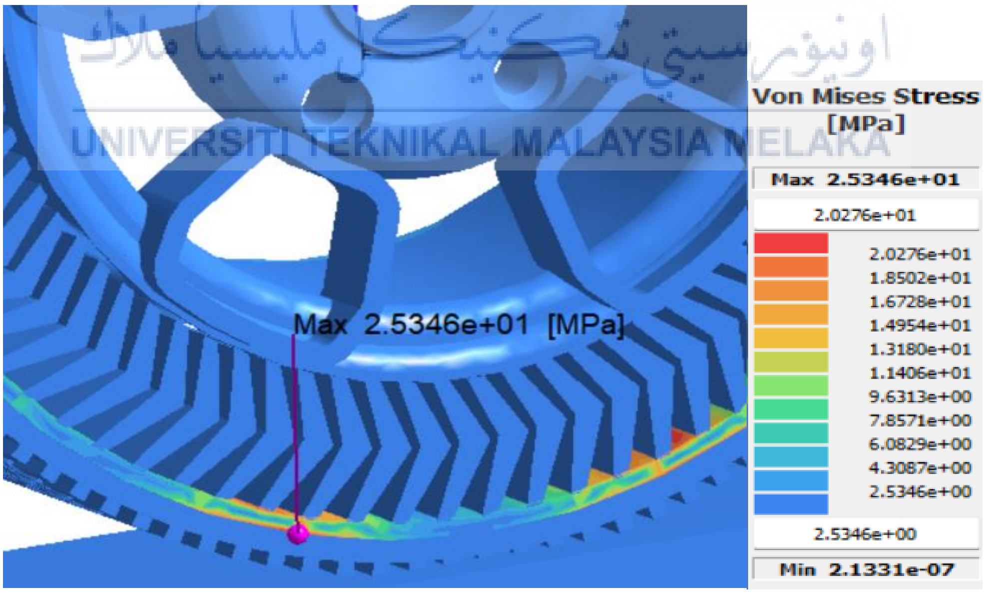

Figure 4.4 Shows the maximum Von Mises Stress at 1000N

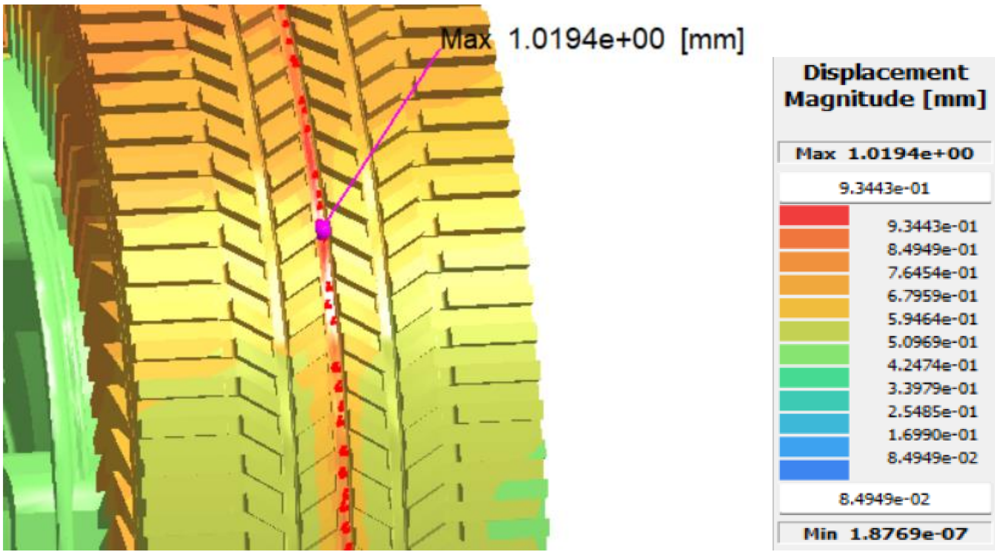

Figure 4.5 Shows the maximum Displacement Magnitude at 2000N

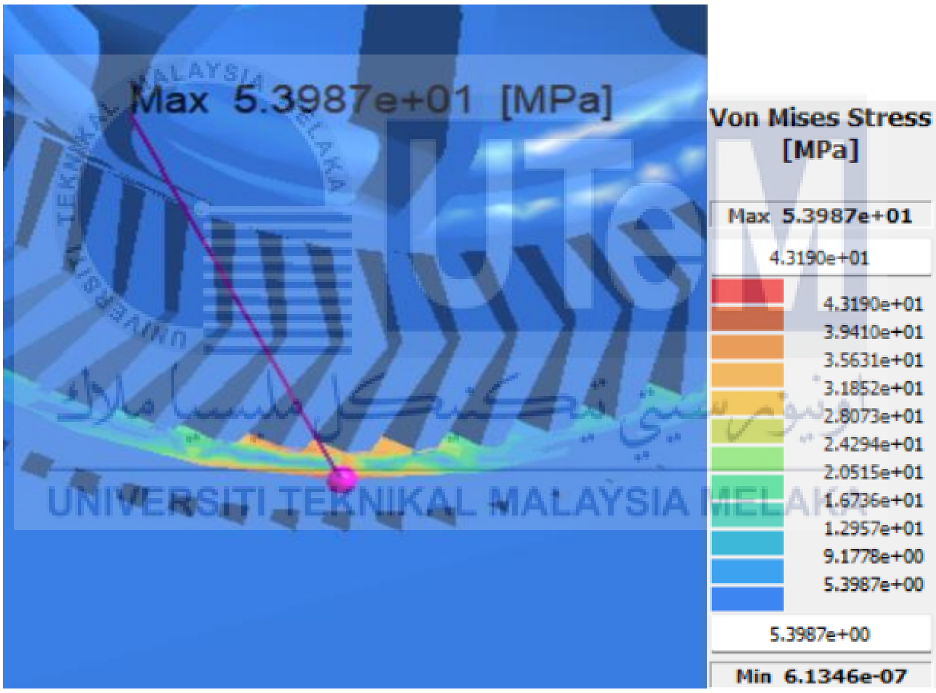

Figure 4.6 Shows the maximum Von Mises Stress at 2000N

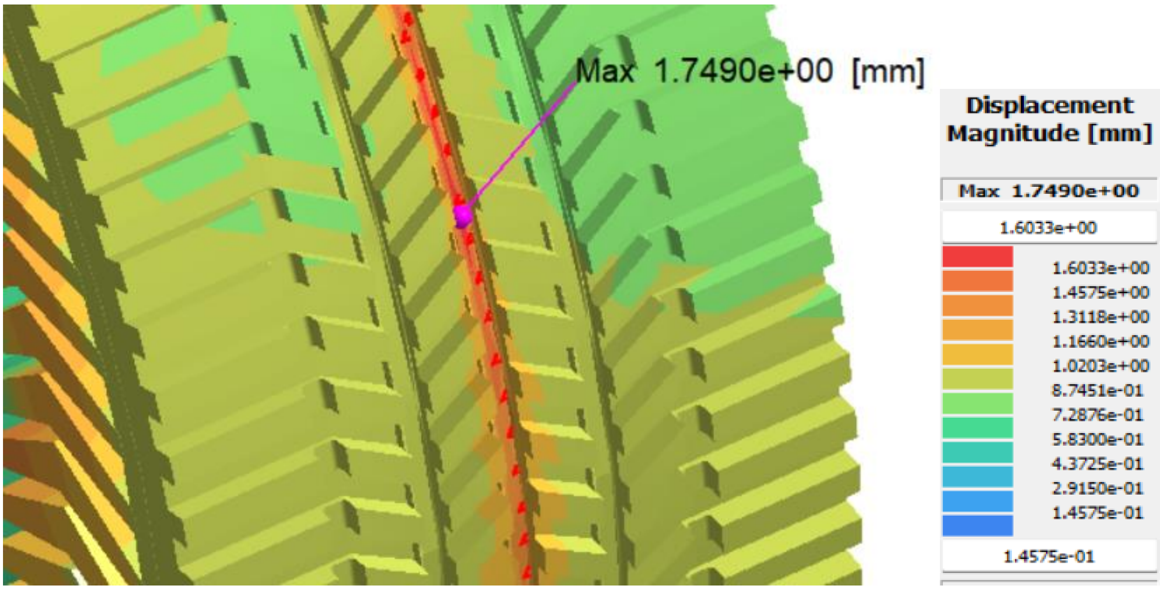

Figure 4.7 Shows the maximum Displacement Magnitude at 3000N

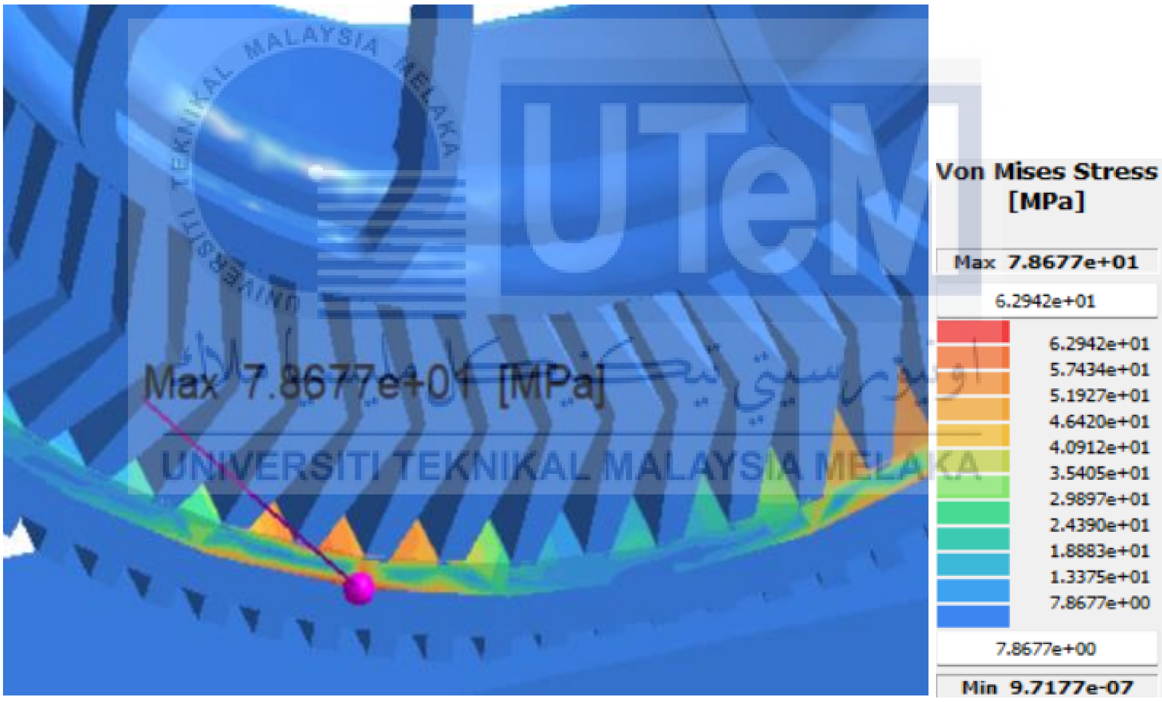

Figure 4.8 Shows the maximum Von Mises Stress at 3000N

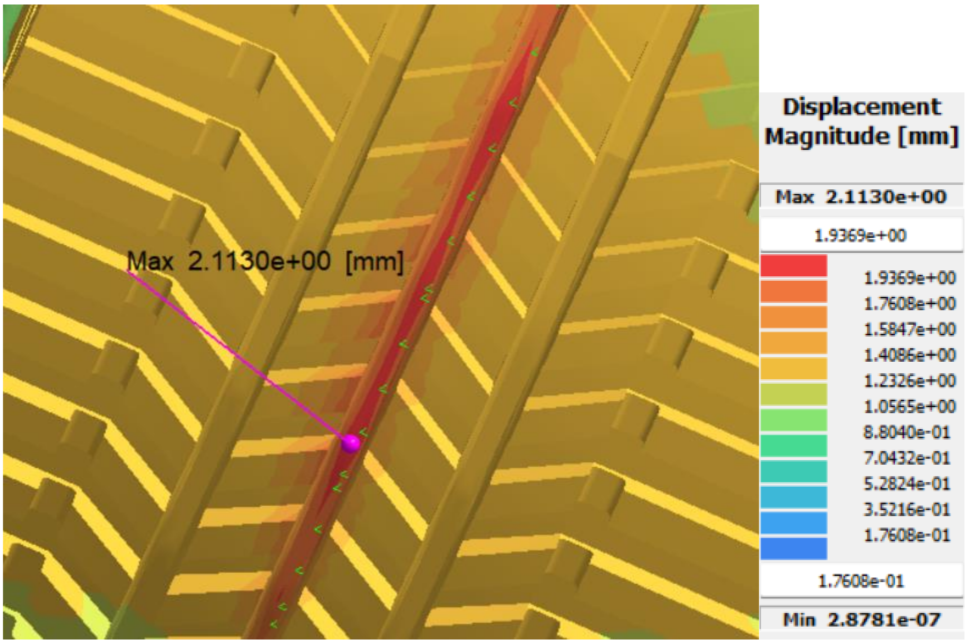

Figure 4.9 Shows the maximum Displacement Magnitude at 4000N

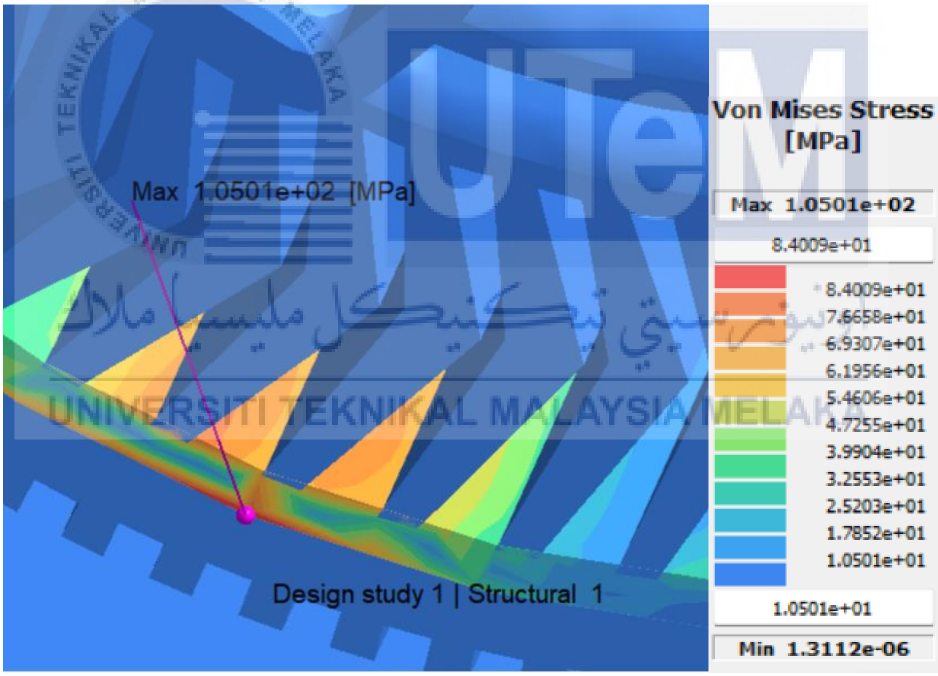

Figure 4.10 Shows the maximum Von Mises Stress at 4000N

Table 4.1 Analysis results of Tweel

Load (N)	Maximum Von Mises Stress (MPa)	Maximum Displacement Magnitude(mm)	Factor of Safety
1000	25.346	0.48925	18.5
2000	53.987	1.0194	8.7
3000	78.677	1.7490	6.0
4000	105.01	2.1130	4.5

4.2.2 Honeycomb tire

The SolidWorks software was effectively utilized to create a honeycomb structure, resulting in a well-defined and exact component. Beginning with the choice of the internal section of the flange, the honeycomb structure was defined in accordance with the provided illustration. Afterwards, the circular pattern command was used to replicate the previously indicated drawing, ensuring that the honeycomb pattern was evenly expanded throughout the whole model. The mirroring function was employed to achieve structural symmetry. The honeycomb structure's solid surface was generated by employing the cut-extrude command on an extruded body. This procedure included perforations that corresponded to the outlined design. With extreme precision, the design adhered to the required proportions and shapes, such as hexagons and trapezoids. The honeycomb structure was constructed with a circular arrangement, yielding a design that is characterized by its low weight, porosity, and structural efficiency. The design effectively fulfills the specified goals of the project.

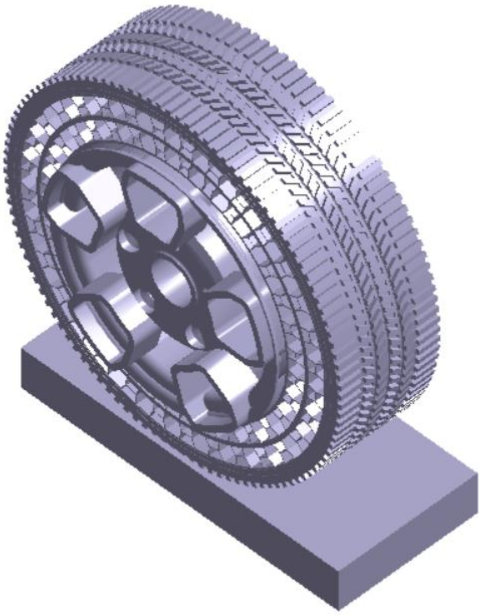

Figure 4.11 Shows the Honeycomb tire in Simsolid

4.2.2.1 Analysis of Honeycomb tire

The honeycomb tire was subjected to a comprehensive evaluation in the structural non-linear analysis using SimSolid. The assessment covered a range of loads (1000N, 2000N, 3000N, and 4000N) to precisely evaluate its structural performance. The investigation entailed the careful establishment of automated connections, taking into account gaps and penetrations of up to 3mm. Immovable restrictions were implemented at the base of the pad to replicate authentic road interactions. A remote load was carefully positioned on the central surface of the tread to replicate different operational situations. The gathered data offers valuable measurements on the tire's performance when subjected to varying loads. The Von Mises stress with a force of 1000 Newtons was measured to be 21.45 megapascals. The displacement magnitude was found to be 0.35754 millimeters, resulting in a factor of safety of 22. At a load of 2000 N, the stress reached 42.86 MPa, and the displacement increased to 0.81577 mm, resulting in a factor of safety of 11. Following the same pattern, the stress rose to 64.24 MPa at 3000N, accompanied by a displacement of

1.5234 mm and a factor of safety of 7.3. At a force of 4000 N, the Von Mises stress reached its highest point at 87.81 MPa, the displacement measured 4.5671 mm, and the factor of safety was reduced to 5.4. This thorough examination guarantees a strong comprehension of the Honeycomb tire's structural reaction to different load circumstances, enabling informed adjustments to the design for improved safety and performance.

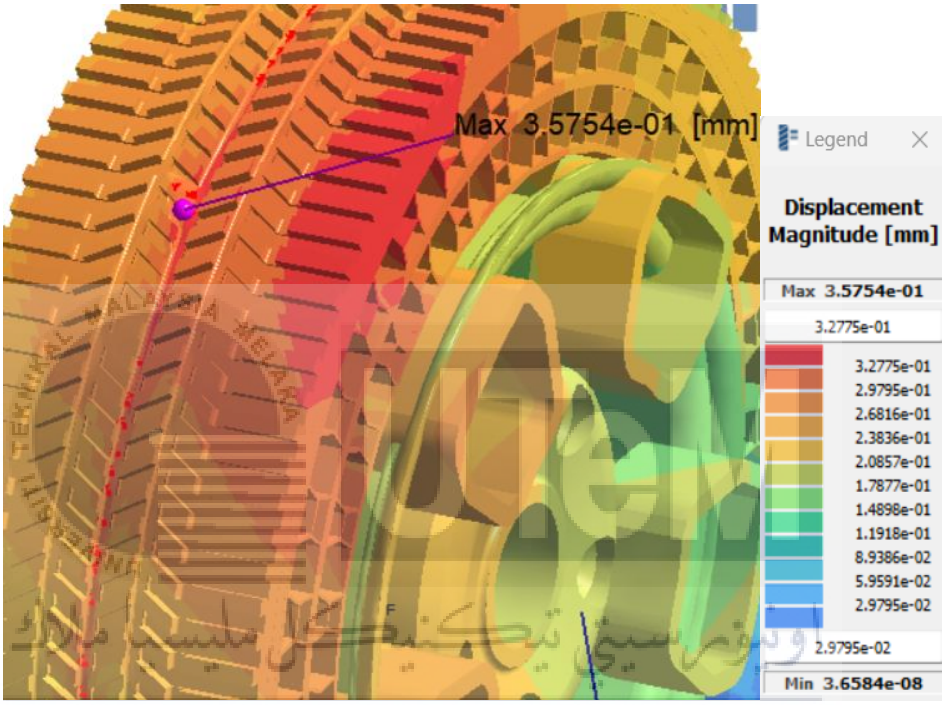

Figure 4.12 Shows the maximum Displacement Magnitude at 1000N

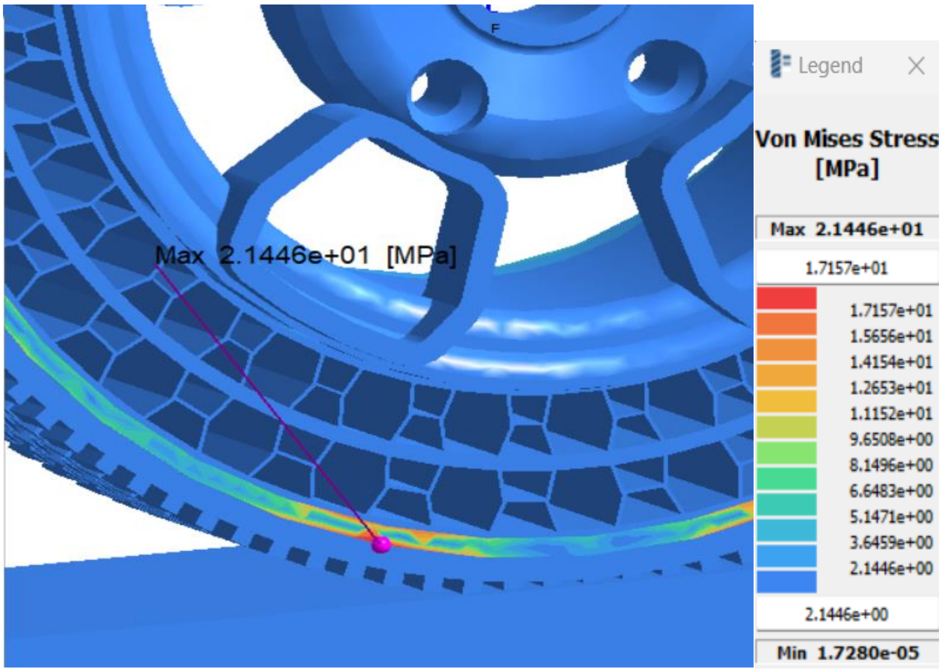

Figure 4.13 Shows the maximum Von Mises Stress at 1000N

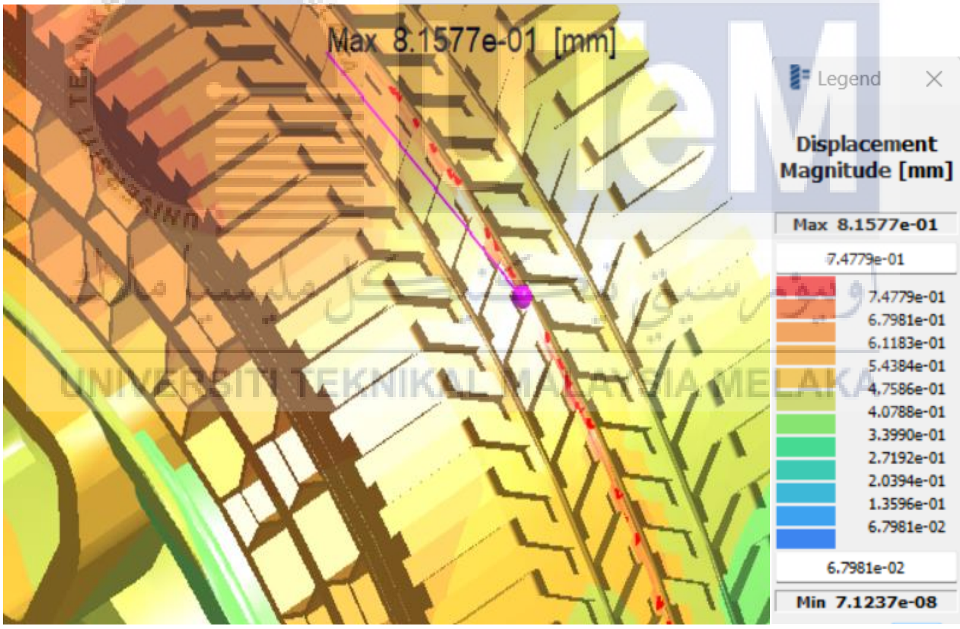

Figure 4.14 Shows the maximum Displacement Magnitude at 2000N

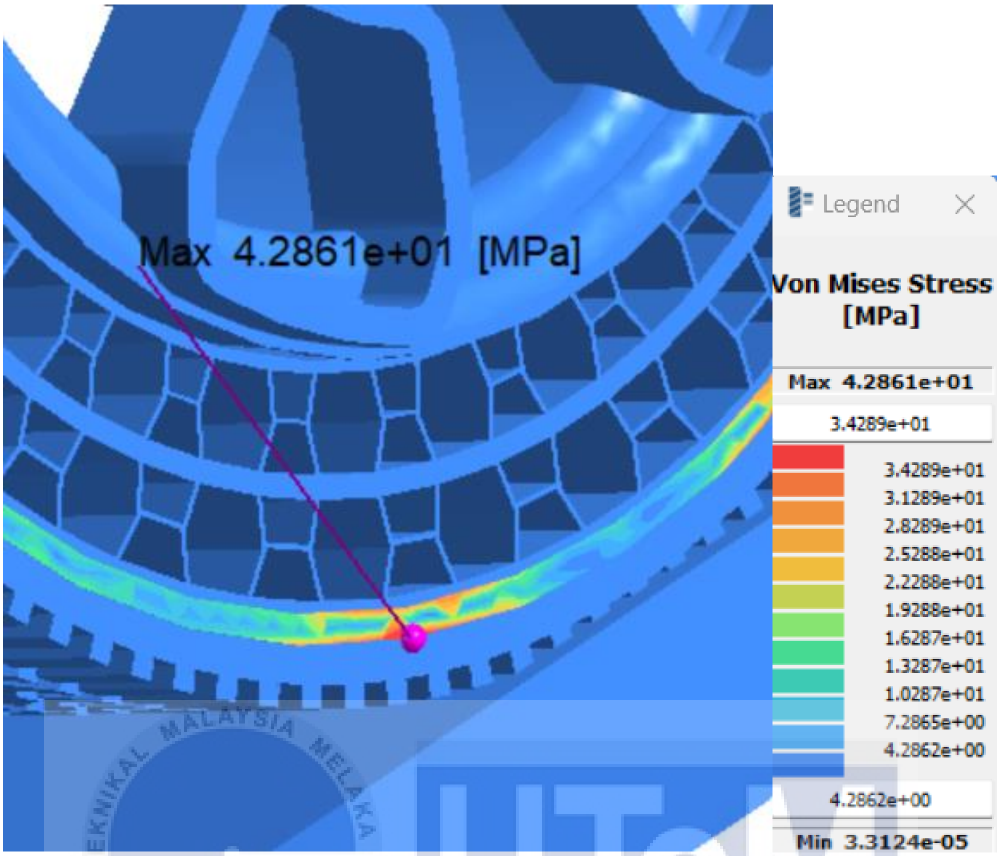

Figure 4.15 Shows the maximum Von Mises Stress at 2000N

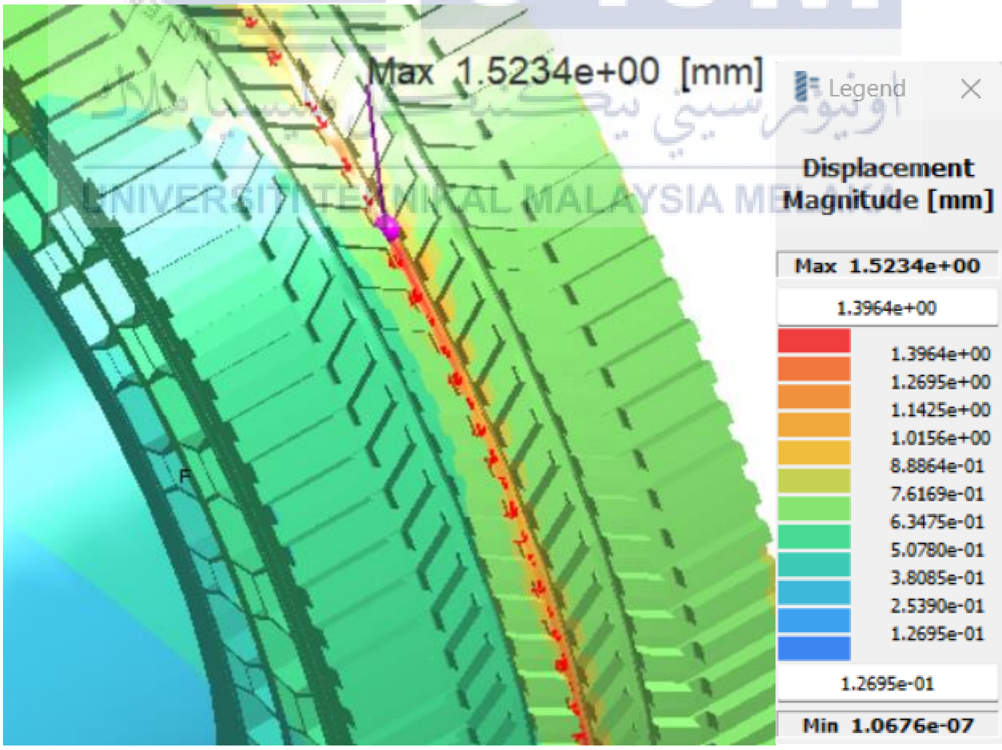

Figure 4.16 Shows the maximum Displacement Magnitude at 3000N

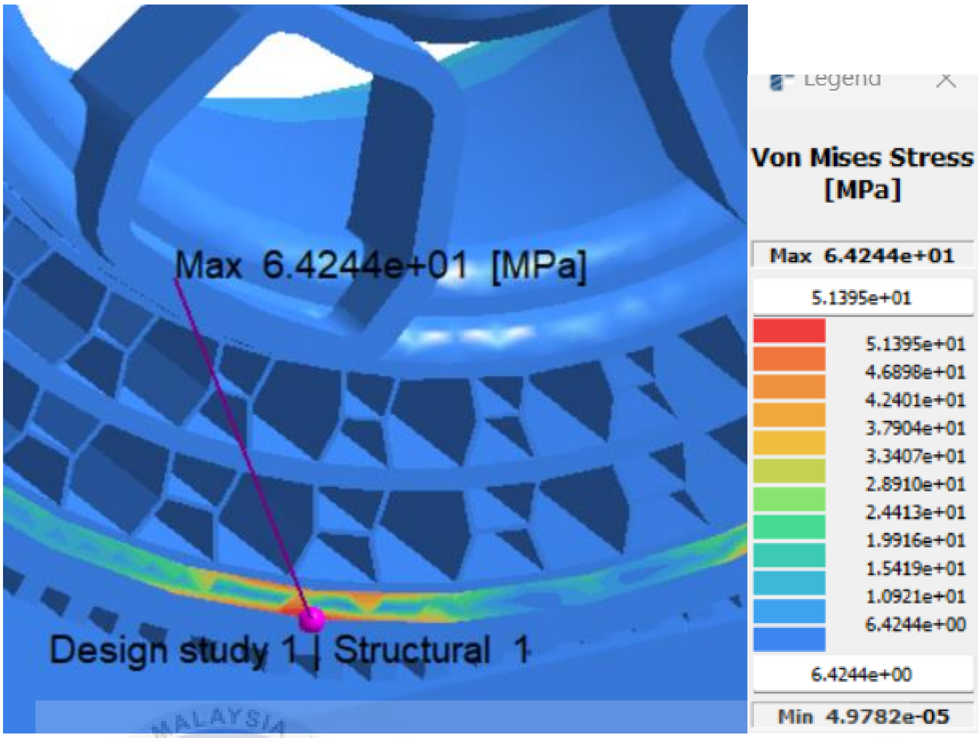

Figure 4.17 Shows the maximum Von Mises Stress at 3000N

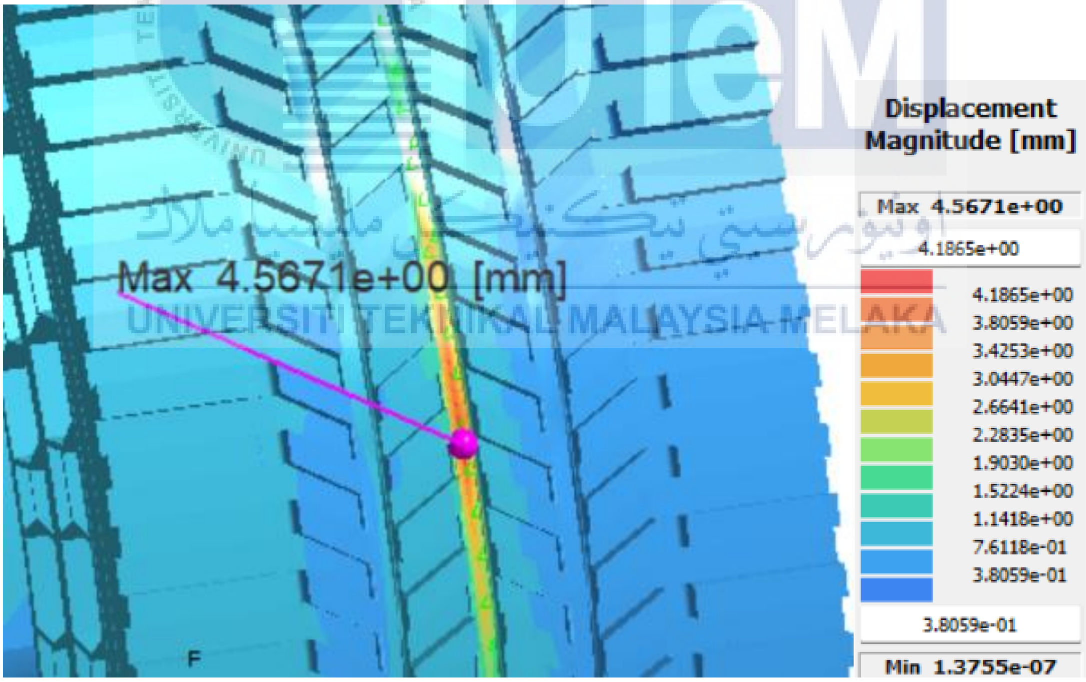

Figure 4.18 Shows the maximum Displacement Magnitude at 4000N

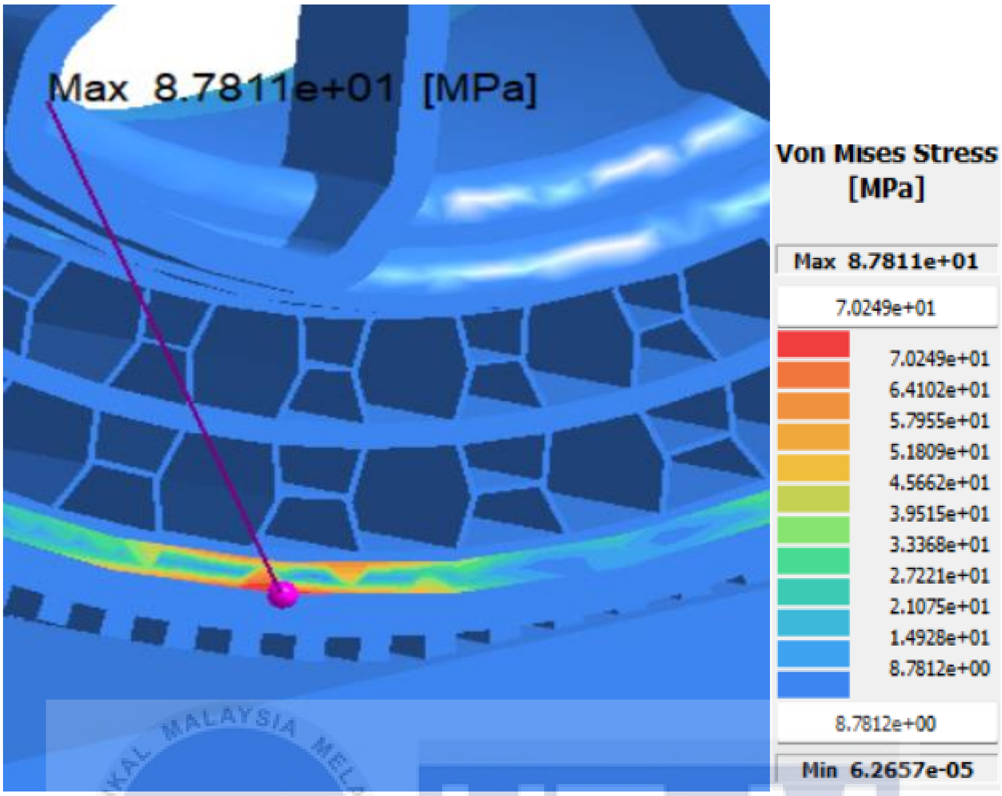

Figure 4.19 Shows the maximum Von Mises Stress at 4000N

Table 4.2 Analysis result of Honeycomb

Load (N)	Von Mises Stress (MPa)	Displacement Magnitude (mm)	Factor of Safety
1000	21.446	0.35754	22.0
2000	42.861	0.81577	11.0
3000	64.244	1.5234	7.3
4000	87.811	4.5671	5.4

4.3 Conventional Tire

The design procedure for the conventional tire was efficiently executed using SolidWorks. The main emphasis of the design was on the central and peripheral components, while the external portion of the tire was disregarded. The core hub and outer rim were meticulously constructed, containing notable elements such as a circular rim held together by five bolt holes. The design procedure involved the creation of a circular shape with a diameter of 17 inches, which was then extended vertically to a height of 5 inches. Subsequent adjustments were made with commands such as "fillet" and "shell" to enhance both the visual appeal and structural soundness of the design. The tread pattern design was meticulously crafted employing a range of precise instructions, such as "Extrude," "Mirror," "Fillet," and "Circular Pattern." The typical tire was accurately and fully shown by merging its many components using the SolidWorks assembly feature. The current design is a valuable asset for future research and evaluation, facilitating the advancement of tire design and engineering processes.

Figure 4.20 Shows the Conventional tire in SimSolid

4.3.1 Analysis of Conventional tire

The structural non-linear study of the conventional tire using SimSolid involved a rigorous procedure to evaluate its performance under different loads (1000N, 2000N, 3000N, and 4000N). The investigation began by establishing automated connections, taking into account a 4mm gap and penetration to replicate real-life situations. The hub was constructed from AL 7075-T6, the tread was made of rubber, and graphite was used to imitate the road surface in the form of a pad. To replicate the tire's interface with the road, fixed limitations were implemented at the base of the pad. Additionally, a remote load was strategically positioned on the central area of the tread to mimic various operational circumstances. The gathered data provides essential insights into the structural behavior of conventional tires. The Von Mises stress for a force of 1000 N was measured to be 11.01 MPa. The displacement magnitude was found to be 8.4479 mm, giving a factor of safety of 45.4. At a load of 2000 N, the stress reached 20.29 MPa, and the displacement increased to 108.29 mm, resulting in a factor of safety of 24.6. Following the same pattern, the stress rose to 49.55 MPa at a force of 3000 N.The displacement reached 129.91 mm, and the factor of safety was 10.1. At a force of 4000 N, the Von Mises stress reached its highest point at 81.33 MPa, the displacement was a significant 751.65 mm, and the factor of safety was reduced to 6.1. This research offers useful insights into the structural reaction of conventional tires under different load circumstances. It gives critical data for modifying the tire's design to improve safety and performance.

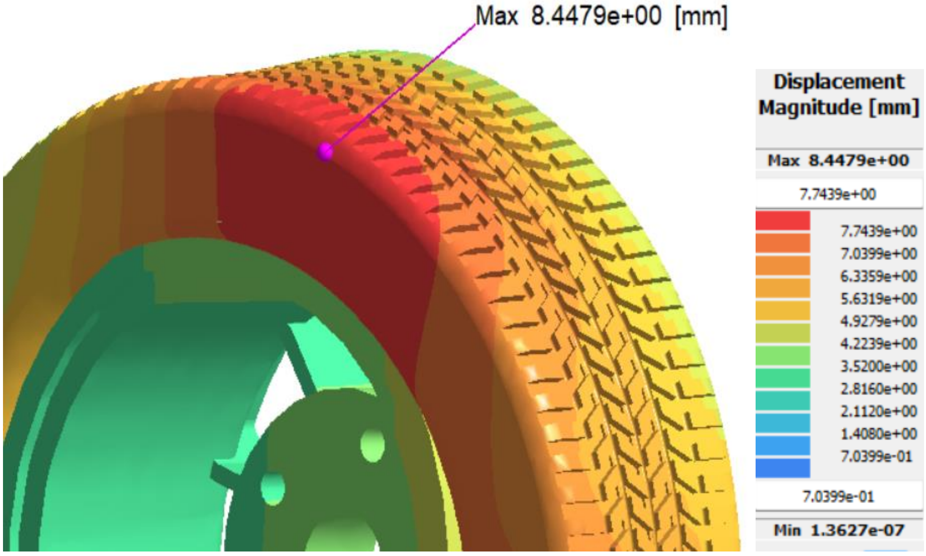

Figure 4.21 Shows the maximum Displacement Magnitude at 1000N

Figure 4.22 Shows the maximum Von Mises Stress at 1000N

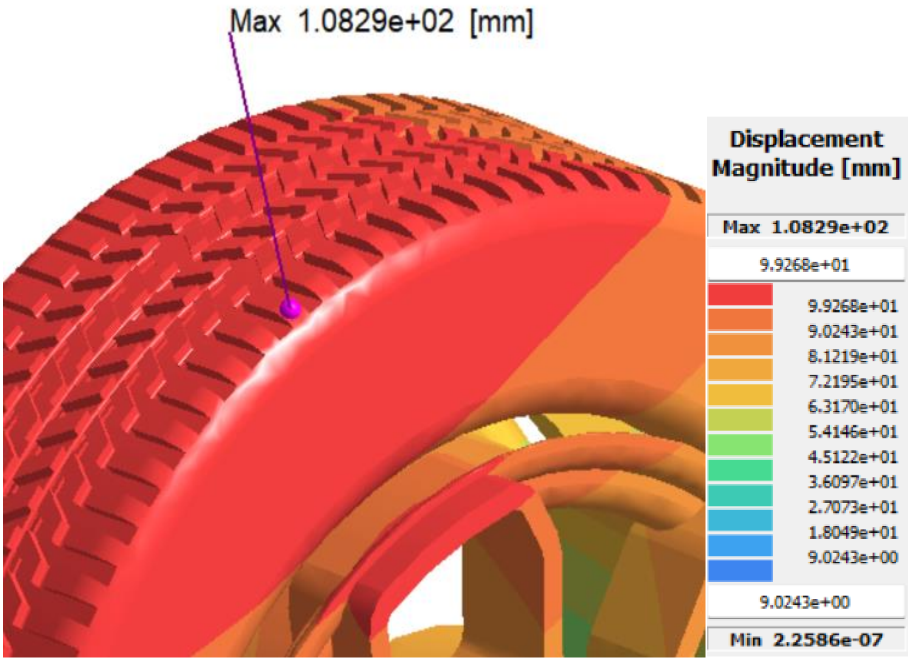

Figure 4.23 Shows the maximum Displacement Magnitude at 2000N

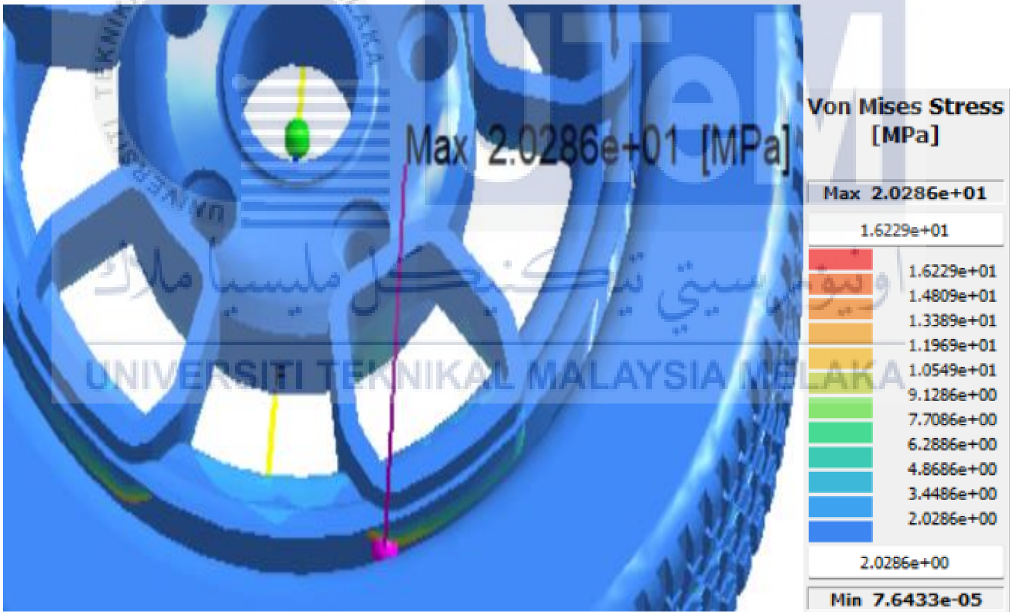

Figure 4.24 Shows the maximum Von Mises Stress at 2000N

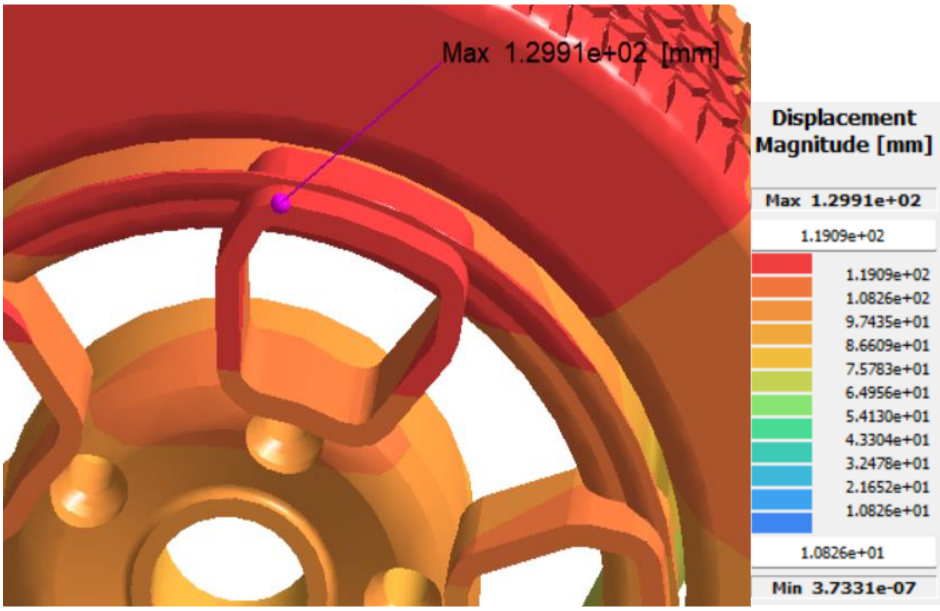

Figure 4.25 Shows the maximum Displacement Magnitude at 3000N

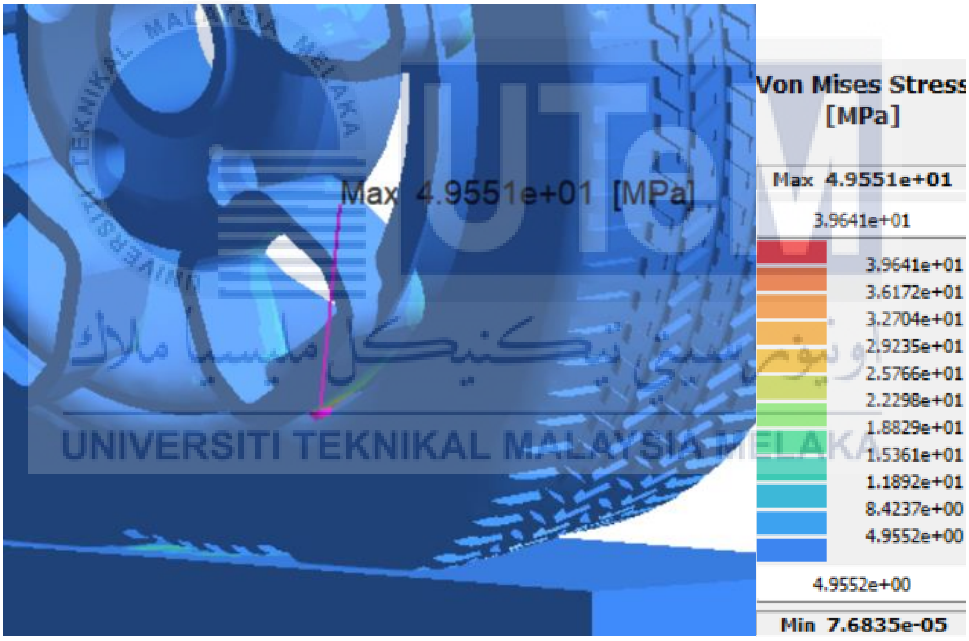

Figure 4.26 Shows the maximum Von Mises Stress at 3000N

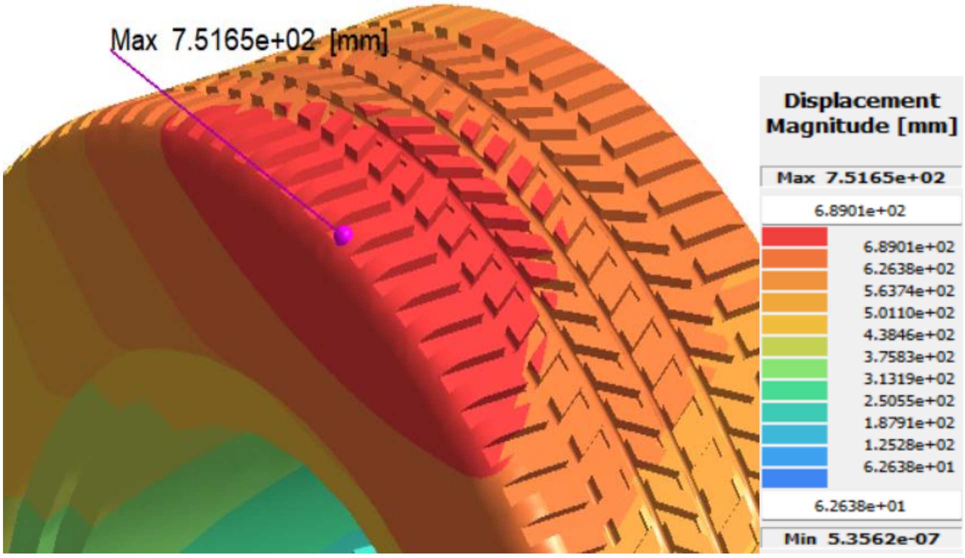

Figure 4.27 Shows the maximum Displacement Magnitude at 4000N

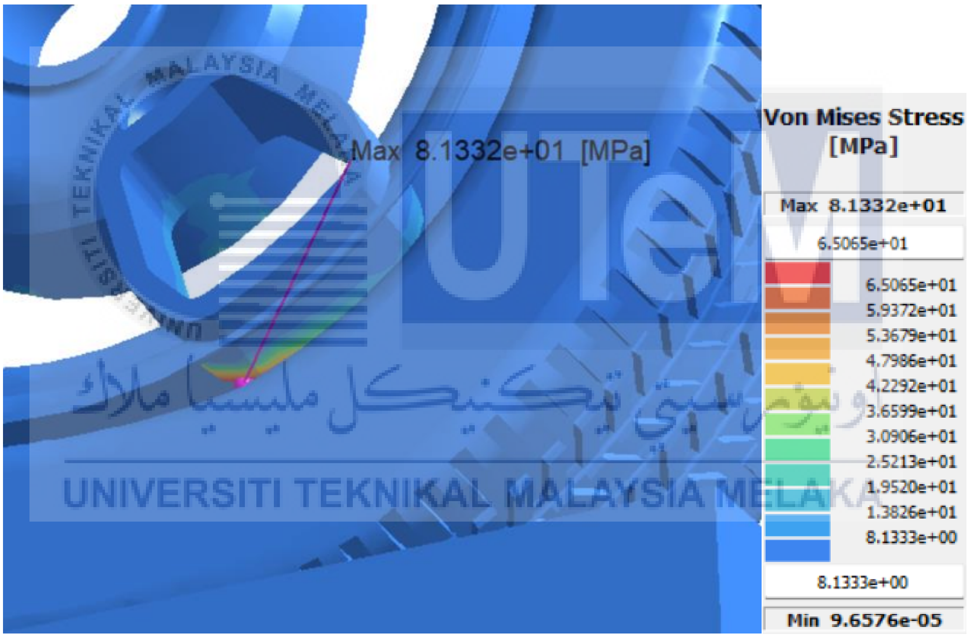

Figure 4.28 Shows the maximum Von Mises Stress at 4000N

Table 4.3 Analysis result of Conventional Tire

Load (N)	Von Mises Stress (MPa)	Displacement Magnitude (mm)	Factor of Safety
1000	11.010	8.4479	45.4
2000	20.286	108.29	24.6
3000	49.551	129.91	10.1
4000	81.332	751.65	6.1

4.4 Comparison of tires (Tweel, Honeycomb and Convention)

The analysis of Von Mises stress, displacement magnitude, and factor of safety across the tweel (triangular), honeycomb, and conventional tire designs offers useful insights into their individual performance characteristics under different loads. The Von Mises stress (MPa) of the tweel increased gradually from 25.35 to 105.01 MPa as the load spectrum varied. This suggests that the Tweel is capable of handling larger loads while maintaining a proportionate stress response. The Honeycomb tire exhibited marginally reduced stress levels, varying between 21.45 and 87.81 MPa, whereas the conventional tire consistently showed lower stress values, ranging from 11.01 to 81.33 MPa. This indicates that each design has a unique pattern of stress distribution.

When analyzing the displacement magnitude (mm) of the Tweel, it was seen that there was a proportionate rise from 0.48925 to 2.113 mm, which corresponded to increased applied loads. The honeycomb design demonstrated a considerable increase in displacement magnitude, particularly at 4000N, with measurements ranging from 0.35754 to 4.5671 mm. On the other hand, the conventional tire exhibited a substantial rise in displacement, specifically reaching 751.65 mm when subjected to a force of 4000 N.This demonstrates different reactions to applied forces, highlighting the impact of design on the properties of deformation.

The examination of the factor of safety uncovered intriguing patterns. The Tweel exhibited a decline in safety factors from 18.5 to 4.5 as the loads rose, indicating a reduction in the safety margin. In a similar manner, the Honeycomb tire experienced a reduction in its safety factors, dropping from 22 to 5.4. On the other hand, the conventional tire exhibited greater safety factors, varying from 45.4 to 6.1, suggesting a more cautious design with significant safety reserves.

To summarise, the Tweel demonstrated a well-proportioned reaction in terms of stress, displacement, and safety considerations. The honeycomb design exhibited distinct displacement characteristics, while the conventional tyre emphasised greater safety margins. The selection of these designs would depend on the individual needs of the application, taking into account elements such as the ability to carry loads, the distribution of stress, and safety considerations.

Table 4.4 Comparison of Von Mises Stress (MPa)

Types of Tires	**Load**			
	1000N	**2000N**	**3000N**	**4000N**
Tweel (Triangular)	25.346	53.987	78.677	105.01
Honeycomb	21.446	42.861	64.244	87.811
Conventional	11.010	20.286	49.551	81.332

Table 4.5 Comparison of Displacement Magnitude (mm)

Types of Tires	Load			
	1000N	2000N	3000N	4000N
Tweel (Triangular)	0.48925	1.0194	1.7490	2.1130
Honeycomb	0.35754	0.81577	1.5234	4.5671
Conventional	8.4479	108.29	129.91	751.65

Table 4.6 Comparison of Factor of Safety

Type of Tires	Load			
	1000N	2000N	3000N	4000N
Tweel (Triangular)	18.5	8.7	6.0	4.5
Honeycomb	22.0	11.0	7.3	5.4
Conventional	45.4	24.6	10.1	6.1

4.5 Summary

a) Provides an overview of the methodology chapter.

b) The chapter provides a comprehensive analysis of three distinct tire designs using SolidWorks and SimSolid.

c) Each design's strengths, weaknesses, and structural characteristics are discussed.

d) Structural analyses using SimSolid provide valuable insights into the performance under varying loads.

e) The comparison highlights differences in stress levels and deformation characteristics, emphasizing the importance of considering specific application requirements when choosing a tire design.

f) The Tweel design exhibits a unique triangular spoke pattern, offering robustness and load dispersion without air.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

An in-depth investigation and evaluation of the tweel (triangular), honeycomb, and conventional tyre designs have yielded a detailed comprehension of their individual performances when subjected to different loads. The Tweel demonstrated an admirable equilibrium among stress distribution, displacement characteristics, and safety features, thanks to its triangle spoke arrangement. The design demonstrated versatility through its gradual increase in Von Mises stress and proportionate development in displacement magnitudes. However, it is important to note that the safety factors decreased as the loads increased. The Honeycomb, however, exhibited notable characteristics, particularly in its substantial rise in displacement magnitude, particularly at 4000N, indicating a different deformation response. The conventional tyre, although it ensures greater safety margins, exhibited higher displacement values, suggesting a more cautious design approach.

Upon analysing these facts, it becomes apparent that every tyre design possesses its own advantages and compromises. The Tweel is advantageous in situations where achieving a delicate equilibrium between load-bearing capability, stress distribution, and safety margins is of utmost importance. The honeycomb's distinctive deformation qualities make it suitable for situations where regulated and predictable deformations are beneficial. On the other hand, the conventional tyre, which prioritises safety margins, may be appropriate for some situations.

The analysis highlights the relevance of creative tyre designs and the need to customise tyre structures to meet individual application needs. The insights obtained from this study serve as a vital basis for future developments in tyre design and engineering as industries progress and the need for efficiency, safety, and performance grows. The incorporation of materials, structural configurations, and sophisticated analyses, as exemplified in this research, will undeniably enhance the continuous development of tyre technology and its varied uses.

5.2 Recommendations

As we examine the potential of airless tyre technology and spoke structures for the future, we can identify various opportunities for further investigation and enhancement. A crucial aspect to consider is conducting a comprehensive experimental verification of the analytical discoveries. Performing comprehensive laboratory experiments and practical field trials will yield crucial observations regarding the actual efficacy of airless tyres compared to traditional ones. The utilisation of this empirical data can improve the precision of forecasts and additionally confirm the effectiveness of the suggested spoke structures.

In addition, given the dynamic nature of materials science and manufacturing technologies, it is imperative for future research to investigate innovative materials and sophisticated manufacturing techniques. Such investigation has the potential to result in the creation of spoke structures that provide enhanced strength, durability, and overall performance.

The utilisation of advanced analytical tools and simulation techniques can enhance our comprehension of spoke behaviour in various conditions, thereby providing a more nuanced understanding. The combination of advanced finite element analysis (FEA) tools and machine learning algorithms can provide predictive capabilities and enhance the design process optimisation. Additionally, a comprehensive life-cycle analysis considering environmental impact, recyclability, and sustainable materials could guide the development of eco-friendly airless tire solutions.

To summarise, the future direction of airless tyre design and spoke structures offers promising prospects for innovation and enhancement. Implementing these suggestions can enhance the ongoing development of airless tyre technology, rendering it more feasible and competitive in the ever-changing field of contemporary transportation.

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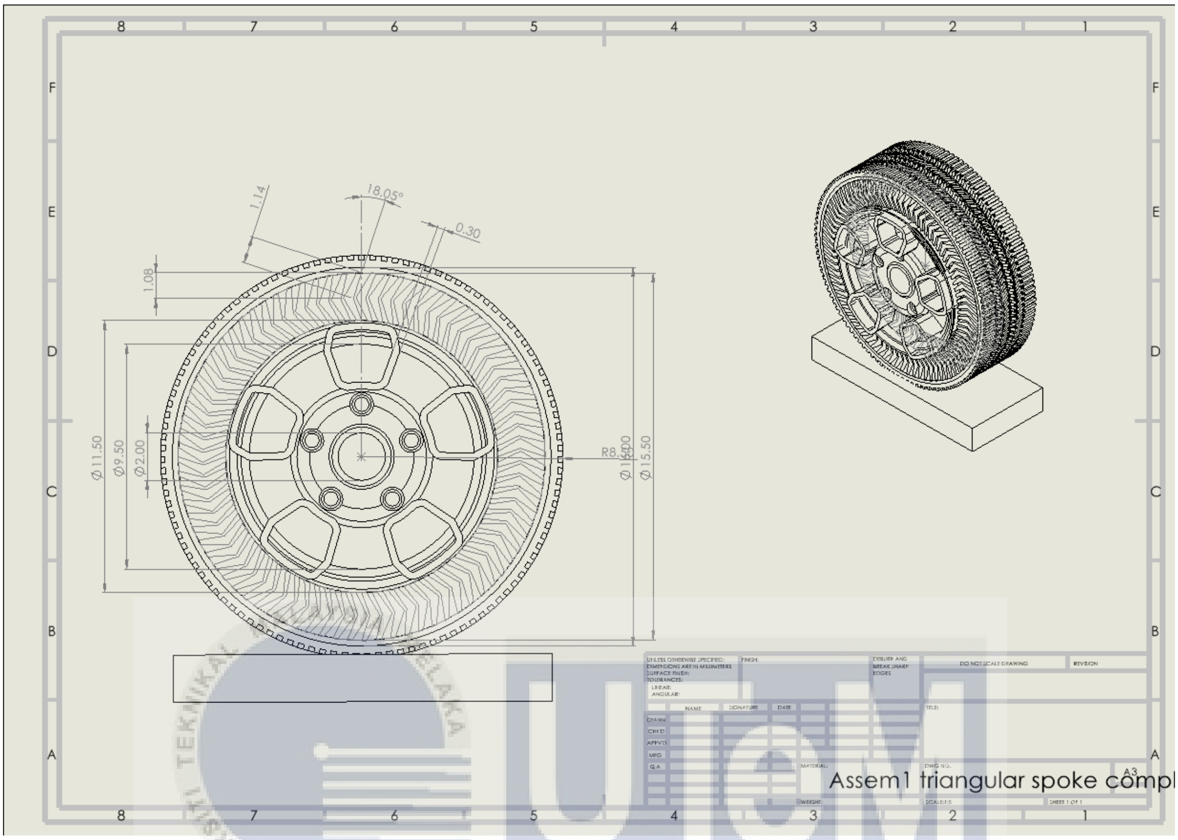
APPENDICES

APPENDIX A Project Planning Schedule (Gantt Chart)

NO	TASK	WEEK														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Planning the spoke design															
2	Confirming spoke design															
3	Designing the tire parts															
4	Modifying the designs															
5	Assembly the tire parts															
6	Assigning the gap and penetration for the part's connection															
7	Collecting data for material properties															
8	Assigning material															
9	Place a remote load and run simulation															
10	Collecting data needed for the comparison															
11	Finalise the outcome with SV's confirmation															
12	Correcting and editing the report for PSM 2															
13	Completing the full report for PSM 2															
14	Presenting the completed project to the panels															

APPENDIX B TWEEL (TRIANGULAR)



APPENDIX C HONEYCOMB