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INITIAL PROPOSAL

The analysis of stone trapping in tire tread for various road conditions

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1. INTRODUCTION

1.1 Background

The automotive industry has progressively advanced into one of the world's largest economic sectors due to its high demand with a huge number of users worldwide. Since the 1860's, automobile has greatly changed the society's life by giving them an opportunity to expand their horizon and improve on their lives [1]. In this era of modernization, many improvements have been made on the components of the vehicle to deliver the best for the vehicle user. One of the most important vehicle components is the tire because tires is the only components of the vehicle that meets the surface of the road. A common issue that the user will face is the short lifespan of the tire which is caused by the tire damage or wear and tear after some period. According to a previous study, an estimation of 800 million of scrap tires had been disposed around the world and is expected to increase by 2% each year due to the rapid increase in road users [2]. Therefore, prolonging the lifespan of a tire has always been the main challenge for the car maker and tire manufacturer around the world. The types of tire damages include punctures, cuts, impacts, cracks, bulges, and irregular wear [3]. Typically, the punctures and cuts are caused by many things like foreign objects/debris such as stones getting trapped between grooves of the tire. **Figure 1** below shows the tread pattern components of a tire.

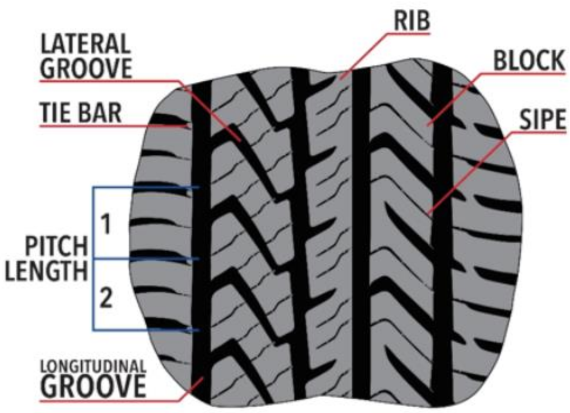

Figure 1. Tread Pattern Components [4]

The tread pattern components of the tire play a huge role on how well the vehicle reacts to different road conditions. The tread pattern design of a tire varies depending on the user's wants as well as the road condition. Every specific tread pattern is important in how they can impact the tire performance in terms of its handling and how much traction can the tire provide depending on the driving conditions. The five main elements of the tire tread's pattern consist of the grooves (longitudinal/lateral), tread blocks, sips, cross slots and ribs [5]. As shown in **Figure 1** above, grooves are the pattern between the ribs that circulates around the tire. Ribs are the elevated pattern which formulate the tread blocks. The tread blocks are also elevated rubber parts that meets the road surface. The cross slots are shaped into a tread element which helps to prevent hydroplaning and lastly the stipes are tiny slits that shaped into tread blocks which helps with the traction [5].

Looking deeper into the tread design of the tires, these are the three most common types in the market which are the symmetric tread tire, asymmetric tread tire and directional tread tire [5]. Among these three tread patterns, symmetric tread pattern tires are the most common ones among the road users followed by the asymmetric and directional tire tread. These tires are very distinct from one another in terms of their tread design/appearance as they are properly engineered their own purposes.

Although there are many types tread patterns out in the market, the issue of stone trapping is still prevalent. This is because the stones can still be trapped in the tires even if the width, depth, and the angle of the groove are adjusted [6]. Too little treads on the tire may results into an unsafe driving conditions for the road users. Besides, a shallow groove may also result in a shorter tire lifespan since the wear volume of the tire had been reduced [7].

The occurrence of stone trapping normally happens in a moving vehicle and it varies depending on stone structure. When the vehicle is in motion, the downward pressure of the tires forces the stone to slide in between the grooves. In some rare cases, stone trapping might puncture the tire and eventually affects the handling of the vehicle that leads to crashes. If the stones are not removed for some time, it may also affect the tire balance due to the uneven tread wear in a long run.

Since this issue deeply affects safety of road users, therefore it is vital to address it by analyzing the influence of tire tread pattern on stone trapping and the characteristic of the pattern on the optimum road conditions. Moreover, this project title addresses to one of the 14 National Academy Engineering (NAE) Grand Challenges which is to engineer the tools of scientific discovery [8]. The aim of this research is to provide a better understanding of how the stone trapping mechanism occurs in the tire and to determine the optimum performance of the tire tread pattern in different road conditions. This research will be conduct by using SolidWorks program and ANSYS finite element analysis method (FEA).

1.2 Research Questions

1. How does different tire tread pattern could influence stone trapping on the dry and wet road surfaces?
2. What is the most optimum tire tread design that provides the best driving performance to the road users?

1.3 Research Objectives

1. To simulate stone trapping performance under various tire tread pattern geometry using ANSYS software.
2. To assess the tire tread pattern with optimum performance in different road conditions using Finite Element Analysis (FEA).

1.4 Hypotheses

The symmetrical tread tire that has more longitudinal groove pattern are more prone to stone trapping and is more likely to occur on the dry road surface than the wet road surface. The asymmetrical tire tread pattern is the most optimum tread design, considering it provides sufficient protection from the risk of hydroplaning as well as providing dry road traction.

1.5 Scope and Limitation

Before conducting a research, it is important to identify the scope and limitation of the project to fully understand the topic that is being studied. The scope of this research topic is to determine which tread patterns are most prone to stone trapping and the performance of these tire will be evaluated in different road conditions. The parameters set for the road condition is limited to the Malaysia's environmental stipulation, which means only wet and dry road surface will be taken into consideration. Besides that, only existing tire tread pattern will be chosen in this project, and no designing of tread pattern is required since the focus of this study is to understand how the stone trapping mechanism works in tire tread pattern. The experiment will only be conducted by using ANSYS finite element analysis, which is appropriate and feasible enough to achieve the objectives of this project. Thus, machine testing will not be considered in this scope of study. Modelling of the tire tread pattens, surface of the road and the irregular stones is limited to the use of SolidWorks software while the simulation on these 3D CAD models is limited to ANSYS software. This is because all the Mechanical Engineering students from Taylor's University had been exposed to both of this software throughout the Degree program and both software will be provided by the Taylor's University computer lab.

2. LITERATURE REVIEW

Considering the tire tread pattern and rubber compound properties are the hypothetical factors that contribute to stone trapping and the performance of a vehicle, a few previous researches focusing on these factors will be reviewed under this section.

2.1 Effect of tread pattern on tire's behaviour

This section will be highliting the behaviour comparison between two different tire treads on a rigid surface. The experiment was based on two commercial high-flotation tire types, which were the high-flotation tractive tread (TT) belted-bias tire and smooth-tread (ST) belted-bias tire without lugs as shown in **Figure 2** below. The rubber compounds for both tires used were of the same mechanical property. This study was conducted using a single wheel testing device to perform the traction test with these tires on rigid and deformable surface.

Figure 2. Tractive tread tire (left) and Smooth tread tire (right) [9]

From the investigation, the results showed a notable deflection of up to 23mm in tire stiffness between both tires [9]. The tire stiffness varies with the deformation in two stages. The first stage specify on the influence of tread structural stiffness while the second stage indicates the influence on the sidewall stiffness. Based on the graph shown in **Figure 3** below, ST showed a greater tire stiffness than TT in the first stage. However, the tire stiffness for both ST and TT started to converge and became similar in the second stage [9].

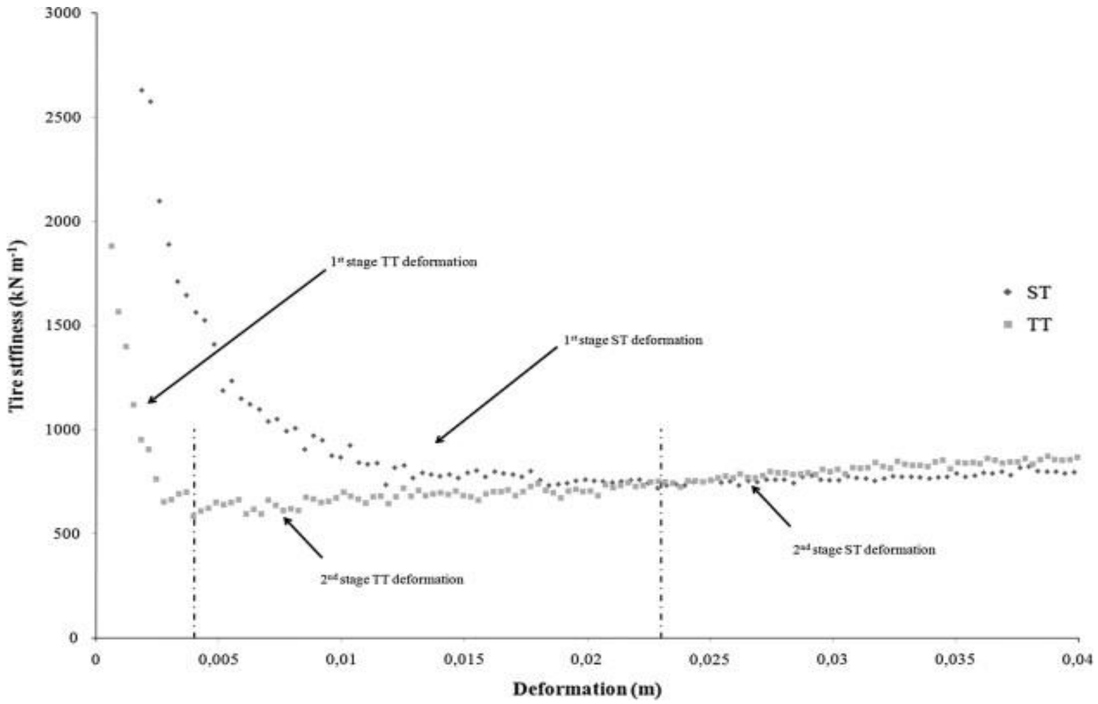

Figure 3. Stiffness against deformation graph [9]

Besides tire stiffness, it was also identified that the radial load could influence the contact surface area. In this case, it was found that the ST had a better contact surface area compared to TT [9]. This is mainly due to the tread difference in both of these tires whereby only the extended tread blocks of TT were touching the ground while the groove area between the blocks was not contributing any load distribution on the surface. On the other hand, the ST had most of its entire area coming into contact with the rigid surface and this creates more load on the surface. However, TT proves to have a better contact area when it was tested on a deformable surface because the groove area between the blocks were in contact with the deformable surface.

Furthermore, the ST appeared to have a lower contact pressure than TT because the surface of ST had the tendency to contribute a uniform stress distribution over the rigid surface while TT doesn’t [9]. On the other hand, the claws from TT had a high concentration of stresses acting on it.

2.2 Effect of carbon black on mechanical properties of rubber

The basic rubber compound consists of Natural Rubber and Styrene Butadienc Rubber. However, it was found that rubbers without filler materials have a very weak mechanical and physical strength [10]. The most popular filler material that has been added into tires is carbon black because it has a tendency to strenghten the properties of rubber vulcanizate. In this research, an experiment was conducted to identify how different carbon black grades could affect the physical properties of the rubber. The carbon black grades used in this experiment were N339/N375 and N550/N660 because they are commonly used in tread rubbers of the passenger tires [11].

The physical properties that were being analysed were the hardness, rebound resilience, tensile strength and tear strength. As for the hardness test, it was shown that hardness values increased by 3 units by substituting both the carbon black grades from N375 to N339 and N660 to N550. Besides, it was also observed that there was a bigger influence on the hardness value when a higher grade of carbon black was used in the absense of oil. From this hardness test, it was found that the hardness and modulus were influenced by the torque. When the torque of the compound increases, the hardness of the compound will also increase [10]. From the rebound resilience test, all the carbon black grades could not show any significant change in its properties. However, there was an increase in resilience when the N550 carbon black grade was substituted from N660 grade but there was a doubt that the hardness value had dropped in this case. From a previous findings, it was deduced that the hardness is inversely proportional to resilience [10]. After conducting this resilience test, it was found that the resilience will only increase when the hardness of the compound decreases [10]. As for the tensile strength test, all the carbon black grades show no effect on the physical property of every compounds [10]. The tear strength test showed some effects unlike the tensile strength test. There was an increase in tear strength by 4 units with the use of N339 carbon black grade. From this test, it shows that the tear strength of the compound increases with a smaller particle size (N339 carbon black instead of N375) [10].

2.3 Effect of tire tread pattern on the effective contact area

In this research, it was found that the tire tread pattern, tire load and tire inflation pressure were the 3 factors that influence the effective contact area. By utilizing the three way factorial ANOVA method on these 3 factors, they were assumed to have no interactions between each other. Hence, the main effect among these factors can be determined from this study [12].

From the statistical analysis, it shows that the tire load contributes the highest effect to the actual contact area followed by tire tread pattern and tire inflation pressure and the approximate variation was as shown in **Table 1** [13].

Table 1. Approximate variation in the contact area [13]

Factors	Approximate variation
Tire Load	51%
Tire Tread Pattern	37%
Tire Inflation Pressure	9%

From the results obtained in this research, it shows that the increment of tire inflation pressure by 50% will cause the actual contact area to decrease by 17% [13]. Besides that, an increase in tire load by 50% will cause the actual contact area to increase by 42% [13].

To measure how each of these tread pattern affecting the real contact area, 7 different tire tread patterns of the same size were used to identify its approximate variation. The tread pattern of the tires chosen varies from low to extremely high contact areas (worn out tire). Regression analysis were conducted in this study to estimate the effective contact area. The final result of this study was as shown in **Table 2** below. From the results, the Dunlop EC 201 tire model was categorized as the low contact area tire while a completely worn out tire was proven to have extremly high contact area [13]. In addition, this study also shows that the traditional method of estimating the contact area is inappropriate as it overestimates the actual tire contact area by up to 92% [13].

Table 2. Contact area measure for different tire models [13]

Tire Models	Contact Area measure
Dunlop EC 201 tire	Low
Dunlop SP Sport J3 tire	Intermediate
Sime Astar 100 tire	High
Complete worn out tire	Very High

Therefore, it can be concluded the contact area will increase with an increment in tire load and a decrement in tire inflation. On the other hand, it was also deduced that the traditional method of estimating the tire contact area is inaccurate.

2.4 The impact of tread pattern and inflation pressure on the risk of hyrdroplaning.

A research had been done to compare how these different tire tread pattern could influence the rate of hydroplanning. The grooves pattern on the tire was set to be the manipulated variable in this investigation. Six different tire groove patterns used were as shown below in **Figure 4**. The groove and rib width for these six tires were kept constant throughout this study in order to ease the comparison. When comes to identifying how these different tire tread groove patterns would affect the risk of hydroplanning, the hydroplanning speed was evaluated in this case. The finite element approach method was used in this hydroplanning analysis. In general, it was found that the hydroplanning speed increases with the groove depth of the tire while decreases when the water thickness of the pavement surface increases [14].

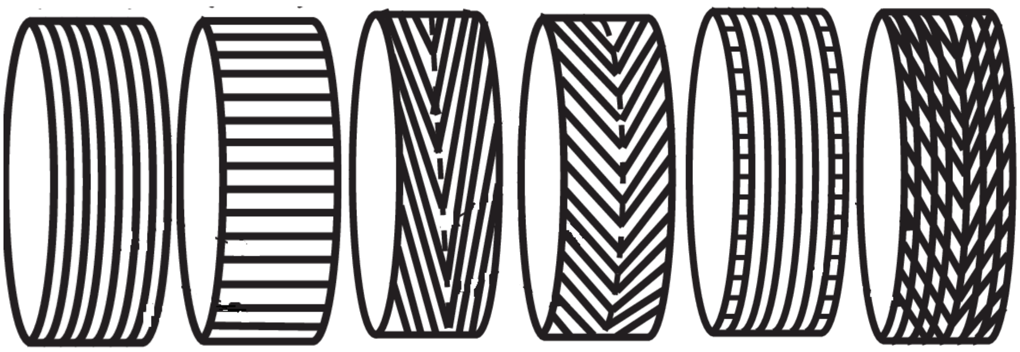

Figure 4. Tire groove pattern: longitudinal, transverse, 20 degrees V-cut, 40 degrees V-cut, combination of horizontal and vertical, combination of longitudinal and 20 degrees V-cut (left to right)

The analysis demonstrated that the transverse groove pattern works best when the vehicle was on the forward sliding movement while the longitudinal groove patterm performs the best for the lateral sliding movement [14]. On the other hand, the V-cut groove pattern provides a sufficient protection from the risk of hydroplanning for both forward and lateral vehicle movement where the hydroplanning speed increases with the inclination angle of the V-cut groove up to 90 degrees. From the result of this investigation, it was shown that the combination of longitudinal and V-cut grooves provides the optimum level of protection from the risk of hydroplaning for both movement manner.

From the previous studies of a few researches, it was observed that an increase in tire inflation pressure would increase the hydroplaning speed [15]. In accordance with the past findings, the risk of hyroplaning will increase with an underinflated tires and the pavement surface with a greater water thickness.

2.5 Effect of treadless tire rolling over irregular stones

Previously, a research had been conducted to study the effect of a tire rolling over various types of stones. A few sets of treadless tires with different rubber thickness were used to identify what were the difference in impact among them in this study. The dimensions of these tires were modelled according to the existing tire. Then, a dynamic finite element analysis test was performed to simulate these tires rolling over the stones under typical driving speed.

From the simulation test result, it shows that the rubber thickness of the tire which ranges from 6mm to 7.5mm causes lofting up to 30 degrees of an angle [16]. The lofting of these stones could reach a vertical speed of up to 5m/s. On the other hand, the simulation test results shows that tire with a rubber thickness of 9mm and above was able to surpressed the occurrence of lofting and pinch launching within a small range of the stone position [16]. Other than lofting, the tire tread also shows no evidence that a stone could stick onto its surface when the tires was completely or partially overlaping the stone. Only viable damage was seen at the leading edge of the tire during the rotation phase when the stones got rolled over.

A dynamic finite element test was also designed to identify the load-indentation measure and it shows that the indentation displacement of the tire increases proportionally with the load applied to it until it reaches the maximum displacement of 24mm. From the indentation of the tire, it illustrated that there was a difference in 6% of the potential energy transferring to the stones that were rolled over by the tire and this eventually causes lofting [16].

2.6 Summary

From the previous researches conducted that was covered in the literature review, the main parameters relating to the tire tread pattern and rubber compound properties are summarise as shown in **Table 3**. Based on these past researches, it can be seen that these studies conducted were focusing mainly on the tire tread pattern affecting the stiffness, contact area and pressure, and the hydroplaning rate. However, there were non of the studies that are focusing on the stone trapping mechanism and how the stone trapping could affect the performance of the tires. Hence, this research study will be conduct to focus on how different tread patterns could influence stone trapping and also to determine the performance degradation in these tires.

Table 3. Summary from the research findings

Parameter	Study Focus	Author	Findings
Tire Tread Pattern (Smooth and Tractive tread)	Tire stiffness	Luis A.P Barbosa and Paulo S.G Magalhaes [9]	ST has a greater stiffness than TT at the first stage.
	Contact Area		ST has a better contact area than TT on rigid surface, TT has a better contact area than ST on deformable surface.
	Contact Pressure		TT has a higher contact pressure than ST.
Filler Material (carbon black grades)	Mechanical Properties of Rubber	Mohd Bijarimi, H. Zulkafli and M.D.H Beg [10]	High carbon black grade causes high torque with low curing times on natural rubber than the low grade.
			Use of low and high carbon black grade shows little effect on hardness, resilience, tear, and tensile strength of natural rubber/styrene butadiene blend.
Tire Load, Inflation Pressure, and Tread Pattern (Low to high contact measure)	Actual Contact Area	Ratnasamy Muniandy, Danial Moazami, Hussain Hamid and Salihudin Hassim [13]	Tire load has the most influence on actual contact area at approximate variation of 51% compared to tread pattern (37%) and inflation pressure (9%).
			Increment of inflation pressure by 50% will decrease the actual contact area by 17%.
			Increment of tire load by 50% will increase the actual contact area by 42%.
			A complete worn out tire and a conventional on road tire (low contact measure) has a mean actual contact area difference of 54%.
Tire Tread Pattern (Groove type)	Hyrdroplanning rate	T.F.Fwa, Santosh S. Kumar, Kumar Anupam and G.P. Ong [14]	The hydroplanning rate decreases with an increase of V-cut groove angle of up to 90º. The hydroplaning rate decreases by 14.3% with an increase in groove depth from 1mm to 9.8mm.
Tire Inflation Pressure		C. Kasbergen [15]	The hydroplaning speed is reduced by 1.25 times when the tire inflation pressure is increases from 110kPa to 165.5kPa.
Thickness of the Tire Rubber	Stone lofting	S.N. Nguyen, E.S.Greenhalgh, L.Iannucci, R.Olsson, P.T.Curtis [16]	Tire thickness ranges from 6mm to 7.5mm causes lofting up to 30 degrees in angle and a horizontal speed of up to 5m/s.
			Tire thickness of 9mm and above able to surpress lofting and pinch launching.
Load Force	Indentation of tire		A 6% of potential energy was transferred to the stone from the deformed tire caused by indentation.
			An applied load of 1900N cause an indentation displacement of 24mm.

3. RESEARCH METHODOLOGY

The research methodology of this project is applied through qualitative and quantitative research. The flowchart shown in **Figure 5** below is an overview of this research project for FYP 1 and FYP 2.

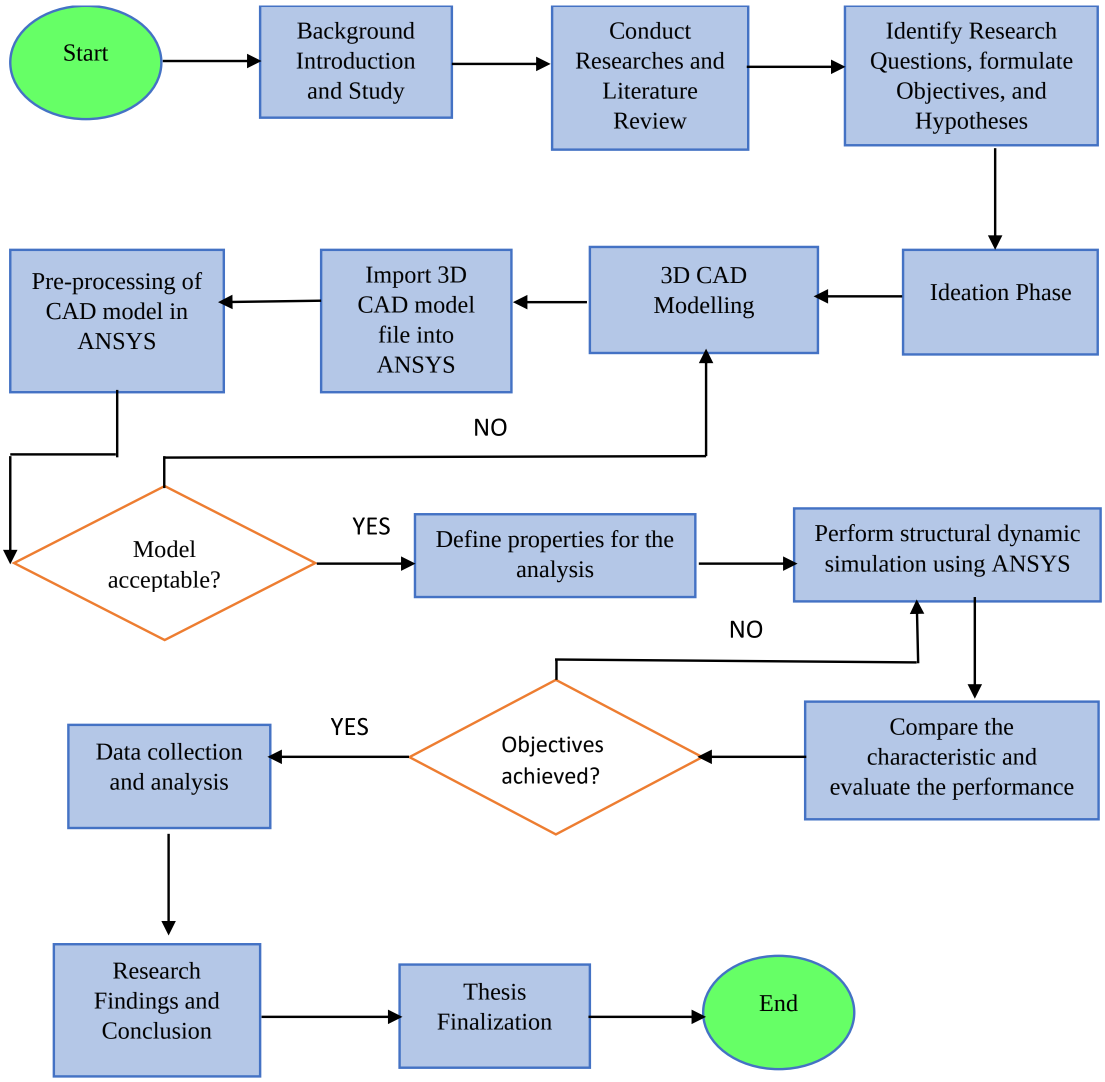

Figure 5. Flow Chart for FYP 1 and FYP 2

The research is started off with the background study of different tire tread patterns and how they perform on various road conditions. The problem statement such as the common issues faced by the road user can then be identified and this leads to the objectives of the research. Furthermore, a brief literature review regarding the tire tread pattern and the rubber compound properties are carried out to spot any knowledge gaps or unsettled challenges that can be address in this research. This stage is significant because it helps with the familiarization of the present knowledge regarding on this research topic. From there, the research questions, objectives and hypotheses are formulated. During the ideation phase, the parameters of every variables and the design criteria of the tread patterns will be identified before proceeding with the modelling and simulation stage. Three different selected tire tread patterns will be modelled using SolidWorks. The two other 3D models which are the road surface and stones will also be created using this software. The mechanical properties of these tire will be simulated using ANSYS in achieving the objectives. Moving into data collection and analysis stage, a decision matrix will be used to evaluate the best/ most suitable tread pattern that provides the most optimum performance.

3.1 3D CAD Modelling

SolidWorks software will be utilized to create the 3D model of all the selected tire tread pattern that will be used for this analysis. The parameter of the 3D CAD model drawing will be based on the existing tires in the current market. The detail of the tire tread surface, such as grooves, is considered in the 3D CAD model as they will be included in the finite element mesh during the simulation stage. A simple road surface model which acts as a fixed support for this analysis will be drawn using SolidWorks. Lastly, a few irregular stones model of different sizes will also be created using this software. The drawing for this stone model will be roughly based on geometric parameters which matches the average stones that found in Malaysia freeways.

3.2 ANSYS Simulation

A dynamic finite element analysis (FEA) program will be used to simulate the tire tread patterns rolling over the stones to evaluate how stone trapping reacts on different tread patterns. This provides a better understanding on how the stone trapping mechanism work. Besides, the dynamic FEA will also be used to simulate the performance of these tire tread patterns that has stones trapped in the tread on a wet and dry road condition. The maximum stresses and total deformation will be evaluated as so to help with the identification of any possible failures on any of these tread pattern’s region. This helps to assess which tread pattern provides the most optimum performance in these road conditions.

4. EXPECTED OUTCOMES

The expected outcome based on the first objective of this research project is to understand how the stone trapping mechanism works in tire tread pattern during the simulation stage. The simulation stage will be done by using 3 common existing tires which are the symmetrical tire, asymmetrical tire, and directional tire. The reason these 3 tires are being chosen because they are extremely different in their tread design and they are also commonly found on the market. The outcome from this simulation will able to identify which type of tire tread pattern has the highest possibility of trapping stones in its groove. The symmetrical tire is expected to have most stones trapped in its groove since it has the most longitudinal groove compared to the other types of tread pattern. The outcome of this objective is significant because the second objective highly relies on it as they are related to one another.

The second expected outcome of this project is to assess the performance of these stone trapped tires and prove that there will be a performance degradation in these tires. The simulation test using ANSYS finite element analysis will be based on different road conditions to identify how these tires react differently. The performance of these tires is characterized in terms of their traction and longevity. Hence, the maximum stresses and total deformation obtained from the simulation test will be used to evaluate these tires. It is expected that the symmetrical tire will have the highest rate of performance degradation which causes the tire to wear out faster. Next, it is also expected that the wet surface will shows a greater effect in the degradation of the tire traction than the dry surface.

5. TIMEFRAME & BUDGET

5.1 Project Budget

Since this is a simulation-based research project, no budget will be allocated. The modelling and simulation of this project will be performed using the SolidWorks and ANSYS software. Both software will be provided by the Taylor's University computer lab.

Table 4. Budget Breakdown

No.	Item	Cost (RM)	Source
1	SolidWorks software	0.00	Taylor's University Computer Lab
2	ANSYS software	0.00	Taylor's University Computer Lab

5.2 Milestone

The milestone of this project for both FYP 1 and FYP 2 will be listed below:

FYP 1:

1. Submission of initial proposal (Week 6)
2. Submission of EURECA abstract and interim report (Week 12)
3. Submission of weekly meeting records (Week 13)
4. Oral presentation and submission of EURECA poster (Week 13 and Week 14)

FYP 2:

1. Generating of 3D CAD model (Week 1)
2. Simulation test (Week 2)
3. Discussion of results and conclusion (Week 6)
4. Submission of EURECA conference paper (Week 8)
5. Submission of thesis writing (Week 13)
6. Oral defense on thesis and submission of weekly meeting records (Week 14)

5.3 Time Frame

Figure 6. Gantt Chart for Final Year Engineering Project 1 (FYP 1)

No.	Tasks	Week													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	**Introduction to Final Year Engineering Project 1**														
1.1	Briefing on Scheme of Work by the module coordinator														
1.2	Selection of project title														
1.3	Project title approval by the module coordinator														
1.4	First meeting with project supervisor														
2	**Initial Proposal**														
2.1	Introduction														
2.1.1	Brief Introduction and Background of the project														
2.1.2	Research on issue faced from stone trapping														
2.1.3	Element of Tire Tread Patterns														
2.1.4	Designs of Tire Tread Patterns														
2.2	Literature Review														
2.3	Project Questions, Objectives and Hypotheses														
2.4	Scopes and Limitations														
2.5	Research Methodology														
2.6	Timeframe														
2.7	Budget														
2.8	Expected Outcomes and References														
2.9	Submission of Initial Proposal														
3	**Further Research**														
3.1	Effect of Tread Depth on the Rolling Noise														
3.2	Finite element simulation of stresses with different tread pattern														
3.3	How to create a testing environment to determine stone trapping mechanism														

3.4	Research finalization														
4	**Interim Report**														
4.1	Introduction														
4.2	Literature Review														
4.3	Research Methodology														
4.4	Results and Discussions														
4.5	Conclusion and Expected Outcomes														
4.6	Submission of Interim Report														
5	**EURECA and Oral Presentation**														
5.1	Preparation of Abstract for EURECA Conference														
5.2	Submission of Abstract for EURECA Conference														
5.3	Preparation of Slides for Oral Presentation														
5.4	Oral Presentation														
5.5	Preparation of EURECA poster														
5.6	Submission of EURECA poster														
5.7	Submission of Weekly Meeting Records														
	Legend		Planned							Deadline					

Figure 7. Gantt Chart for Final Year Engineering Project 2 (FYP 2)

No.	Tasks	Week													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	**Introduction to Final Year Engineering Project 2**														
1.1	Briefing on Scheme of Work by the module coordinator														
2	**Conducting Project**														
2.1	Generate Drawings of Tire Tread Pattern using SolidWorks														
2.2	Perform Analysis on the Tread Pattern using ANSYS FEA														
2.2.1	Stone Trapping Test														
2.2.2	Tread Pattern Performance test on different road surface														
2.3	Tabulation of Results														
2.4	Results and Discussions														
2.5	Conclusion and Recommendations														
3	**EURECA**														
3.1	Preparation of EURECA Conference Paper														
3.2	Submission of EURECA Conference Paper														
3.3	Preparation of EURECA Paper Presentation														
3.4	Submission of EURECA Paper Presentation														
4	**Thesis and Oral Defense**														
4.1	Introduction														
4.2	Literature Review														
4.3	Research Methodology														
4.4	Results and Discussions														
4.5	Conclusion and Expected Outcomes														
4.6	Submission of Thesis														
4.7	Submission of Weekly Meeting Records														
4.8	Oral Defense on Thesis														
Legend			Planned						Deadline						

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