Design and Numerical Analysis of a Spring Tire for Replacement of Inflatable part of Rubber Tire

Submitted by

Batiru Tasew Abebe

A Thesis Submitted to

The Department of Mechanical Engineering,

School of Mechanical, Chemical, and Materials Engineering

Presented in Partial Fulfillment of the Requirement for the Degree of

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Office of Graduate Studies

Adama Science and Technology University

June 2023

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Also I would like to express my deepest gratitude to Ambo University and adama science and Technology University, deeply indebted to mechanical engineering department for their facilitating and funding me to study my MSc program.

DECLARATION

I hereby declare that this Master's thesis entitled "**Design and Numerical Analysis of a Spring Tire for Replacement of Inflatable part of Rubber Tire"** is my original work. That is, it has not been submitted for the award of any academic degree, diploma, or certificate in any other university. All sources of materials that are used for this thesis have been dully acknowledged through citation.

____________________	________________________________	_____________________
Name of student	Signature	Date

RECOMMENDATION

I, the advisor of this thesis, hereby certify that I have read the revised version of the thesis entitled "**Design and Numerical Analysis of a Spring Tire for Replacement of Inflatable part of Rubber Tire** " prepared under my guidance by Batiru Tasew Abebe submitted in partial fulfillment of the requirements for Master of Science in automotive engineering. Therefore, we recommend the submission of a revised version of the thesis to the department following the applicable procedures.

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Major Advisor	Signature	Date

APPROVAL PAGE

We, the advisors of the thesis entitled "**Design and Numerical Analysis of a Spring Tire for Replacement of Inflatable part of Rubber Tire"** developed by Batiru Tasew Abebe; hereby certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

Major Advisor	Signature	Date

We, the undersigned, members of the Board of Examiners of the thesis by Batiru Tasew Abebe have read and evaluated the thesis entitled "**Design and Numerical Analysis of a Spring Tire for Replacement of Inflatable part of Rubber Tire** " and examined the candidate during open defense. This is, therefore, to certify that the thesis is accepted for partial fulfillment of the requirement of a Master of Science in Automotive Engineering.

Chairperson	Signature	Date
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Finally, approval and acceptance of the thesis is contingent upon the submission of its final copy to the Office of Postgraduate Studies (OPGS) through the Department Graduate Council (DGC) and School Graduate Committee (SGC).

Department Head	Signature	Date
School Dean	Signature	Date
Office of Postgraduate Studies, Dean	Signature	Date

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ABBREVIATIONS

ANSYS	Analysis Systems
FEA	Finite element analysis
LS-DYNA ANSYS	Livermore dynamic explicitly analysis software
UT	Internal Energy
KET	Kinetic Energy

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ABSTRACT

It is well known that the most common tires are pneumatic tires, which are complex vehicle components with intricate material properties and highly non-linear behavior that have a significant impact on vehicle handling. A mixture of steel, nylon, polyester, and rubber, it takes the form of a round object and is responsible for most of the vehicle's tire properties. The drawback of these new tires is, the increased hardness of the solidity of tires makes them always have unstable, vibrating, shaky rides which are not comfortable like the previous pneumatic ones. The purpose of this thesis is to design and perform numerical analysis of spring tires that can replace inflatable pneumatics tires. The method used in this paper is, a specified vehicle tire selected and the model developed by the 3D modeling software Ansys Space Claim and analyzed with dynamic explicit analysis software Ansys LS Dyna Software. A comparison was made between the existing model and the modified model. The simulation was carried out with four cases. The first case (i) of analysis is a selection of a better spring model, case (ii) of analysis is recommended number of springs on the circumference of the tire, case (iii) of analysis is testing the spring tire model based on different material properties, case (iv) analyzing recommended spring type, spring number, and materials and comparing with a pneumatic tire which has 33psi internal pressure. From three different spring type wire types, the result shows that single wire spring has a good energy absorption mode which is 28% better than flat spring and 4% better than C section cross section spring. There the number of wire springs used circumferential radius on a wheel rim. The percentage of mass change is estimated by adding the number of sprigs mass with Rubber and wheel rim. The decided number of springs for the designed spring tire model is 100. The decision is made by comparing the percentage of weight and resilient energy change of arrayed springs from numerical simulation case studies. From the analysis of 50, 100, and 150 numbers of the spring model. The third case analysis carried out based on material properties makes AMS 7233, ASTM A 1000, ASTM 303, and Inconel 718 Materials are rejected from the case for they have big dynamic fluctuation energy loss and large deformation. From these finally, the selected material for the spring tire is ASTM A231 for its good in deformation than ASTM A 679. And the selected material of the proposed spring is simulated with 100 number of spring shielded by the original tire rubber and their deformation and resilient energy is compared with a pneumatic tire.

Keywords: *Existing tire, resilient energy, spring tire*

CHAPTER ONE

INTRODUCTION

1.1. Background of the Study

A tire is a circular and ring-shaped vehicle component that makes contact with the ground. Tires are attached to wheels and compressed air is used to inflate them. Since its inception, natural rubber has been the most widely used material in tire manufacturing. The most prevalent type of tire is made of leather bands wrapped around a wooden wheel. The leather was quickly replaced with metal bands that lasted considerably longer. Rubber tires, on the other hand, are created by vulcanization, which occurs when rubber is heated with sulfur (Gawdzik et al., 2020). Rubber is a soft substance that has been turned into a strong, flexible material that is perfect for tires. As vulcanization grew more efficient, rubber became the new material of choice for tires. They are strong, can tolerate mild damage, and absorb shock well (Fazli & Rodrigue, 2020; Van Hoek et al., 2021).

At low temperatures, low-quality rubber tires stiffen, resulting in an uncomfortable ride for the machine operator (Drozd et al., 2022). Top-tier solid tires, on the other hand, often feature a special addition to the rubber composition that prevents tire stiffening when it is cold. The weight, on the other hand, makes for a challenging ride. The research was conducted on non-pneumatic tires, which are not protected by environmental weight. It's a hybrid tire that negotiates expressiveness without the usual wheel center gathering. The researcher created a robust internal center point connected to the vehicle shaft and encircled by polyurethane spokes (Drozd et al., 2022).

Other issues with airless tires include dissipating the heat generated while they are driven. Instead of air, airless tires are occasionally filled with compressed polymers (plastic). The current study focuses on spring-formed configurations in vehicle tires, in other words replacing inner tubes that contain air in the tire by spring configuration. This research involves deformation, internal energy, and dynamic load measurements on a typical tire, as well as design and analysis. The novel feature in the spring-formed tire then transfers to the classic tire without air inflation to raise the recommended tire parameters by using appropriate spring material selection.

These days, an industry standard lab test for evaluating the dynamic inputs to the wheel axle is performed by rolling a tire assembly mounted on a pinned axle and loaded to a road drum with a mounted surface cleat. The dynamic inputs are assessed by measuring and analyzing the pinned axle force response components, primarily the in-plane vertical and longitudinal directions. These types of tests have been performed since the late 1950s [1], and from the late 1990s, finite element models have been used for simulation [2,3].

The dynamic response was shown to be mainly dominated by belt inertial and carcass compliance and effectively captured using the ring-based approach [4]. Currently, commercially available ring-based tire models such as MF [5] and FTire [6] (a flexible belt model based on a multi body lumped-mass approach) are commonly used by vehicle companies. They are preferred because of their significantly faster computational speed, empirical creation, and limited access to finite element tire models that are associated with protected intellectual property. Zeglaar [7] and Schmeitz [8] performed a comprehensive literature review of dynamic tire models and developed the rigid ring-based tire model (MF) for simulating tire cleat response. Dorfi [9,10] used FTire to study the dynamic response of tires rolling over cleats with different rolling speeds, cleat shapes, tire constructions, and loading conditions.

To understand tire dynamics relevant for tire force transmission, another common approach is using tire vibration mode characteristics and associated understanding to relate the force transmission to ride performance. Numerous studies have shown that the tire in-plane rigid ring modes influence the force response from the cleat [4,11]. These rigid ring modes refer to a fundamental subset in which the belt behaves as a rigid inextensible body without belt bending. Typically, rigid ring modal frequencies are less than 85 Hz; at frequencies higher than this, belt flexibility is important [10,12]. The first objective of this study is to understand how these rigid ring modes are excited. A second set of objectives is to understand what key tire design parameters affect these rigid ring modes and under what conditions they are excited. Physical understanding of these modal sensitivities will be helpful toward providing guidelines for enhancing vehicle ride performance.

1.2 Statement of the Problem

The honeycomb, Spokes, triangle, and diamond structures of airless tires withstand more stress while demonstrating very less overall deformation. As a result, these tires are typically seen on heavy-duty vehicles where the load factor is crucial (Mathew et al., 2017). The major issue with these tires is that their increased stiffness leads them to ride in an unstable, rattling, wobbly manner. With air-filled tires, the wheel absorbs the bulk of the shock. Solid tires cannot absorb shocks.

Pneumatic tires that are air-inflated soften the ride and give a better driving experience. When overcoming potholes, obstructions, and bumps, the air helps absorb shock, resulting in a better ride for the operator. However, with pneumatic tires, it might be difficult to get the exact tire pressure required for the application. Air pressure fluctuations may have a significant impact on tire performance, and finds it difficult to attain the ideal air pressure.

Pneumatic tire's inner tube uses for short period of time because of punctures by pinpoint from the road and this inner tube must be either maintained or replaced. During this, it need maintenance time and maintenance cost. In order to exculed this problem, pneumatic tire replaced by spring tire.

The fact that air-filled pneumatic tires are filled with air can be both a pro and a con. the air gives it a smooth ride, but it also means that the tire is more prone to getting punctures, difficultto get the right tire pressures, and susceptible to temperature change causing poorer handling, less maneuverability, and deflating often at very inconvenient times. (J.D Walter., 2006)To overcome this problem, the researcher considered the metal spring as a replacement for air and the other as the same pneumatic tire to meet the requirement of tire design.

In this thesis selection of a better spring model, analysis of the number of springs on the circumference of the tire, analysis and testing the spring tire model based on different material properties, analyzing recommended spring type, spring number and materials,3D modeling of different spring shapes and Numerical Simulation Using Ansys LS DYNA are well studied.

1.3 Objectives

1.3.1 General Objective

The main objective of this thesis is to Design and Numerical Analysis of a Spring Tire for Replacement of inner part of Inflatable Rubber Tire for overcoming the problems of existing tire behavior.

1.3.2 The Specific objectives

The specific objective of the study is described as,

- To design and model springs with different cross-sections.
- To analyze selected spring models with different material properties using softwarepackage called LS Dyna
- For dynamical analysis, the tire was assembled with selected springs with different spring numbers of level road and bumped surface.

1.4 Significance of the thesis

This study includes the following significance.

- It will minimize the manufacturing workload for the repair with almost no care at all. No need to worry about designing tire pressure with them. But unless replacing them, no need to worry about maintenance too much.
- It will help to improve the safety of automobiles during rides. Because of spring tires are impossible for them to get perforated and go flat. Flats in pneumatic tires, for the most part, are not that common. It'sfairtoassumethatsomeroadswillbemuchworseforpneumatictires.The lack of flats will play a crucial role and spring-form tires will be a better choice.
- Glance at the idea of spring tires for further researchers as new tires and a fundamental significance in its advance is the combination of tire and wheel.

1.5 Delimitation (scope)

The concentration of this thesis is on the Conversion of the pneumatic tire into a spring tire and replacing the inner tubes of the tire that contain air by spring configuration which includes modeling and simulation with dynamic behavior testing software.

1.6 Organization of the thesis

This thesis is divided into five chapters. The first chapter provides an introduction to the theoretical underpinning of conventional tires. This chapter also discusses the issue statement, research purpose, and research scope. The second chapter provides a literature evaluation of existing vehicle tires. This chapter provides an overview of the review and the research gap. The materials and procedures employed are described in Chapter Three. The workflow has been detailed in depth in chronological sequence, and the Finite element technique has also been clarified.

CHAPTER TWO
LITERATURE REVIEW

2.1. Introduction

The tire has three basic functions and purposes; to carry, guide and transmit. Carry the load resulting from the weight of the vehicle and all the overloads linked to dynamic movements of the vehicle, together with any aerodynamic overloads at high speed, at the same time absorbing the irregularities in the road. This chapter examines previous efforts on the subject of tire numerical analysis systems, materials, and the methodology used by researchers. Explain the importance of numerical simulations, which may employ faster computers and simulation. By executing a test in software, it is possible to evaluate and display the concentration of stressors and identify the most affected areas. This allows the changes needed to ensure the system's proper operation to be examined and appraised. As a result, the following terms are used to characterize the research work done by various tire researchers.

2.2. Review of Related Literature

Spring tires are considered non-pneumatic tires. Many types of research on non-pneumatic tires have been undertaken. The examples below are of literature surveys. Mathew et al. (Mathew et al., 2017) studied an airless tire model that employed natural rubber materials in the tread rather than synthetic rubber and polyester rather than nylon in the carcass. The design and materials of several airless tire types were studied and compared to pneumatic tires. A brief structural study of the spokes of an airless tire was performed and assessed using ANSYS software. Their research was carried out on a range of structures, including honeycombs, Spokes, triangles, and diamonds, with an applied force of 1200N. A study was undertaken to compare many structures made of different materials, and the results indicate that a tire with a diamond structure made of synthetic materials deforms less than other structures. According to the design analysis, the Diamond tire construction is more durable and can handle more weight than the other types. Material improvements in the carcass and the tread have also led to a decrease in overall deformation. This work can withstand more force while exhibiting a comparably minimal overall deformation. The study finds that these sorts of tires are best suited for heavy-duty vehicles where the load factor is critical. But the main gap of these studies is material selection

Gasmietal., (Gasmi et al., 2012) created an analytical model for a non-pneumatic tire that is compliant on friction less, stiff terrain. This work's tire model is made up of a thin flexible annular band and spokes that connect the band to a rigid hub. Curved beam theory is used to represent the annular band, which accounts for bending, shearing, and circumferential extension deformations. The impact of the spokes, which are continually dispersed in the model and act as linear springs, is only taken into account in tension, resulting in a nonlinear reaction. The quasi-static, two-dimensional study focuses on how the stiffness qualities of the band and spokes affect the contact patch, vertical tire stiffness, and rolling resistance. In terms of these angles, closed-form representations of contact stress, stress-resultants, and displacements at the centroids of the flexible band cross-sections are expressed. The model was validated by comparing it to two computer models created with the commercial finite element program ABAQUS, as well as experimental rolling resistance data. Experiment findings verify this technique, demonstrating how the quasi-static model may be used to steady state rolling at modest speeds. At greater speeds, spoke dynamics to the spokes should be considered in addition to inertia effects.

Manibaan et al., (Manibaalan et al., 2013) examined airless tires or non-pneumatic tires in a specific structure employing a poly-composite material substitution in place of air. These tires are investigated by contrasting them with pneumatic tires. A brief structural study on the spokes of airless tires that is significant to rolling resistance and fuel efficiency is available. The airless tire must meet the following criteria to function with minimal rolling resistance and give higher fuel efficiency. Because polyurethane composite possesses both elasticity and stiffness, it is suitable for outperforming pneumatic tires in terms of rolling resistance. Based on structural research, polyurethane has a wide range of operations that is suitable for a variety of load applications. This is achieved by altering the geometry of the structure or the properties of the polyurethane composite used. According to the material study, the lack of rubber and increased dominance of polyurethane in the production of an airless tire makes it more eco-friendly and increases fuel efficiency. Rolling resistance is decreased to less than 3% as a consequence, compared to 4-5% in standard tires.

Sanjeev Kumar et al., (Sanjeev Kumar et al., 2021) used a numerical technique to study the design optimization of an airless tire. He notes that it may replace all of the components of a

Typical outspread tire and consists of an inflexible center point connected to a shear band by adaptable, deformed polyurethane spokes and a track band, all of which function as a single unit. As a single item, the pneumatic tire may be changed by an airless tire. The pneumatic tire's challenge is that it has a shorter life, there is a risk of explosion, maintenance costs are high, and pressure monitoring is required. Structures formed of airless tires are composed of robust materials. A quick foundational study on airless tire spokes was conducted and analyzed using ANSYS programming. A study on a range of constructions, including spokes, triangles, odd circular, and hexagonal shapes, was conducted using an applied force of 1000N. A circular tire constructed of engineered materials twists less than other designs, as shown in Figure 2.1, according to a correlation study that was conducted among various buildings made of various materials.

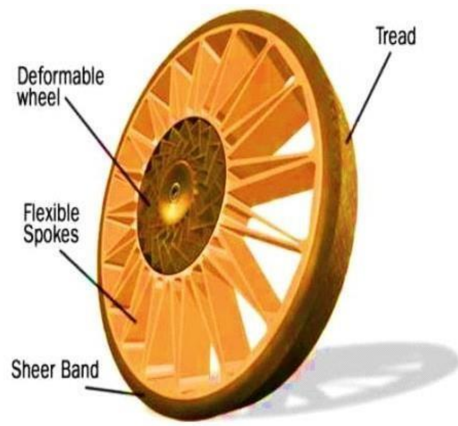


Figure 2.1 Part components of airless tire (Sanjeev Kumar et al., 2021)

According to Sanjeev Kumar et al., (Sanjeev Kumar et al., 2021) the boundary conditions on airless tires incorporate layers of the inner band and the outside band to build a composite structure. Steel rings are also utilized as reinforcement elements in airless tires. The main annoyances of a deficient approach to warm development and driving comfort are frequently addressed by tires. To create an airless tire design, one must be ready to predict the mechanical direction of the tire under actual load. It is crucial to look at how the concurrent spread of concern energy evolved. The forecasting of metallic component acceptance was tested in contrast to the air tire findings. The approval of the metallic component forecast contrary to air tire results got attempted. Using a metal element analysis; they evaluated the distribution of strain energy and deflection beneath loading while the wheel is loaded vertically. The entire tire half is weighed by dividing it into its solid tetrahedral components. Dimensions of the square are E = 2.7 Gpa and

Density = 1400 kg/m3. The same material specifications and a 1000 N wheel load are used for each band. The same edge load distribution at the tire-rim contact is depicted in Figure 2.2 as the common boundary conditions shared by all models. The material parameters of polyethylene are listed in the following table 2.1 with the alternative design form shown in image 2.2.

Properties	Polyethylene
Young's modulus (GPa)	2.7
Poisson's ratio	0.4
Density (kg/m3)	1400

Table 2.1: Properties of Polyethylene (Sanjeev Kumar et al., 2021)

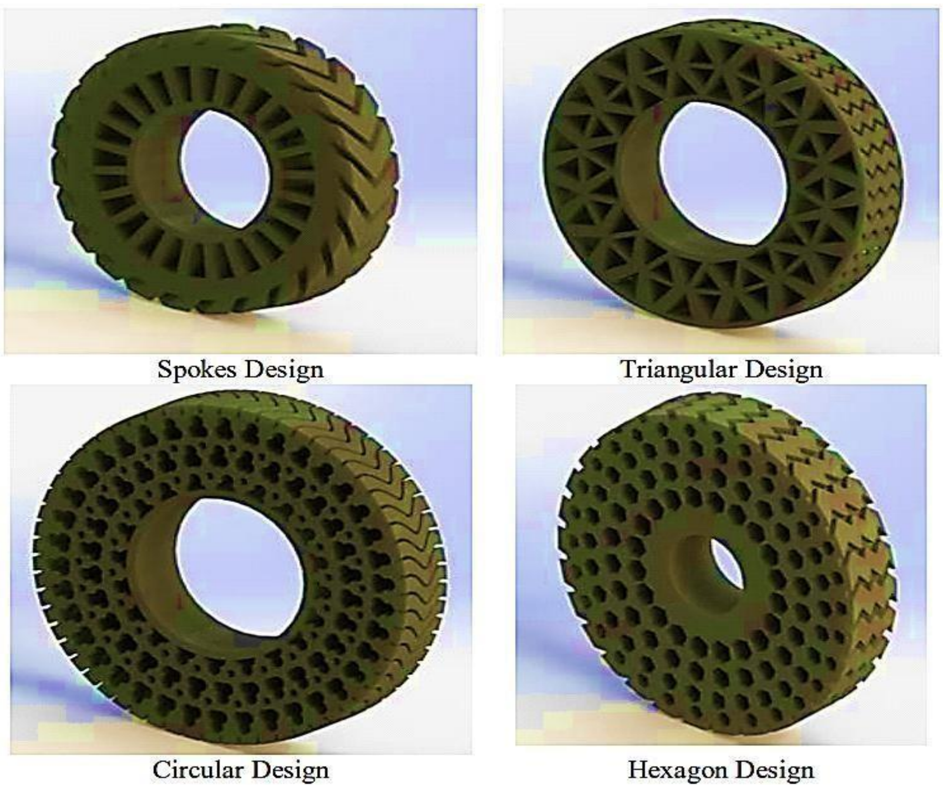


Figure 2.2 Different proposed models (Sanjeev kumar et al., 2021)

The road and tread did not match the order contact conditions, as shown by their load deflection and analysis. The removal is positioned inside the parallel bearing, whereas the avoidance is situated inside the stacking route of the wheel community. The numerical results of the analysis are shown in Table 2.2.The gaps are structural problems and design problems

Table 2.2 Results of Different models (SanjeevKumar et al., 2021)

S No	Design concept	Maximum Total deformation (mm)	Equivalent Stress (Mpa)	Equivalent Strain
1	Spokes	0.010543	10.028	5.2024e-5
2	Triangular	0.019843	24.158	0.00014651
3	Circular	0.0067021	11.343	9.794e-5
4	Hexagon	0.0082758	10.085	3.9268e-5

Shashavali et al. (SHASHAVALI, 2016) presented four-wheeled airless tires, and as described on this page, they designed airless tires to replace pneumatic tires, wheels, and tire systems as a whole. It consists of a tread band, a flexible, bending polyurethane spoke, and a stiff hub that all work together to take the place of every component of a typical radial tire. Airless tires like the Tweel, which have flat-proof construction, can take the place of pneumatic tires on domestic automobiles. However, as a result of its widespread usage in military and construction applications. In this researches the design and analysis of an airless tire for domestic cars; will be followed by a stress analysis study. The model was developed by Professional Engineer and analysis is done in ANSYS. The 3D model analyzed is as follows in Figure 2.3 below.

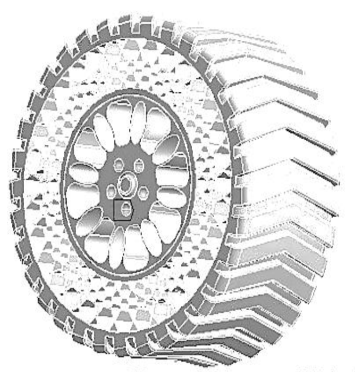


Figure 2.3 Airless tire Imported from Pro-Engineer (SHASHAVALI, 2016)

The results obtained from the analysis are replacing the air tire with an Air-less tire. Air is eliminated in the tire providing good traction, and a cushion effect. The airless tire is analyzed by

The FEA with two materials like Nitrile Rubber and Nylon 4-6. Analysis parameters of Air-less-tire are presented in Table 2.2.

Table 2.3 Material properties of airless tire(SHASHAVALI, 2016)

Material	**Maximum Total deformation (mm)**	**Equivalent Stress (Mpa)**	**Heat Flux**	**Temperature (^{o}C)**
Nitride Rubber	0.05925	66.671	175.54	350
Nylon 4-6	0.03509	66.678	123.46	440

To reduce deformation from the above table concluded that, the material Nylon 4-6 is preferable, by comparing to Nitride rubber. From static structural, modal, and thermal analysis, the material Nylon 4-6 is preferable, because the material Nylon 4-6 is got less deformation as 0.03509 mm and stress of 66.678 MPa from static structural analysis and less heat flux as 123.46 W/mm^2 and high temperature 440 ^{0}C and less deformation at high frequency and high temperature with less heat flux by comparing to Nitrile rubber. Heat flux or thermal flux is the rate of heat energy transfer through a given surface per unit of time. The SI-derived unit of heat rate is joule per second or watt. Heat flux density is the heat rate per unit area. In the case of material selection Nylon 4-6 is preferable to design spring tires.

Design and Static Analysis of Airless tire were proposed by Mathew et al.,(Mathew et al., 2017)(Mathew et al., 2017). This piece introduces a model of an airless tire with natural rubber materials used in place of synthetic rubber in the tread and polyester used in place of nylon in the carcass. By comparing various types of airless tires with pneumatic tires, structure, and material research is carried out. A quick structural analysis using ANSYS software was conducted on the airless tire spokes. With an applied load of 1200N, analysis has been done on a variety of structures, including honeycomb, Spokes, triangular, and diamond. They studied numerous constructions made of various materials, and the study found that diamond-shaped tires made of synthetic materials deformed less than other forms. Different spoke tensions may be employed, and lateral stiffness and PRN may change depending on the handling characteristics. The spoke tensions and lateral stiffness of the T weel, however, cannot be changed once it has been formed as shown in Figure 2.4 below.

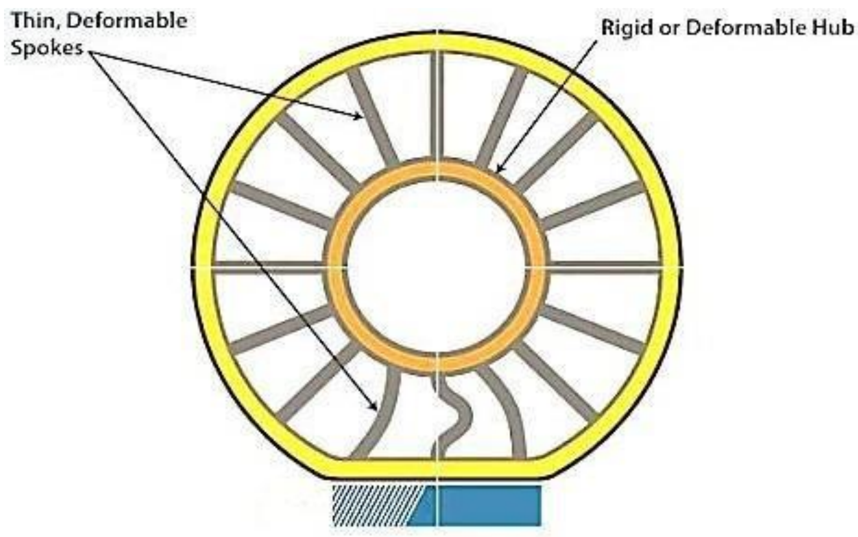
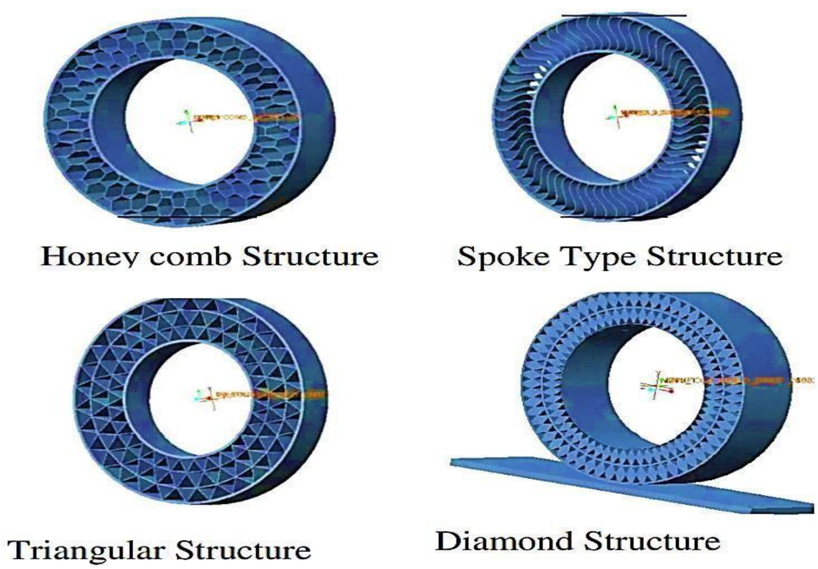


Figure 2.4 Deformation of spokes (Mathew et al., 2017)

In addition, Mathew et al., (Mathew et al., 2017) built four 3-D airless tire models employing models including honeycomb, spokes triangular, and diamond. The tread, belt, carcass, and air-filled volume make up an air tire. The geometrical design of car tires is referred to as the tire model

.



- Figure 2.5 Various Structure of air less tire(Mathew et al., 2017)

These air-less tires use layers of the inner band and outer band to produce a composite construction for the load and boundary conditions. In air-less tires, steel rings are also employed as reinforcing components. Due to heat buildup and comfortable riding, tires frequently

Experience major challenges with failure. The mechanical behavior of the tire under applied load must be predicted to improve the Air-less tire design. It is necessary to assess the combined stress and strain energy distribution that was created (Mathew et al., 2017).

The validation of metallic element prediction against the findings of the air tire test was carried out by Mathew et al. (Mathew et al., 2017). Utilizing metallic element analysis, the distribution of strain energy and deflection below loading was also distributed. The application of an evenly distributed edge load at the tire-rim contact area causes vertical loading on the wheel. Utilizing the solid tetrahedral components, the whole tire half was broken. The dimensions of the tread are E=30Mpa and density=1300 kg/m3. Each band accounts for identical material characteristics, and a 1200 N wheel load is used. Results of the analysis and comparison of the constructions made of conventional and composite materials are provided in Table 2.3 below.

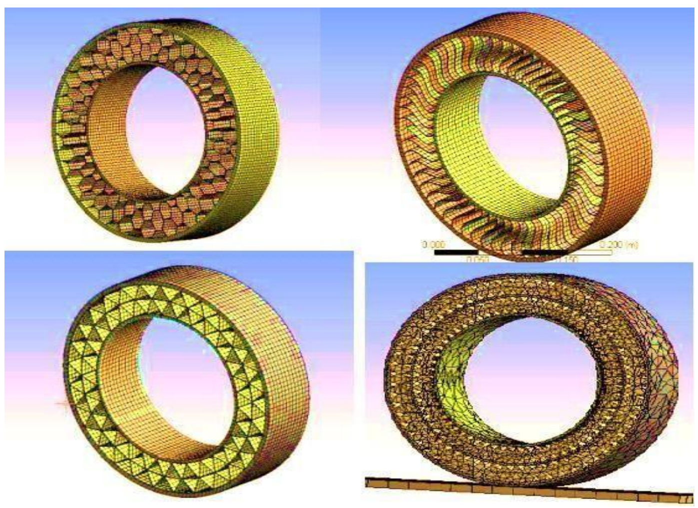


Figure 2.6 Various Structure of air less tire Mesh (Mathew et al., 2017)

Table 2.4 result of normal and composite materials(Mathew et al., 2017)

SNo	**Structure**	**Force Applied (N)**	**Total Deformation Exciting material (mm)**
1	Honeycomb	1200	0.0007972
2	Spokes	1200	4.648e-7
3	Triangular	1200	8.2519e-6
4	Diamond	1200	0.016874

Table 2.4 displays the results of the performance study of the four different structures, including honeycomb, spokes, triangular, and diamond shapes. Which diamond structure has less deformation than the other three structures is indicated among the overall deformations of the various structures. As a result, the diamond structure has a large capacity for transporting loads. The gap is a structural problem and needs more maintenance time.

2.1 Review on Tire Dynamics

Georg Rill (2006) investigated first-order tire dynamics using the presented technique, in which the first-order tire dynamics are created by a Taylor-Expansion of the steady-state forces and torques. As a result, the steady-state tire characteristics automatically provide relaxation durations that incorporate the wheel load and slip dependencies. With minor model changes, it is feasible to recreate even stick-slip effects during parking maneuvers. The outcomes of this basicyet efficient strategy match measurements fairly well.

The model element "tire/road" is particularly important for the dynamic simulation of on-road vehicles due to its effect on the feasible outcomes. One of the most significant problems of vehicle modeling is to provide an adequate description of the interactions between tyre and road since all other components of the chassis impact the vehicle's dynamic characteristics via the tyre contact forces and torques. As a result, in the interest of balanced modeling, the precision of the entire vehicle model should be proportional to the performance of the applied tyre model. Currently, two types of models may be distinguished: handling models and structural or high- frequency models.

Steady State Tire Force:-In any point of contact between the tire and the road surface normal and friction forces are transmitted, Fig. 2.7. For the calculation of the contact patch geometry, the tireis considered as a rigid body. Then, the tire deformation, the orientation of the local contact area, the location of the contact point, and the contact point velocities can be calculated from the momentary state of the wheel rim and the description of the road surface. Adding the knowledge or at least an approximation about the tire elasticity results in the wheel load Fz and the tipping torque Tx. The rolling resistance torque Ty which is less important for vehicle dynamics may be approximated by a rolling resistance lever.

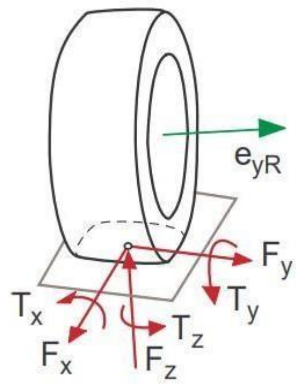


Figure 2.7 Tire forces and torques

Where, F_x longitudinal force, F_y lateral force, F_z vertical force or wheel load, T_x tipping torque Ty rolling resistance torque T_z self-aligning and bore torque

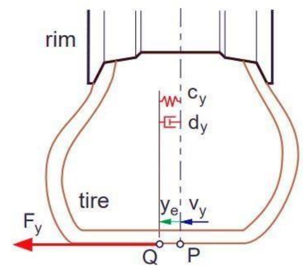


Figure 2.8 Lateral Tire Deflections

The relaxation length r_y for the lateral tire deflection depends on the wheel load Fz and it is a function of the lateral slip s_y or the slip angle $\alpha = \arctan s_y$

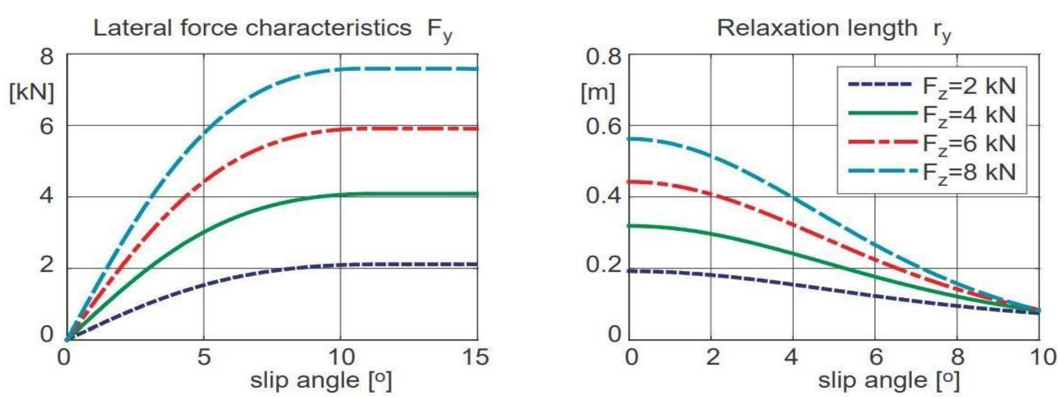


Figure 2.9 Lateral force characteristics and computed relaxation length

This Lateral force characteristics and computed relaxation length for a typical passenger car tire (S205/50 R15, 6J) with cy = 160 000 N/m, dy = 600 N/(m/s), rD|Ω| = 60 km/h

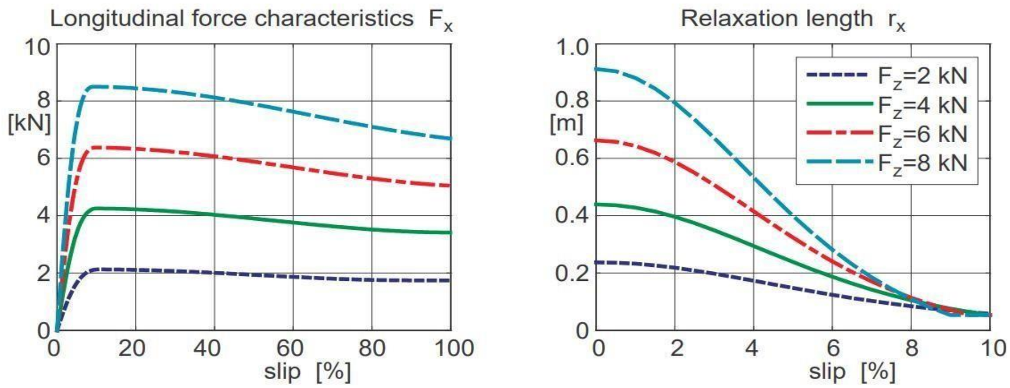


Figure 2.10 Longitudinal force characteristics and computed relaxation length

Longitudinal force characteristics and computed relaxation length for a typical passenger car tire (S205/50 R15, 6J) with cy = 220 000 N/m, dy = 700 N/(m/s), rD|Ω| = 60 km/h

2.1. Summary of Review

From general concepts, one's rubber tire is vulcanized they were strong, could take reasonable amounts of damage, and has good shock absorption. However, they were heavy and still gave an uncomfortable ride. For example, tires made of solid rubber are strong, can absorb shocks, and resist cuts and abrasions. Even though they are vast in improvement, these tires are very heavy and did not provide a smooth ride. The future idea that was developed by researchers is for Tires are constantly growing and developing. Due to the Rising oil prices and environmental concerns problems. New technologies such as Airless tires called non pneumatic are being trial edon commercial vehicles.

The predominant fear of designing non-pneumatic tires is the deformation of the tire in dynamic conditions–pneumaticandpneumatictiresarecarryingamassiveloadwithdeformation but the distinction is that air fewer tires are with the absence of contact pressure. For they may be opposing the tire needs to be sufficiently strong to preserve the auto and stand up to a lot of loads, and additionally can change quite when it interacts with the road. The approach of flexible spoke for non-pneumatic tires is validated by experimental results which show how the quasi-static model can be applied to steady-state rolling for moderate speeds. But at higher speeds, in addition to inertia effects, spoke dynamics to the spokes should be accounted for.

2.5 Research Gap

Based on surveyed collected works the research gap detected from previous works is described as follows.

- From previous work, the non-pneumatic different tires are analyzed based on, applying the load. The researchers considered minimum deflection tires as the best of the rest. This shows that tires have been designed for rigidities behavior, which means they have no more flexibility for comfort matters like pneumatic air springs and rubber which are based on the springing behavior of the tire which is called regain or resilient energy after deformation. And also still the researchers have not done the dynamic character of the solid tire by applying dynamic load with time-variant terms. This should be included as a research gap because uneven road behavior or the Drop and Debbeding Test has a critical case study which is a transient analysis that may transfer a huge amount of dynamic load under the general condition.
- In this thesis the air spring tire model is replaced with multiple metal springs and the conditions of the above-described state are analyzed using any Ls dyna and the result has been compared with the existing tire.

CHAPTER THREE

MATERIALS AND METHOD

3.1 *Introduction*

This chapter includes a list of the materials used in this research. Also, a description of the various steps involved in the methodology is given in this chapter. Materials and methods are the most important heading to evaluate the general quality of any research distribution product since they are the ones that explain to the readers what procedures, approaches, designs, and treatments have been carried out in the research, which will allow us to replicate the studies. A thorough literature survey helped in the proper choice of working materials, research methodology, and simulation software. In this study, the design has been carried out using an appropriate working material selection.

3.2. Materials

This section is used to ensure the credibility of the research. In other words, whatever materials and procedures that chosen should be suitable and valid to answer the research questions. Additionally, it ensures the reproducibility of methods so that other research may repeat this research. And to guide readers on how the research is conducted and organized and tell a compelling story of research. Researchers may wonder what guidance has to do with writing.

Table 3.1 Materials to be used

Characteristics of material	**Materials Name**
Simulation Software Tools	LS Dyna Software
Computer	Processor Unit, 32RAM
Flash Disk	64GB

3.3 Methodology

This part describes the methodology used to complete the objectives of the research. It means the section involves studying the methods used in the theories or principles behind them, to develop an approach that matches the objectives. Figure 3.1 below shows the detail of the workflow for the thesis.

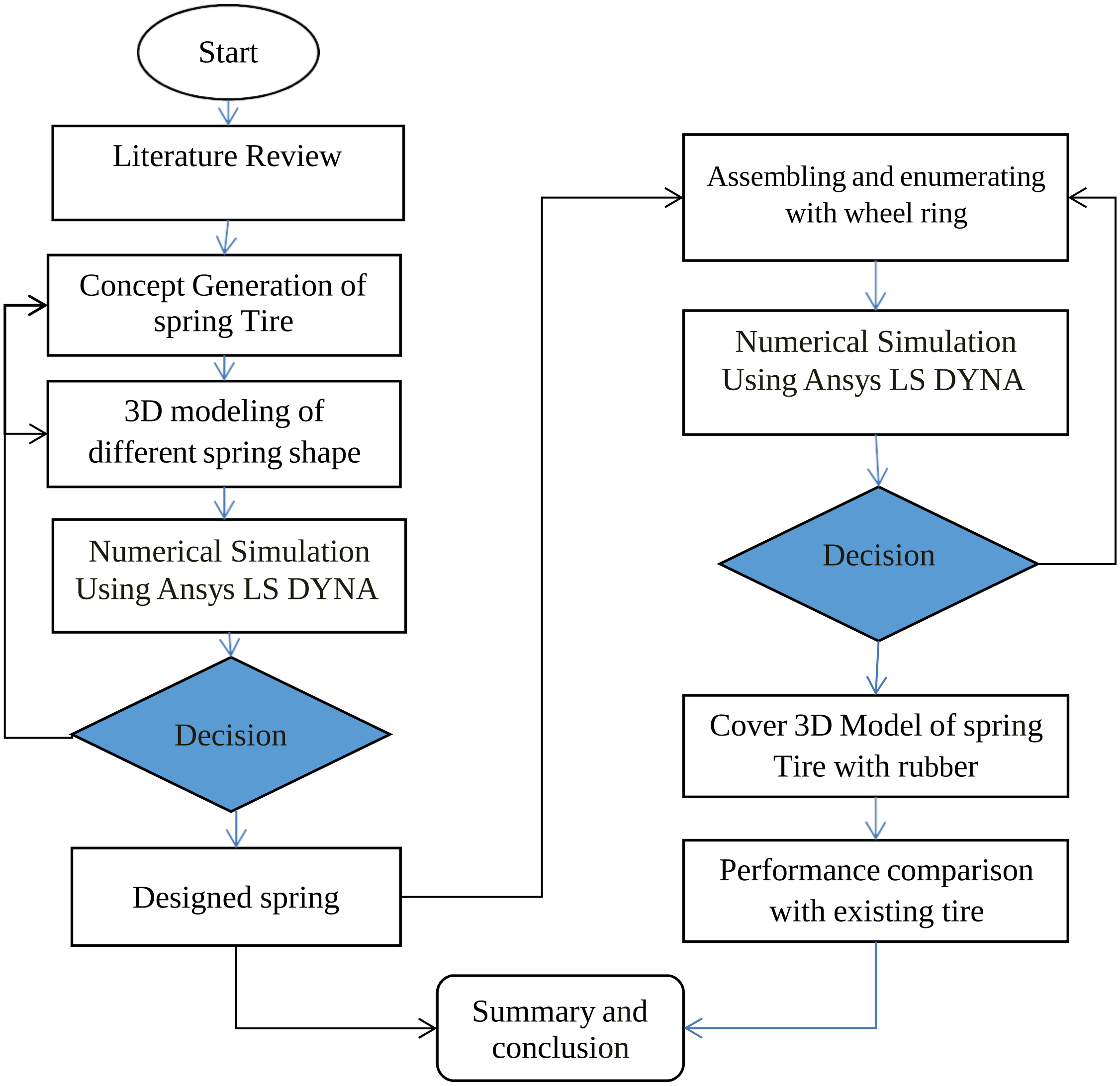


Figure 3.1 Methodology

3.4 Literature Survey for Proposed Design

It is recognized that data is the information collected by a literature reviewer to inform a if there is gab or drawback at the area of studies. As a result, the literature review process can be considered as a data collection tool that is, a method of gathering a body of material relevant to a certain topic of interest. Therefore the collected data for the analysis of spring tires is based on the primary and secondary types of Data. To resolve the described problems the type of data to be used is both primary and secondary data.

Problem Identification

This section is the section the researcher clearly should identify the root cause of a problem as described in chapter one of the statement of problems. Developing a detailed problem statement, that includes the problem's effect on a population.

Data Collection (Primary)

For primary data it is necessary to measure the dimension of a tire of a specific vehicle. It is known that detailed data on tires should be needed for this type of research. Therefore, the investigator has tried to collect the Primary data based on the model number obtained from the innovative Crista tire vehicle from the insurance company vehicle manual.

Data Collection (Secondary)

But for the case of secondary data, many observable sources like journals papers, Conference papers, reports, theses, the internet, magazines, and videos etc. were used.

Tire Selection and Material Properties

Information on the pneumatic tires is exceedingly based on that for numerous a long time, tire engineers depended on the monograph, “Mechanics of Pneumatic Tires”, altered by S. K. Clark, for nitty gritty data around the standards of tire plan and utilize. Distributed initially by the National Bureau of Benchmarks, U.S. Office of Commerce in 1971, and an afterward (1981) version by the National Thruway Activity Security Organization (NHTSA), U.S. Office of Transportation, it has long been out of print.

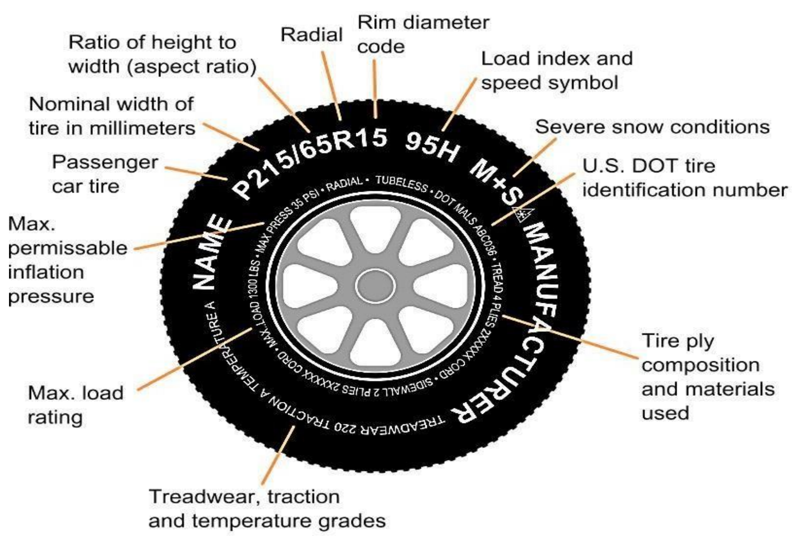


Figure 3.2 Tire Properties Identification

Exiting Tire Model

From the following data the Innova Crystavariant(s) tire which is Toyota Innova Crysta GX Automatic Tire Size 205/65 R16, Tubeless type, and alloy wheel selected. So the original tire type Selected for the design of the new spring tire is the Innova Crysta tire. This tire is used by various vehicles. The following Table 3.2 shows the models used on Innova Crysta variants.

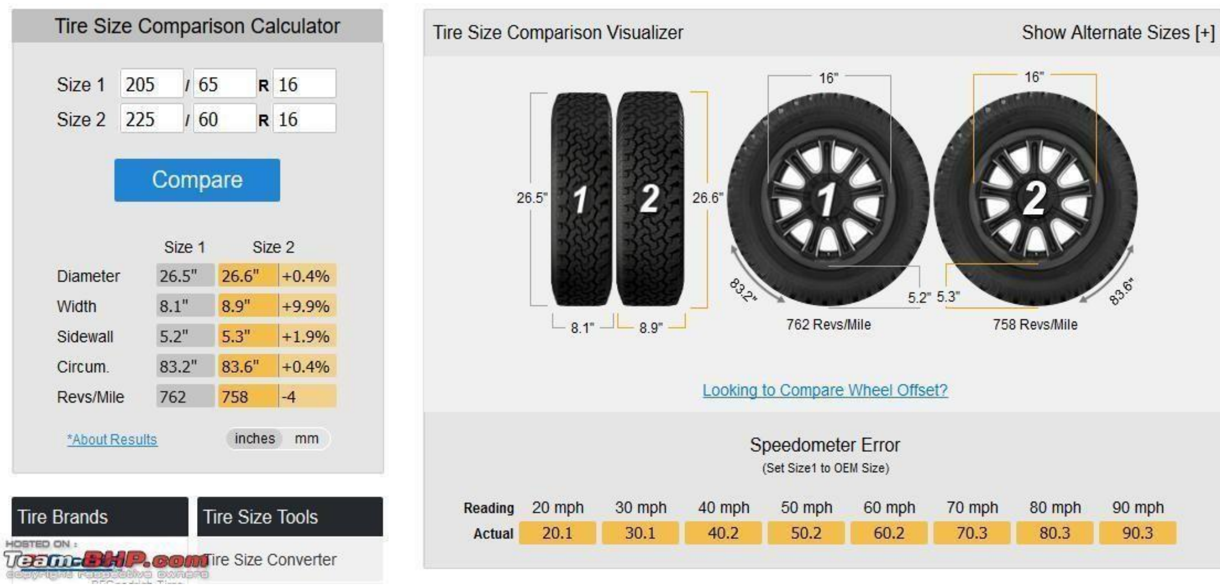


Table 3.2 Innova Crysta Variant Tire

Innova Crysta Variant(s)	Tyre Size	Tyre Type	Wheel Type
Toyota Innova Crysta GX Manual	205/65 R16	Tubeless	Alloy
Toyota Innova Crysta GX Automatic	205/65 R16	Tubeless	Alloy
Toyota Innova Crysta VX Manual	205/65 R16	Tubeless	Alloy
Toyota InnovaCrysta ZX Manual	205/55 R17	Tubeless	Alloy
Toyota Innova Crysta ZX Automatic	205/55 R17	Tubeless	Alloy

Rubber Mechanical properties

Natural rubber is the polymer cis-1, 4-polyisoprene. Typically, a small percentage (up to 5% of dry mass) of other materials, such as proteins, fatty acids, resins, and inorganic materials (salts) are found in natural rubber. Polyisoprene can also be created synthetically, producing what is sometimes referred to as “synthetic natural rubber”, but the synthetic and natural routes are distinct.

Table 3.3 Rubber Mechanical Properties

Name	Properties value
Phase at STP	Solid
Density	1100 kg/m3
Ultimate Tensile Strength	5 MPa
Yield Strength	15 MPa
Young’s Modulus of Elasticity	0.05 GPa
Brinell Hardness	N/A
Melting Point	177 °C
Thermal Conductivity	0.5 W/mK
Heat Capacity	1300 J/g K
Price	2.2 $/kg

3.5 Spring Material Properties

What Varieties Make a Good Spring Material?

To choose material qualities for a suggested spring tire to maximize impact Resistance, energy absorption, and drop resistance. This necessitates a high resilience modulus (yield strength / elastic modulus).

High resilience is required for maximum deflection, whereas high strength is require for maximum permissible stress. They maximize the amount of energy that the spring can absorb before failure as the modulus of resilience. Minimizing Wear uses a material with a high hardness to decrease contact friction and minimize abrasive wear. These materials are High Carbon Spring Wire, Carbon & Alloy-Specialty Spring Grade, Alloy Steel Wire, Stainless Steel Wire, Non-Ferrous Alloy Wire, High-Temperature Alloy Wire, etc. The selected material for spring is shown in Table 3.4

Table 3.4 Spring Material Properties

High Carbon Spring Wire	Grade	Min. Tensile Strength (psi x 10^3)	Modulus of Elasticity (psi x 10^6)	Design Stress % Min. Tensile	Modulus in torsion (psi x 10^6)	Density Kg/m^3
High Tensile Hard Drawn	ASTM A679	238-350	30	45	11.5	7860
Carbon & Alloy-Specialty Spring Grade						
Grade A Chrome Silicon	ASTM A1000	231-305	30	45	11.5	7860
Alloy Steel Wire						
Chrome Vanadium	ASTM A231	190-300	30	45	11.5	7860
Stainless Steel Wire						
17-7 PH	ASTM A 303	235-335	29.5	45	11	7860
Non-Ferrous Alloy Wire						
Monel 400	AMS 7233	145-180	26	40	9.5	7860
High Temperature Alloy Wire						
Inconel 718	Inconel 718	210-250	29	40	11.2	7860

Road bump profile

Positively, theoretical findings by Bachok et al. (2016) recommended hump heights of 50 mm - 100 mm and lengths of approximately 3 m - 4 m to achieve vehicle speeds within the 35 km/h speed limit in Malaysian urban residential areas. Further research by Bachok et al. (2017) also indicated the guidelines for road humps by the Malaysian Ministry of Road Works (2012) and SIRIM, (2009) which is given in Table 3.5.

Table 3.5 Malaysian Road Hump Profile

Source	Dimension	spacing	Others
Malaysian Ministry of Works,2012	a) Flat-Top Hump; Height:75mm-100mm, Length: 2.5m-4m	100m	1) Vehicle speed 30km/hr-60km/hr
	b) Round-Top Hump; Height:50mm-100mm, Length: 3.7m-4m		2) Allowed on district roads, residential roads, access roads, rural road
	c) Sinusoidal hump; Height: 75mm-100mm, Length: 3.8m-4m		3) Road geometry:2-way and 2-lane roads with no curbs
			4) Should not be located near road intersections

3.6 The theoretical background of tire modeling

This section gives a summarization of the tire models that are developed for on-road simulation requests. The main challenge in studying the performance of the vehicle in on-road conditions is simultaneously characterizing the tire structural response and the tire-terrain interaction. A wide variety of models have been advanced for formulating and simulating this collective problem. The degree of complexity for these models is based on the application, accuracy, and computational cost of development. Generally, these models can be grouped into three main categories:

- Empirical models,
- Semi-empirical models, and
- Physics-based models.

Empirical models

The applicative models use the experimental data of the tire response, and link it to the important parameters of the system through mathematical equations. One of the most well-known empirical models is the Magic Formula Tire Model. This model is based on the tire steady-state response data and relates the tire forces and moments to wheel pure slip values.

Model of Physic-based

Instead of using experimental analysis to characterize the tire-road interaction, physics-based models incorporate the physical principles and analytical methods to represent tire and terrain structures, in addition to their interaction. This multi-disciplinary field of models incorporates applied mathematics, numerical analysis, computational physics, and even computer graphics to evaluate the performance of wheeled vehicles. The degree of complexity varies from the simple models that consider the tire as a rigid ring and the terrain as a spring-damper system, to very detailed models that use finite element formulations for both the tire and the terrain.

Tire models of finite element

Mechanical behavior of the tire and tire-terrain depends on many aspects, such as tire geometrical and material properties, in addition to terrain texture and frictional characteristics. Identifying all of these parameters and correlating them to the vehicle performance using empirical closed-form formulations are limited to similar test conditions. On the other hand, using simple physics-based methods to model the terrain can lead to significant errors in both estimating model input parameters and capturing terrain mechanics. This will ultimately cause the vehicle response to deviate from experimental data. One alternative numerical method for analyzing vehicle performance is the finite element method. On the other hand, models that inherit a three-dimensional, full FEM, nonlinear, and fine mesh can capture the dynamic response of the tire with high fidelity. Regarding the FEM framework, many researchers used the available FEM packages such as ABAQUS, ANSYS, LS-DYNA, PAM SHOCK, and MARC for modeling and simulation purposes which help reduce the chance of programming errors.

Contact and Interaction Modeling Techniques

Once the tire structure and tire material properties are modeled and implemented in a FEM framework, the interface between the model and road surface should be established. This interface searches for the nodal points that are close to the ground (contact search algorithm), and when the contact is detected it applies the required contact condition (contact interface algorithm). Therefore, the contact simulation is initiated by detecting the penetration between the objects (tires) and contact road.

3.7 Tire Structure Components

A modern typical tire is manufactured from nearly 10-35 different components. The tire's parts are created by rubberizing different components including cables, textiles, and steel belts with rubber compounds. These components are assembled on the tire assembly machine into an elastic green tire. Then, a tire goes through the vulcanization (curing) process to become a unified part. During the curing process, high-pressure steam is conducted into the curing pad inside the curing press and pushes the elastic green tire against the molds. At this stage, the tread pattern and side texts on the tire sidewall are created.

Conceptual Design

The concept for the spring tire is going to be developed, by converting the previous tire to the spring tire model; for conceptual design, the following dimensional parameters are to be predicted on both modeling of the tire to study comparatively.

- Tire Diameter(*D)*
- Wheel Diameter(*d)*
- Tire Width (*w*)
- Sidewall(s)

Figure 3.3 General Tire Dimension

And the basic parameters for analysis are Inputs (Axle motion, effective road profile, brake torque or axle load) and outputs Axle reaction forces, strain, deformation, etc. The following Figure 3.3 shows the general concept of including nonlinear tire modeling terms.

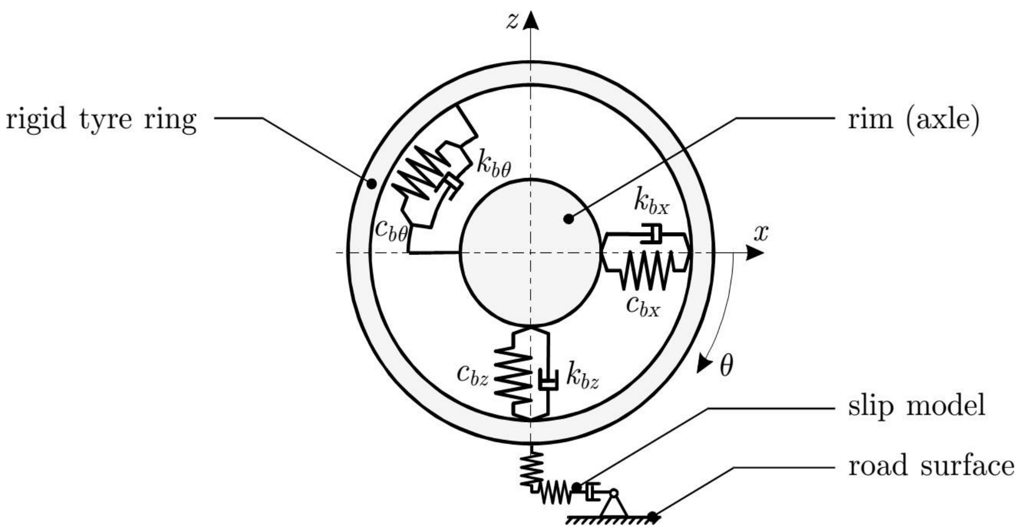


Figure 3.4 The Generic concept of tire modeling

where C_b torsional tire dumping coefficient

C_{bz} vertical tire dumping coefficient

C_{bx} Longitudinal tire dumping coefficient

k_b torsional stiffness coefficient

K_{bx} Longitudinal tire stiffness coefficient

K_{bz} vertical tire stiffness coefficient

Tire 3D Modeling

It is famous that 3D modeling is the process of making a 3D representation of any surface or object by manipulating polygons, edges, and vertices in simulated3Dspace.In this study, the3Dmodel is prepared by alternatively, CATIA and ANSYS space claim. The following figure shows the tire 3D model that is going to be simulated.

Figure 3.5 Tubeless Tire 3D Modeling

Contact patch estimation

The contact patch's size is about equal to the car's weight divided by the compressed air pressure inside the tires. The size of the contact patch is also controlled by the stiffness of the sidewalls and other physical qualities of the tire, so this isn't a perfect equation. There the contact patch is determined from the pneumatic tire model numerically tested results based on internal pressure and axle load applied. 1000kg axle mass and 33psi internal pressure applied.

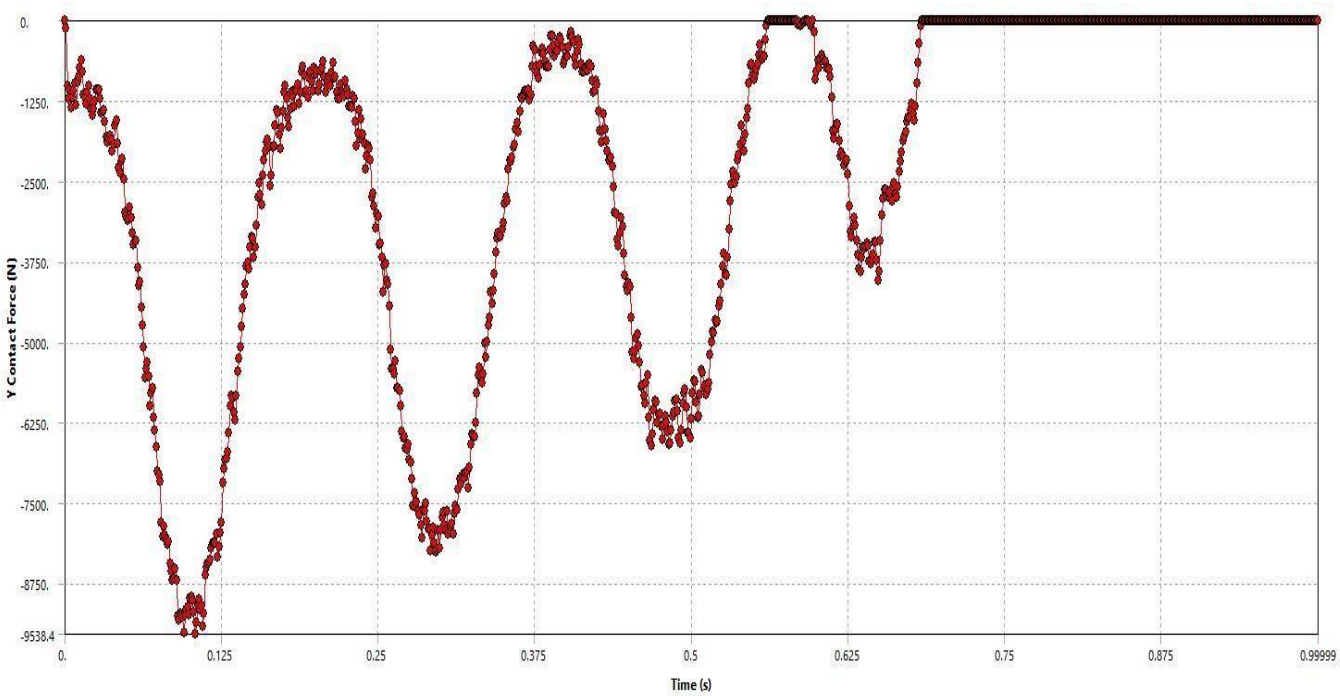


Figure 3.6 Ground Contact Force

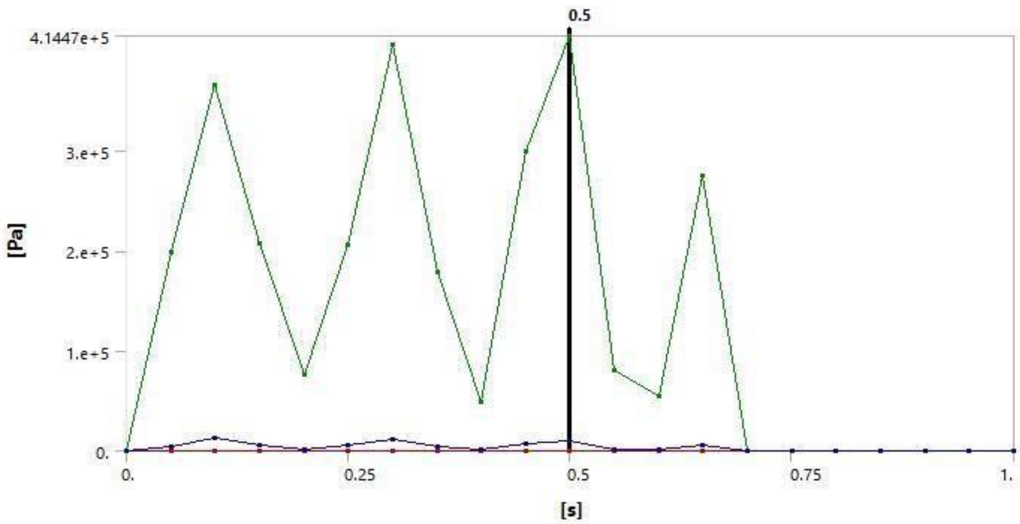


Figure 3.7 Ground Contact Tire Pressure

Contour plot of Vertical dynamic Load and pressure

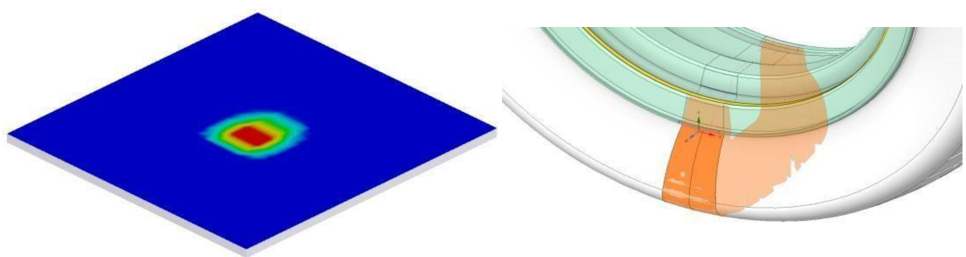


Figure 3.8 Contact patch estimation from Tubeless tire

The maximum load from the ground is 9538.4 N and the normal pressure from the ground is 4.0527e+005 N/m^2contact area is,

$$\text{Area} = \frac{\text{maximum load from the ground}}{\text{Normal Pressure}} = 0.0235\text{m}^2$$

Based on tire width and longitudinal tire thickness the sector volume has been considered, for a single spring equivalent tire model. The figure below shows the sectioned part of the contact zone.

Parameters

Parameter design is a process that seeks to set main factors to achieving a response objective (Maximum, Minimum, Target) while at the same time allowing subsidiary factors to vary in a "customary" way. From the design concept of the spring tire, four different input parameters and criteria have been considered. Input Parameters (1) thickness of flat Type Spring, Input Parameters (2) based on the diameter of Single Wire type spring, Input Parameters (3) based on the diameter of C cross section of Wire type spring, and Input Parameters (4)based on Number of spring over Circular length (arc length). The following table 3.5-3.7 is used to show the detail of input parameters and table 3.8 is used as output parameters variable.

Input Parameters (1)

Table 3.6 Spring tire thickness

spring Concept	based on thickness (mm)
Leaf Type Spring	2
	2.5
	3
	3.5

Input Parameters (2)

spring Concept	based on diameter (mm)
Cylindrical Single Wire type Spring	2
	2.5
	3
	3.5

Input Parameters (3)

Table 3.7 wire type spring

spring Concept	based on diameter (mm)
C cross section Single Wire type Spring	2 2.5 3 3.5

Input Parameters (4)

Table 3.8 wire type spring

spring Concept	based on the number of spring
Number of springs over Circular length (arc length)	50 100 150

Input Parameters (4)

Table 3.9 wire type spring

spring Concept	Based on materials for Spring
Fixed Number of springs over Circular length (arc length)	Material1ASTM A679 Material2ASTM A1000 Material3ASTM A231 Material4ASTM A 303 Material5AMS 7233 Material6Inconel 718

Output Parameters for all Concepts

Table 3.10 Output Parameters for all Shapes

Names	Results-oriented
Resilient Energy of spring	Reference to kinetic energy
Failure or Fracture Test of spring	Based on Resilient Energy or Safety factor
The directional velocity of spring bouncing	Reference to Road

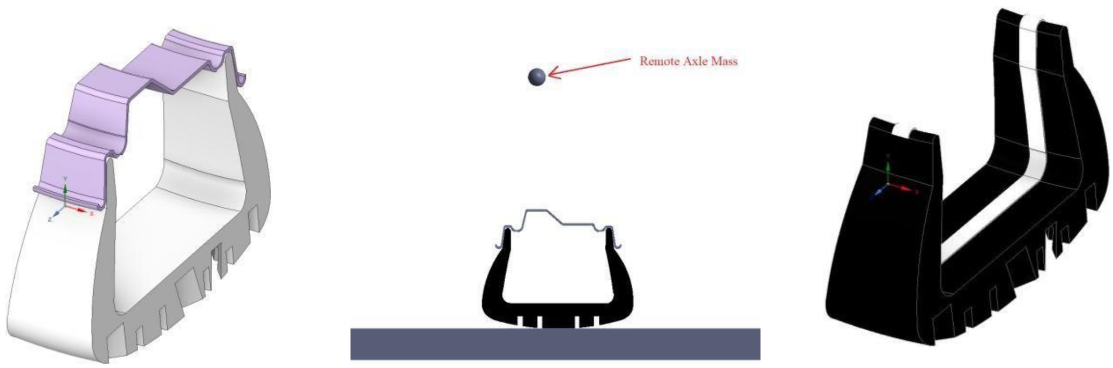
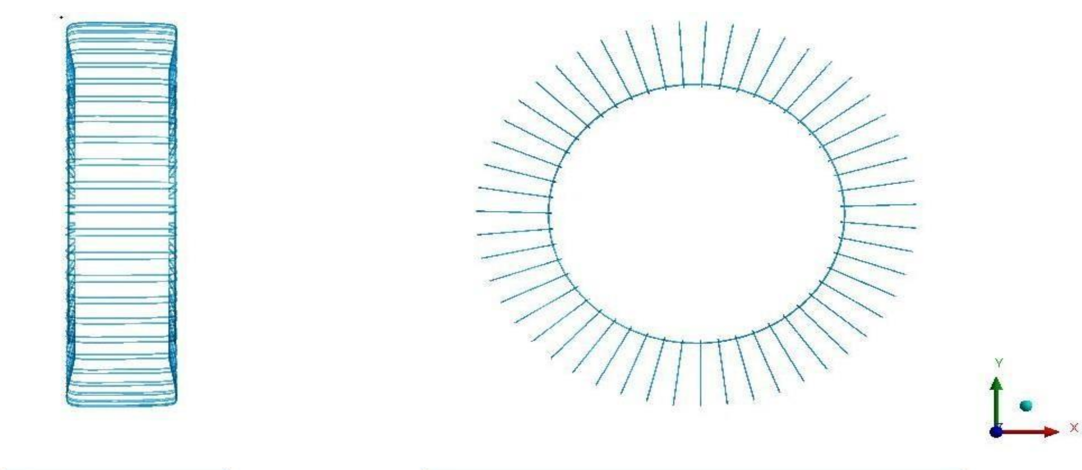


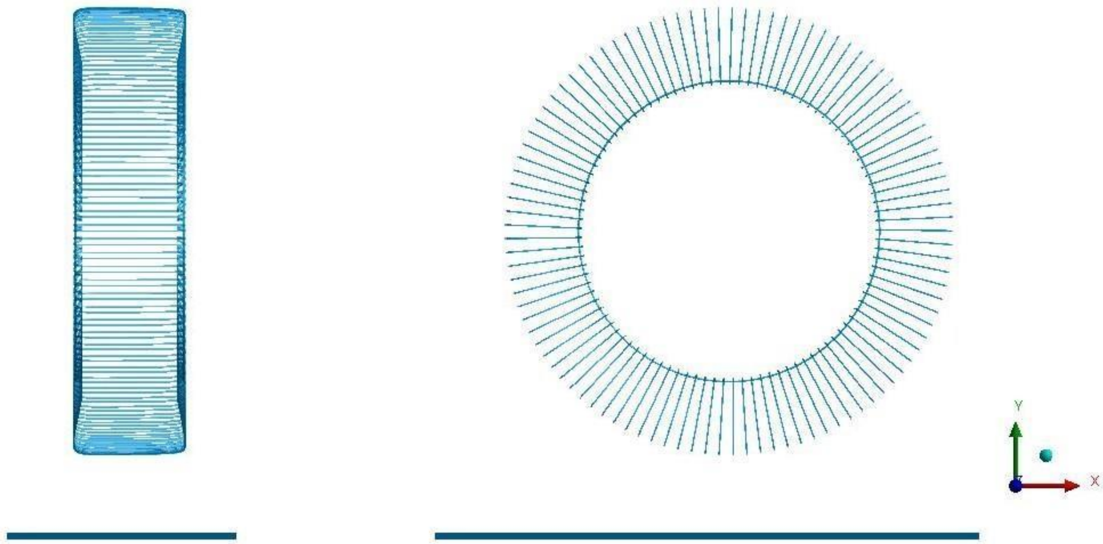
Figure 3.9 Contact patch 3d Model from Tubeless tire

Detail analysis of existing tire contact patch

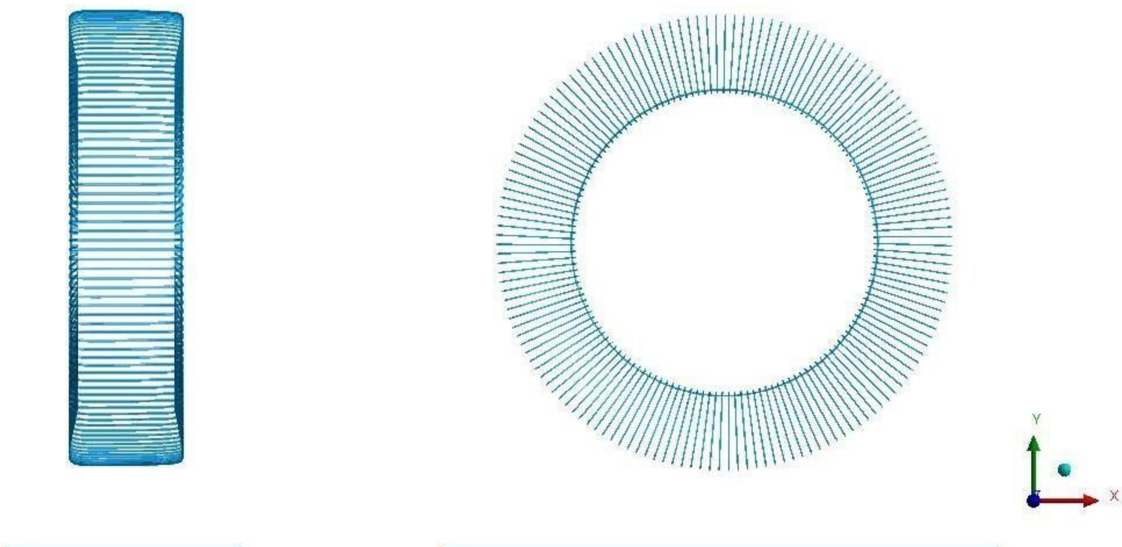
The basic parameters used on pneumatic tire test is direct testing existing model, based on stiffness behavior with internal energy and deformation



a) Spring number 50



b) Spring number 100



c) Spring number 150

Figure 3.10 (a) 50 number, (b) 100number, (c) 150number; 3d Model of Spring tire

Road modeling

To simulate tire-terrain interaction, the ground is considered an analytical rigid surface, and a surface-to-surface contact interface is established between the tire tread and the road to avoid the tire tread mesh penetrating the ground. The zero-gap contact is achieved by modeling the contact problem using a Lagrange multiplier method with a combined coefficient of friction of 0.8. 50 The Lagrange Multiplier method satisfies the contact boundary condition more accurately than other methods, such as the Penalty method.

General Tire Behavioral Testing

i. DE bedding

Before testing of tire the basic consideration of tire is DE bedding, which occurs when a vehicle leaves the roadway it is likely that the tires will interact with objects on the roadside such as pavements, guardrail posts, and other roadside accessories that may lead to deflation of the tire. Tire deflation in these cases is due to crosswise overloading of the side shoulder of the tire that causes the beaded coil to separate from the flange of the rim and slide toward the well in the rim base. When the coil falls off the edge of the well, the air seal is immediately lost and the tire deflates completely. Lateral Tire Deflection is one type of debeding. In this thesis, the assumption taken as putting the vertical load to the negative side offset the test of the debeding behavior.

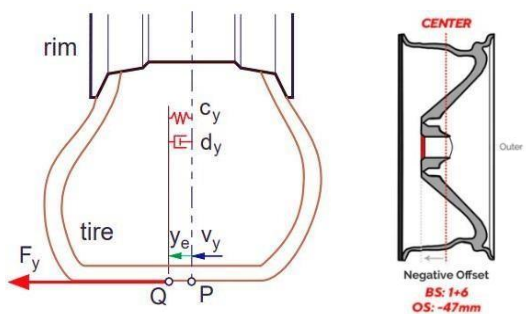


Figure 3.11: Lateral Tire Deflection for the case of -47mm offset for the selected tire

ii. Tire vibrations

During development, vibrations in the tire occurred regularly. These vibrations could be caused during inflation of the tire, due to tire rotation, and due to the tire impacting another object. Often the vibrations would lead to instabilities that were quite interesting. Numerous techniques for damping these vibrations were attempted.

iii. Width expansion due to pressurization and gravity loading

The width of the filled tire was monitored because depending on the material properties, the tire expands more or less during pressurization. Thus, various sidewall-to-sidewall measurements were made on a tire for both un-pressurized and pressurized conditions. Similarly, the tire compresses and expands after it is loaded by the weight of the vehicle through the suspension system. In this case, the changes are not uniform as they are due to pressurization.

Finite Element Analysis Process (FEA)

Itisknownthatfiniteelementanalysisisthesimulationofanygivenphysicalphenomenonusing the numerical technique called finite element method (FEM). The problem will be solved numerically by LS Dyna software. Which is an advanced general-purpose Multi physics simulation software package developed by the former Livermore Software Technology Corporation (LSTC),which was acquired by Ansys. The package contains more and more possibilities for the calculation of many complex, real-world problems, it is origins andcore competency lie in highly nonlinear transient dynamic finite elements. Therefore on this software, all boundary and initial conditions are to be set, and the simulations become applied to achieve the goal of the objectives. The following flowchart Figure 3.4shows the FEM analysis technique.

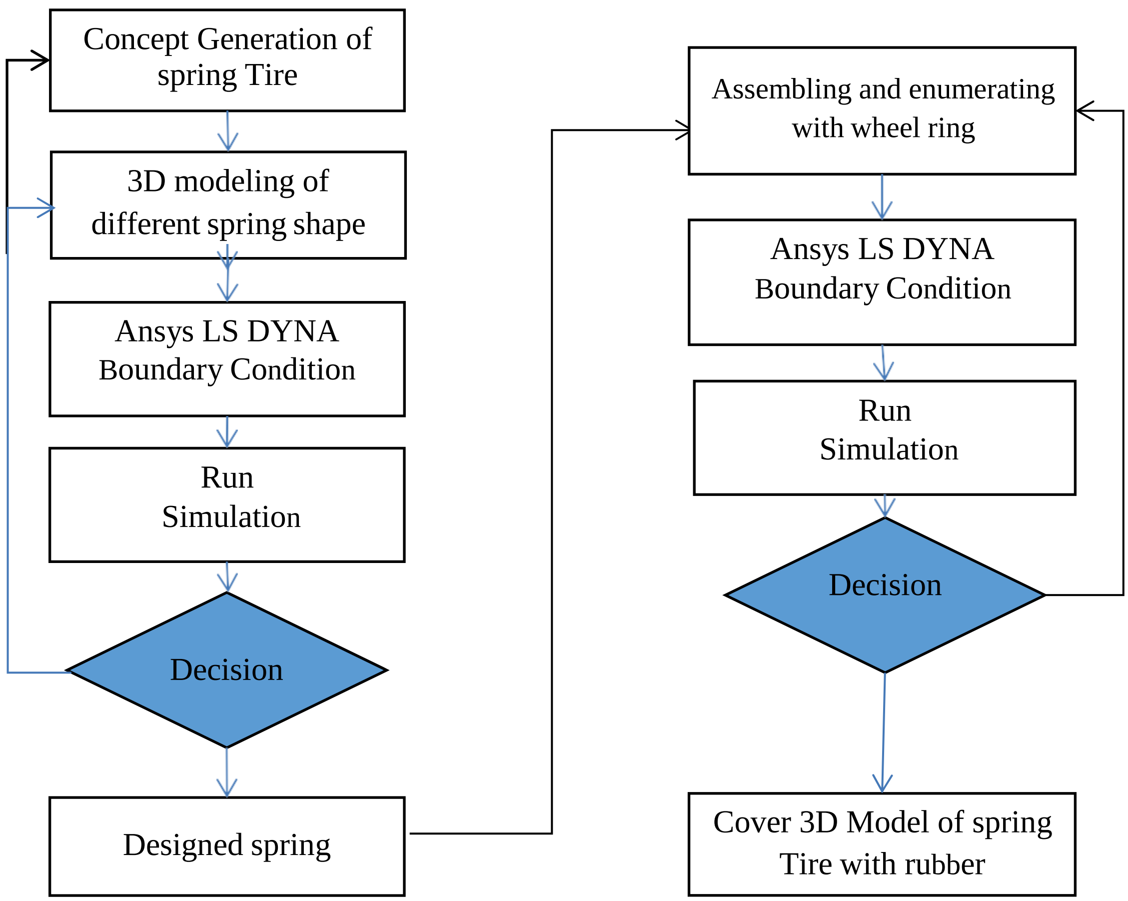


Figure 3.12 Finite Element Analysis Procedures

Boundary Condition

Internal Pressure of Conventional Tire

It should be noted that a constant inflation pressure is often assumed in tire analysis even though a slight change in the pressure is known to occur when a vehicle is running on the road. This change can be due to variations in operating temperature and the internal air volume. It has been assumed in the tire model development that the temperature is about 20°C. "Pressure changes during tire deflection are small", and quotes a 2% pressure rise from the unloaded state. It is therefore considered acceptable to model the tire with constant pressure. A pressure of 33 psi (2 is applied to the surface of the mesh on the inside of the tire. A check must be made to ensure that the direction of the nodal forces is correct. Therefore generally the detail of the boundary condition that going to be used in the software has been described in the following table.

Time step from Continuum Wave Propagation velocity's

$$\Delta t = \frac{l}{c} = \frac{l}{\sqrt{\frac{E}{\rho}}} = l\sqrt{\frac{\rho}{E}}$$

Table 3.11 Boundary Condition/ Initial Conditions

Boundary Condition		**Initial Conditions**	
Tire wall	Rotator	Rolling resistance	0.01
Inflation Pressures	33psi	Tire Rotation Speeds	2000rpm
Operational Temperature	20°C	Road Type	Dry Asphalt
Wheel rime wall	Bonded with the tire wall	Kinetics Friction	0.3
The direction of inflation force	outward	Vertical Axil Load	4000kg
Time step			9.75E-7
Uneven Road Profiles		Sinusoidal	Ysin
Level road		Slope	0
Bump		Height	0.1m

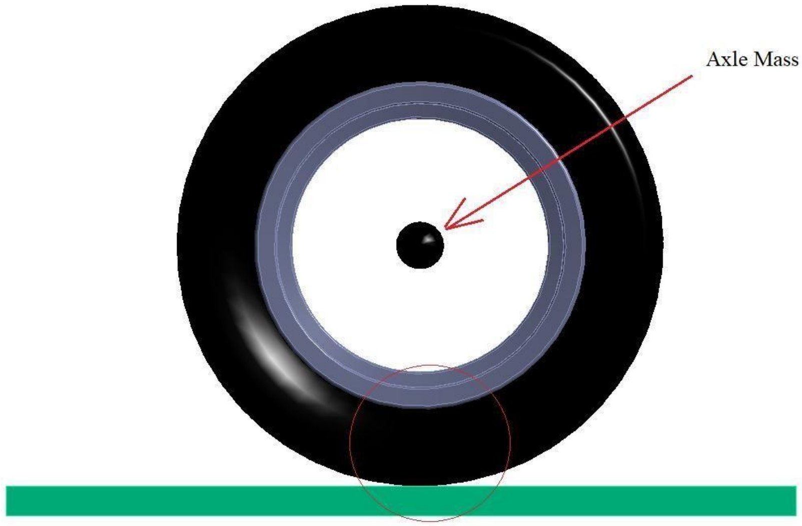


Figure 3.13 Finite Element Analysis Procedures

Grid-independent Test based on grid convergence index (GCI)

Although there is a guideline for the ratio between the grid conditions for GCI calculation, it has a limitation that requires subjective judgment by the researcher to select the reference grid. GCI is an indicator used for the determination of the optimal grid by calculating the convergence errorof the grid based on Richardson's extrapolation. As an indicator that quantifies the error of the numerical analysis by a grid, it is used to determine the adequacy of the grid. To calculate the GCI, grid refinement ratio (r) is calculated using.

$$r = \left(\frac{\Delta_{\text{fine}}}{\Delta_{coarse}}\right)^{1/3} \qquad (1)$$

Where Δr_{fine} is the number of grids of the fine grid condition and Δr_{coarse} is the number of grids of the coarse grid condition. For the grid refinement ratio, a higher value than 1.3 is recommended to distinguish the discrete error from other errors [29]. In this study, the optimal grid resolution derived through the grid independence test was defined as the medium grid. Using this grid as the reference, the coarse and fine grids among the grid resolutions that satisfy the grid refinement ratio were defined. The GCI is calculated according to Richardson's extrapolation with the;

$$GCI = \frac{F_s s}{r^p - 1} \qquad (2)$$

Where Fs is the safety factor, p is the order of convergence, and ε is the relative error of two grid conditions in the simulation. The value of 1.25 is used for Fs when comparing three or more grids [25]. p is calculated as follows

$$p = \frac{\ln/(f_{coarse} - f_{medium})\,/(f_{medium} - f_{fine})/}{lnr} \quad (3)$$

$$s = \frac{f_{coarse} - f_{fine}}{f_{fine}} \quad (4)$$

The numerical solution error of the GCI is calculated by the mean energy of the model. Based on this, the GCI between the fine and medium grids and between the medium and coarse grids is calculated. A larger GCI value denotes a larger error according to the grid, and this implies that a fine grid design is required. The adequacy of the medium grid was determined by comparing the GCI between the coarse and medium grids and between the medium and fine grids.

Table 3.12 Grid Refinement Ratio of Different Models

Model. S No	e/t1	e/t 2	e/t 3	r21	r32
Model 1	10343	15087	23655	1.318	1.451
Model 2	10465	15198	23808	1.315	1.447
Model 3	10358	15321	23537	1.315	1.442

Table 3.13 Grid-Refined Stress Value of Different Models

Model. S no	Stress1	Stress 2	Stress 3	P21	P32
Model 1	8.97E+07	1.02E+08	9.80E+07	4.322	0.677
Model 2	9.26E+07	1.03E+08	9.93E+07	3.640	2.362
Model 3	9.05E+07	1.05E+08	9.68E+07	1.999	2.226

Table 3.14 GCI of different Model

P21	P32	Error21	Error32	Safety	GCI 21	GCI 32
4.322	0.677	0.0842	0.00796	1.25	5%	3%
3.640	2.362	0.0669	0.0224	1.25	5%	2%
1.999	2.226	0.0650	0.0479	1.25	11%	5%

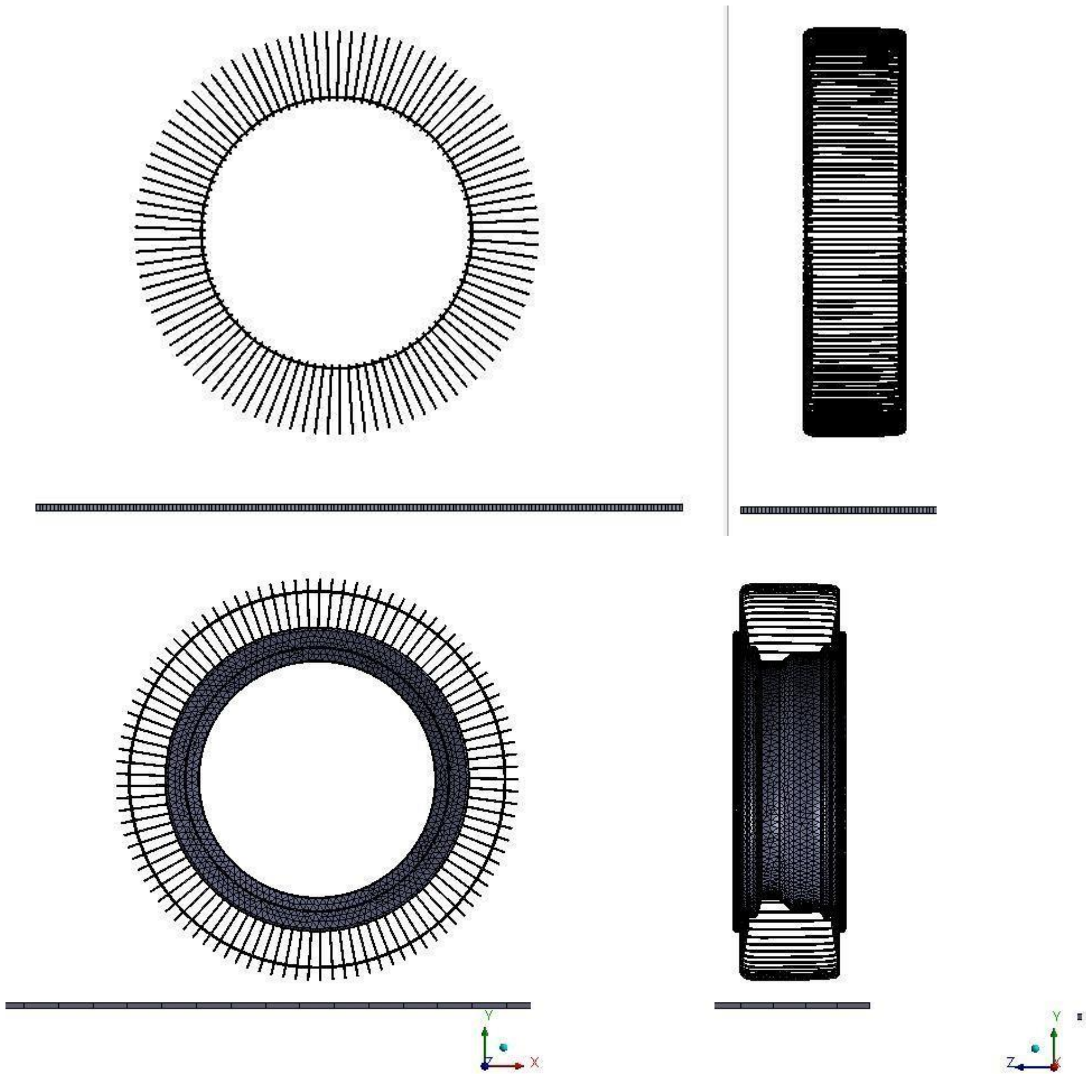


Figure 3.14 Finite Element Mesh

CHAPTER FOUR

RESULT AND DISCUSSION

The results chapter or section simply and objectively reports what founded, without speculating on why found these results. The discussion interprets the meaning of the results, puts them in context, and explains why they matter. In this thesis, results and discussion are combined.

Spring shape based Design Results

A) Rectangular cross-section spring (Leaf spring) type Result

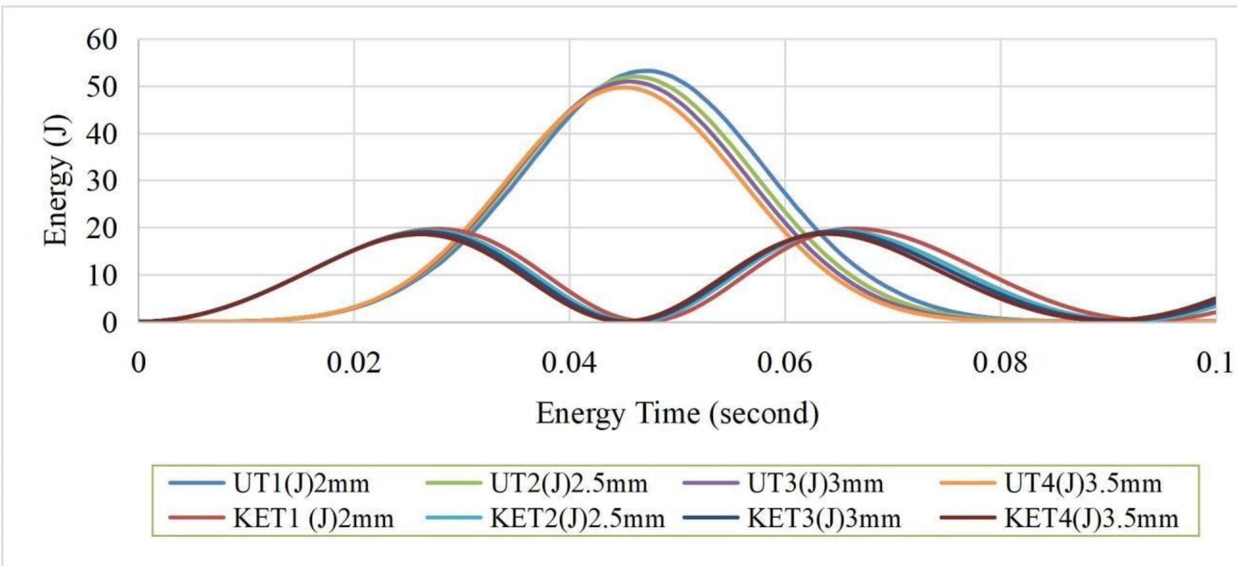


Figure 4.1The leaf spring's internal and kinetic energy

B) Cylindrical shape cross section(wire type spring) Result

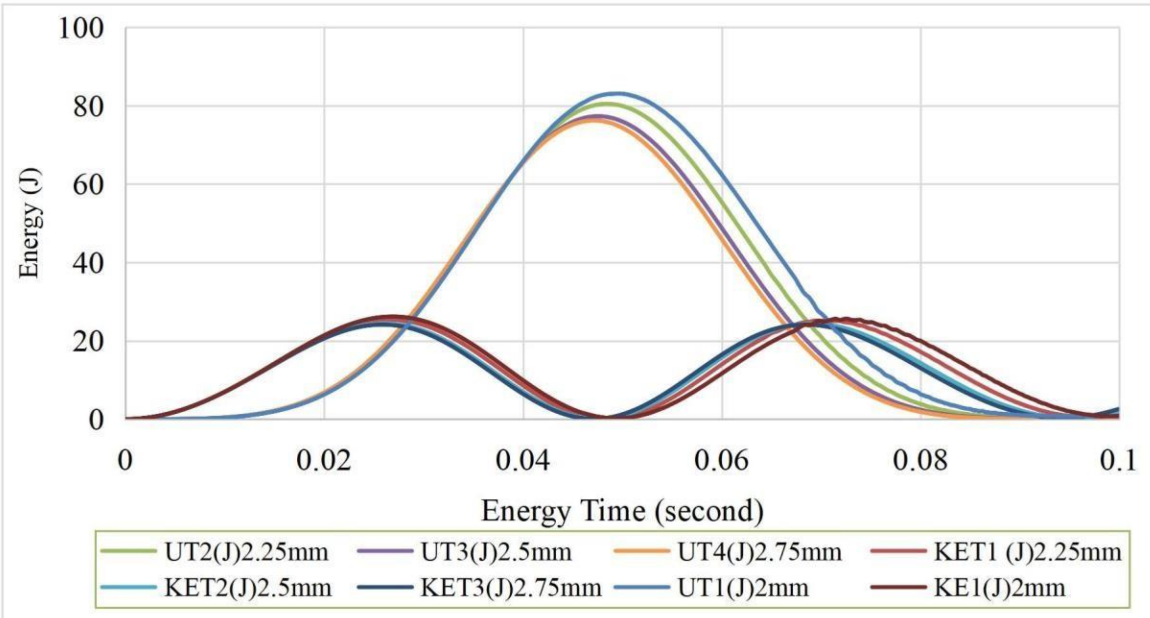


Figure 4.2 Cylindrical cross-section spring internal and kinetic energy

C) C cross section (C wire type spring)

Result

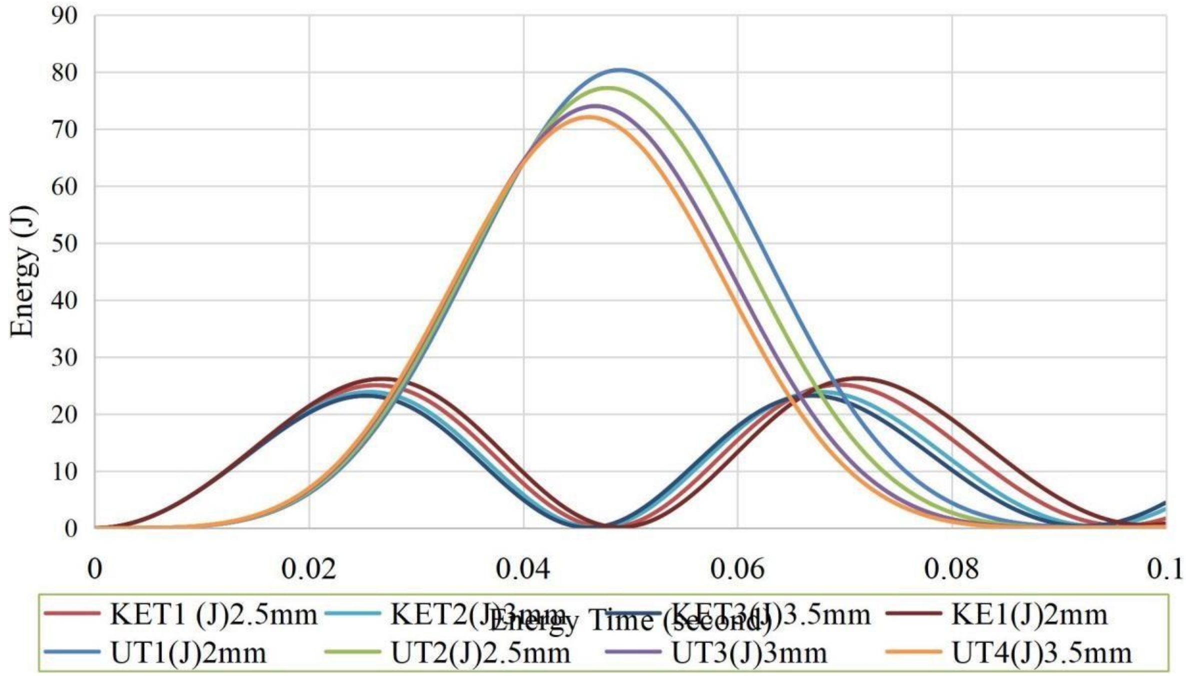


Figure 4.3 C cross section (C wire type spring) internal and kinetic energy

Table 4.1 Summary of spring shape energy

Sno	**Thickness**	0.25mm	0.5mm	0.75mm	1mm	%
1	Leaf spring type (rectangular)	65J	62J	60J	58J	Reference
Diameter		2.25mm	2.5mm	2.75mm	3mm	
2	Cylindrical shape cross-section	83J	80J	77J	76J	28%
Diameter		2mm	2.5mm	3mm	3.5mm	
3	C cross-section spring	80J	77J	76J	72J	23%

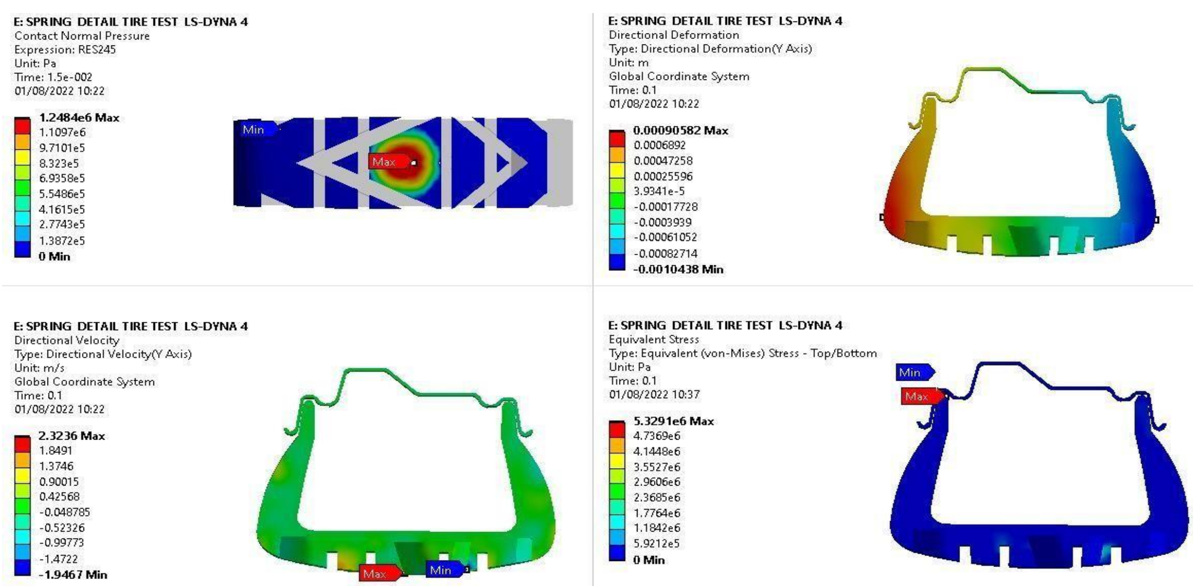
Table 4.2 Weight in (kg)

Radius/Thickness	2mm	2.5mm	3mm	3.5mm
Flat spring	0.05469	0.06835	0.08203	0.09569
Cylindrical cross-section	0.04376	0.06262	0.08565	0.11893
C cross-section	0.02691	0.03633	0.04788	0.06157

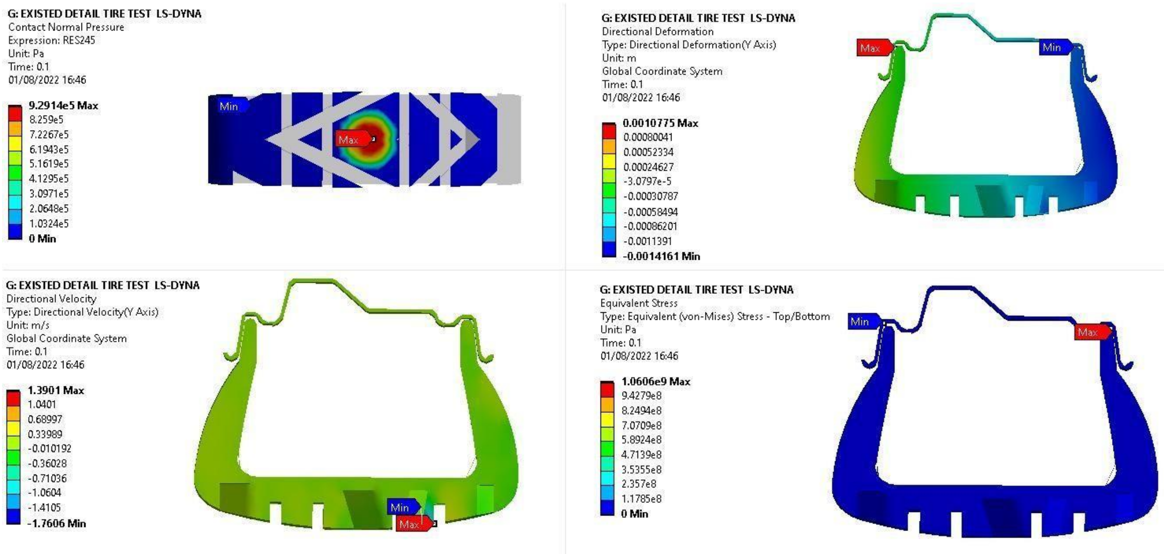
Discussion on Spring Design

From Figure 4.1, the flat spring's internal energy is increased as the thickness of the cross-section decrease. This is good for energy absorption of shock load from the ground and bumped surface of the road. But as it's good for energy absorption it’s also not special for it's subjected to series damage like failure criteria or the shape must be safe under the given load condition and stiffness is not this much good. Figure 4.2 shows that the cylindrical cross-section which has maximum internal energy is 83J for a minimum diameter of 2.25mm which is 28% of the leaf spring and also C cross-section spring of Figure 4.3 contained around 23% of the leaf spring. There the shape of the spring must be large resilience energy. So the selected designed shape is a cylindrical shape cross section. The potential energy stored as a result of the deformation of an elastic object, such as the stretching of a spring. It is equal to the work done to stretch the spring, which depends upon the spring constant k, as well as the distance, stretched. From the simulation results of three spring shapes. The design shows that round wire gives more resilient energy. These kinds of springs are known for their efficiency since they can store a large amount of energy in a relatively small space. Round wire compression springs can handle as much rapid bouncing and rebounded action. But flat springs are shown to have a high failure rate. Round wire springs can store more energy which results in a greater amount of force applied. This round wire springs shape is U form a loops that can have large rebound power because it is based on the shape.

Thickness=0.25mm



Thickness=0.5mm



Thickness=0.75mm

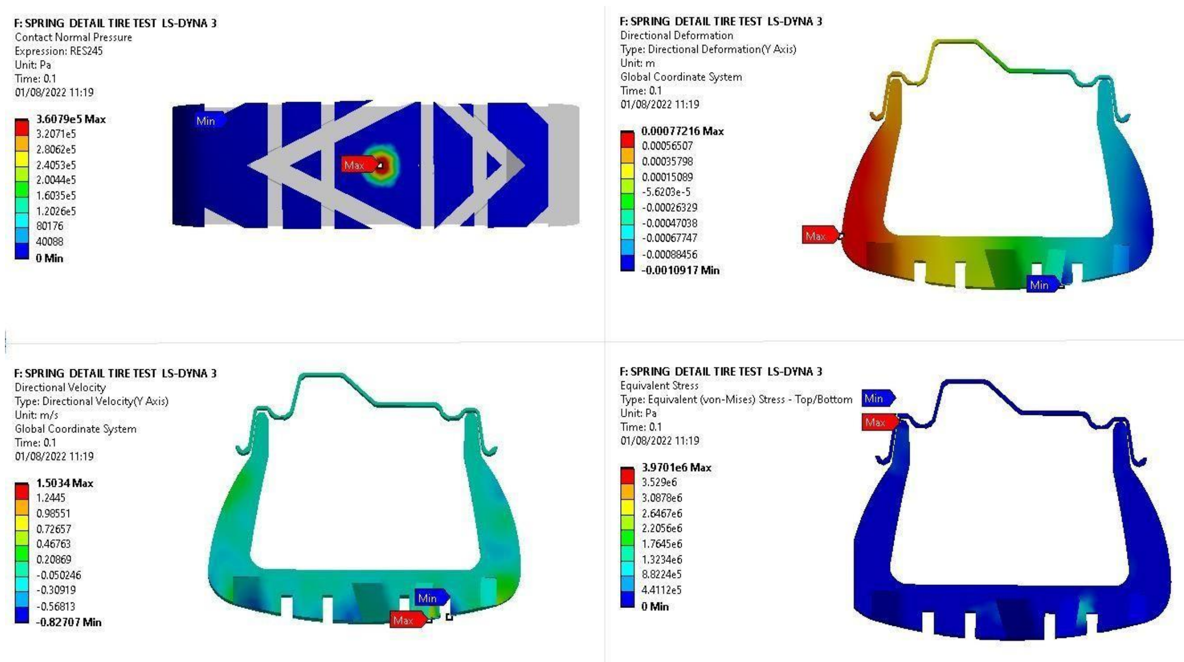


Figure 4.4 (a) 0.25,(b) 0.5, (c) 0.5.The leaf spring Contour plot Results

Results Based on the Number of spring without Guidance

A. Spring Tire Drop Test

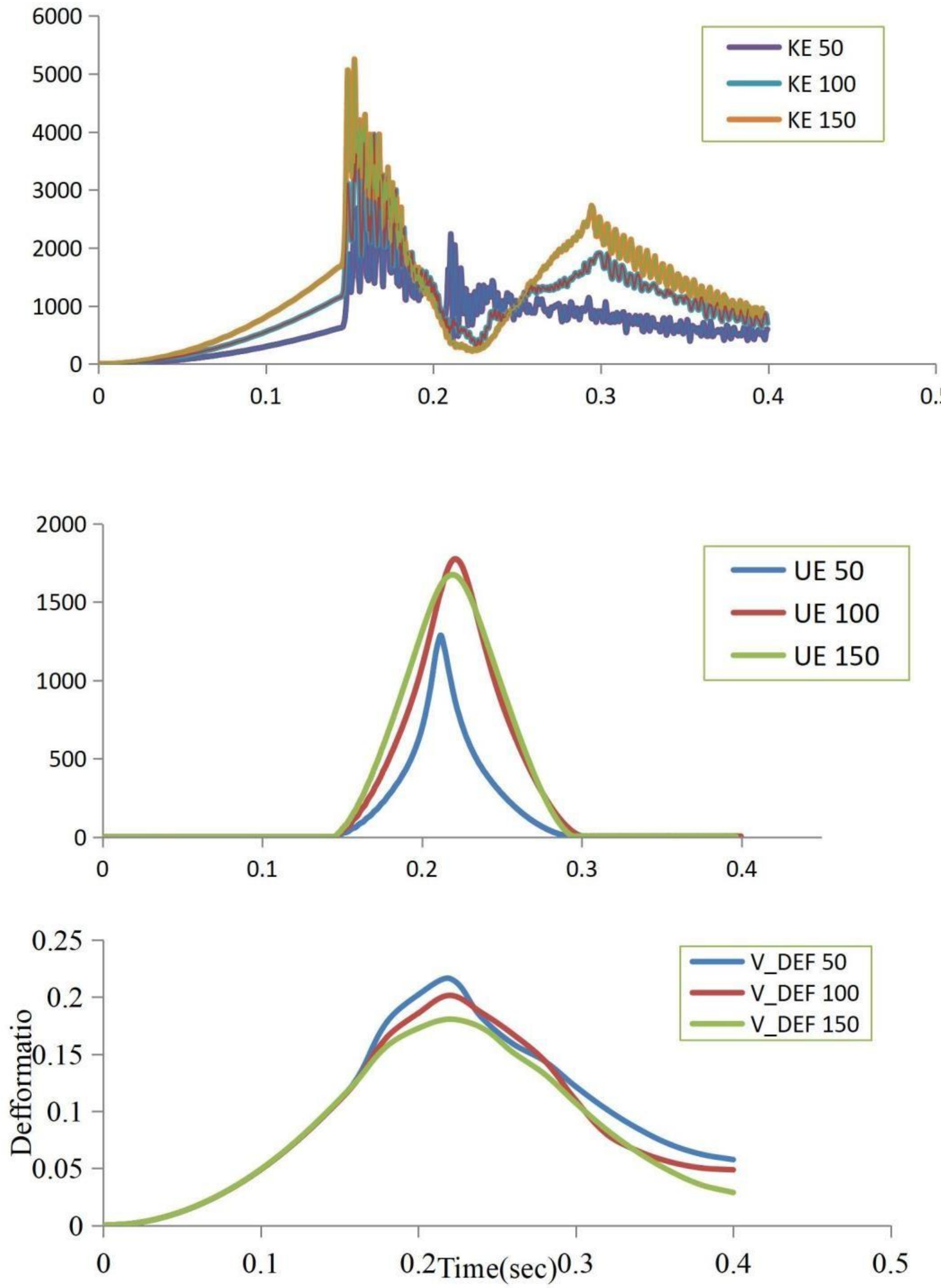
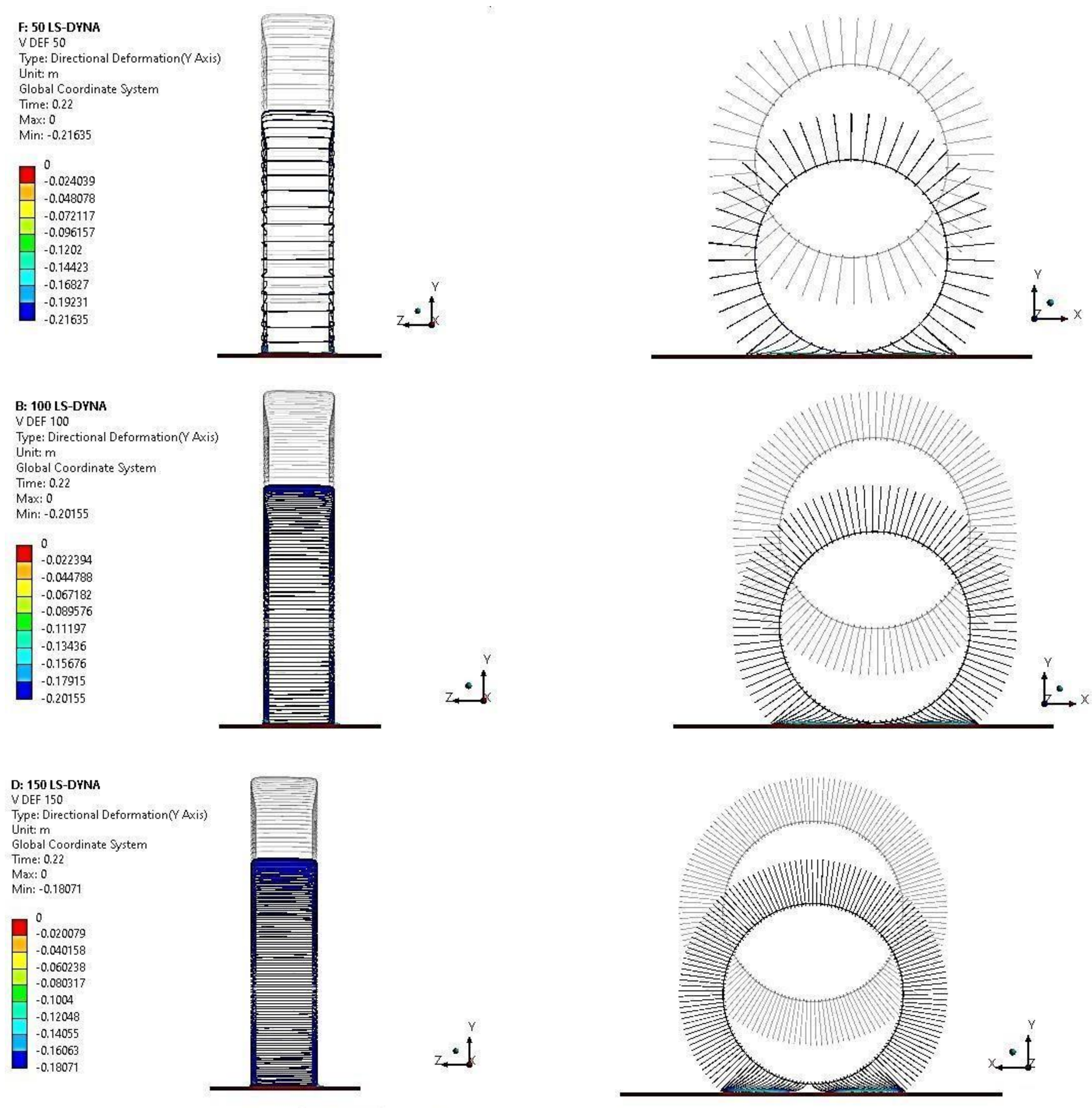
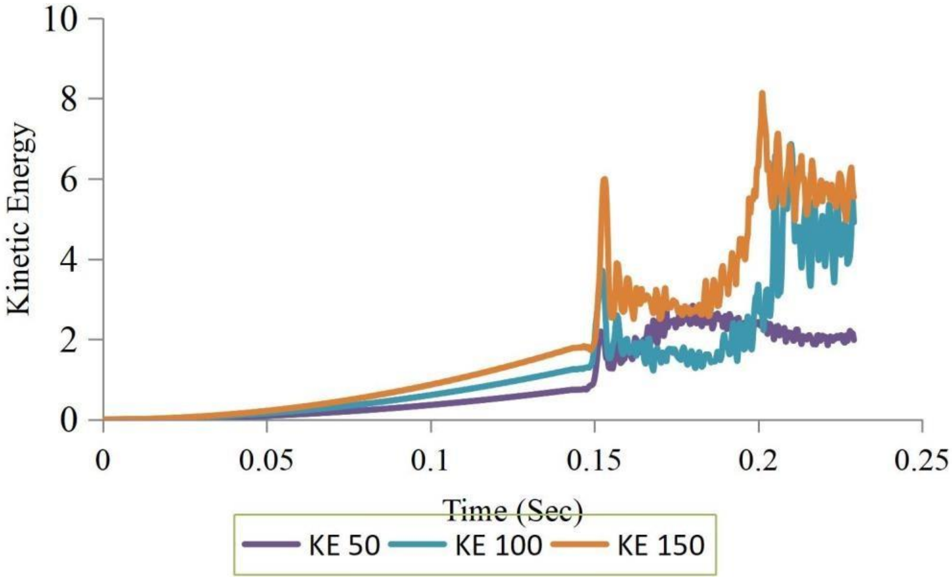


Figure 4.5 (a) Kinetic energy during drop test,(b) internal energy (c) Deformation. Without any Guidance

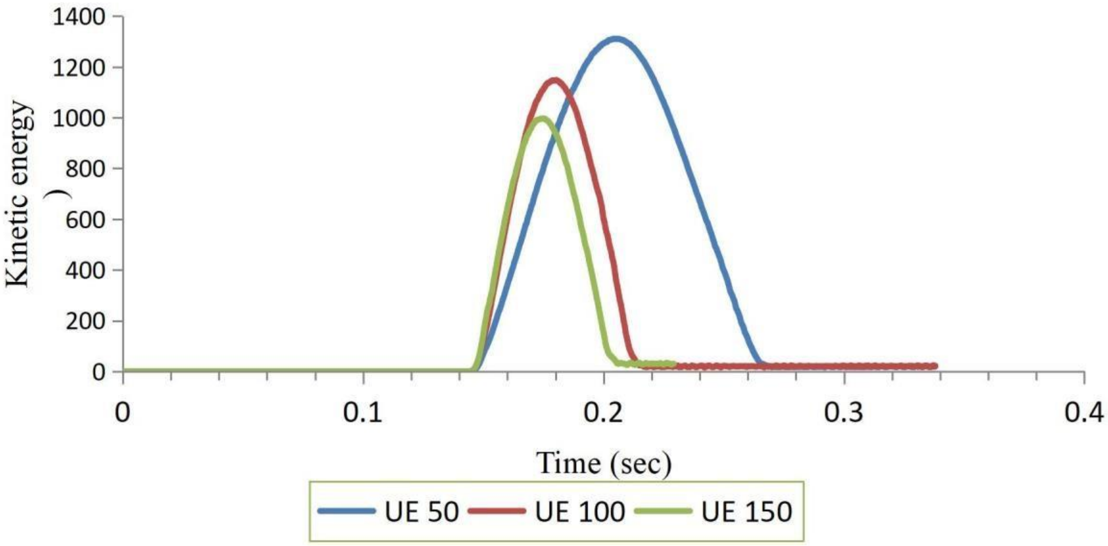

F: 50 LS-DYNA
V DEF 50
Type: Directional Deformation(Y Axis)
Unit: m
Global Coordinate System
Time: 0.22
Max: 0
Min: -0.21635
0
-0.024039
-0.048078
-0.072117
-0.096157
-0.1202
-0.14423
-0.16827
-0.19231
-0.21635
B: 100 LS-DYNA
V DEF 100
Type: Directional Deformation(Y Axis)
Unit: m
Global Coordinate System
Time: 0.22
Max: 0
Min: -0.20155
0
-0.022394
-0.044788
-0.067182
-0.089576
-0.11197
-0.13436
-0.15676
-0.17915
-0.20155
D: 150 LS-DYNA
V DEF 150
Type: Directional Deformation(Y Axis)
Unit: m
Global Coordinate System
Time: 0.22
Max: 0
Min: -0.18071
0
-0.020079
-0.040158
-0.060238
-0.080317
-0.1004
-0.12048
-0.14055
-0.16063
-0.18071

Simulation-based on the number of springs with ring Guidance

B. Spring Tire DE bedding Test

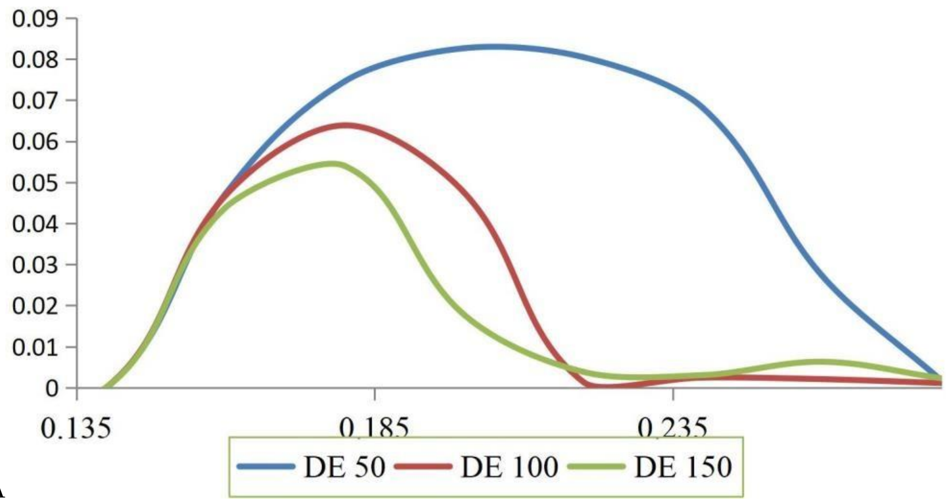


A

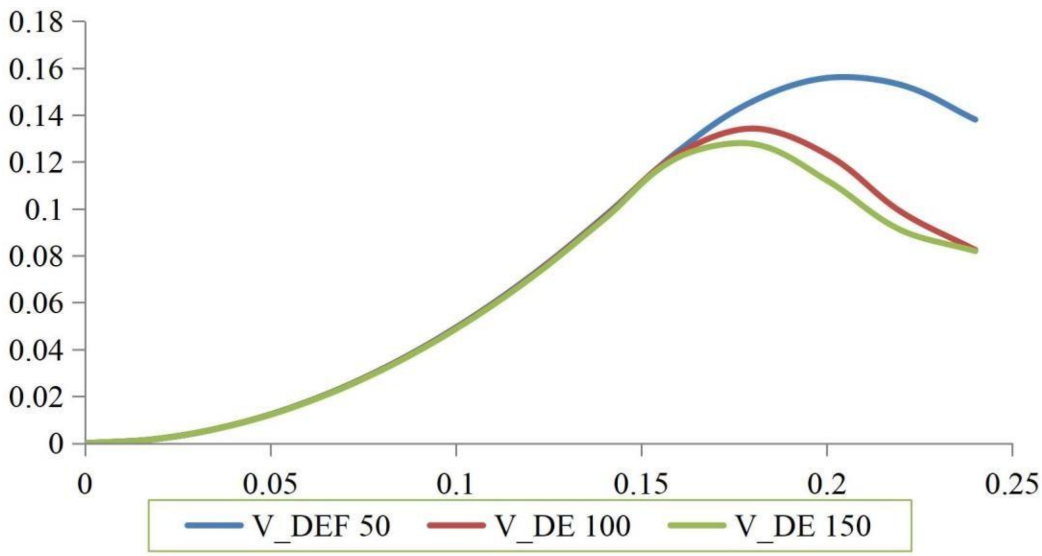


B

Figure 4.6 (a) Kinetic energy during drop test,(b) internal energy. Without Guidance



A



B

Figure 4.7 (a) Debbeding deformation, (b) Vertical Deformation. With Guidance

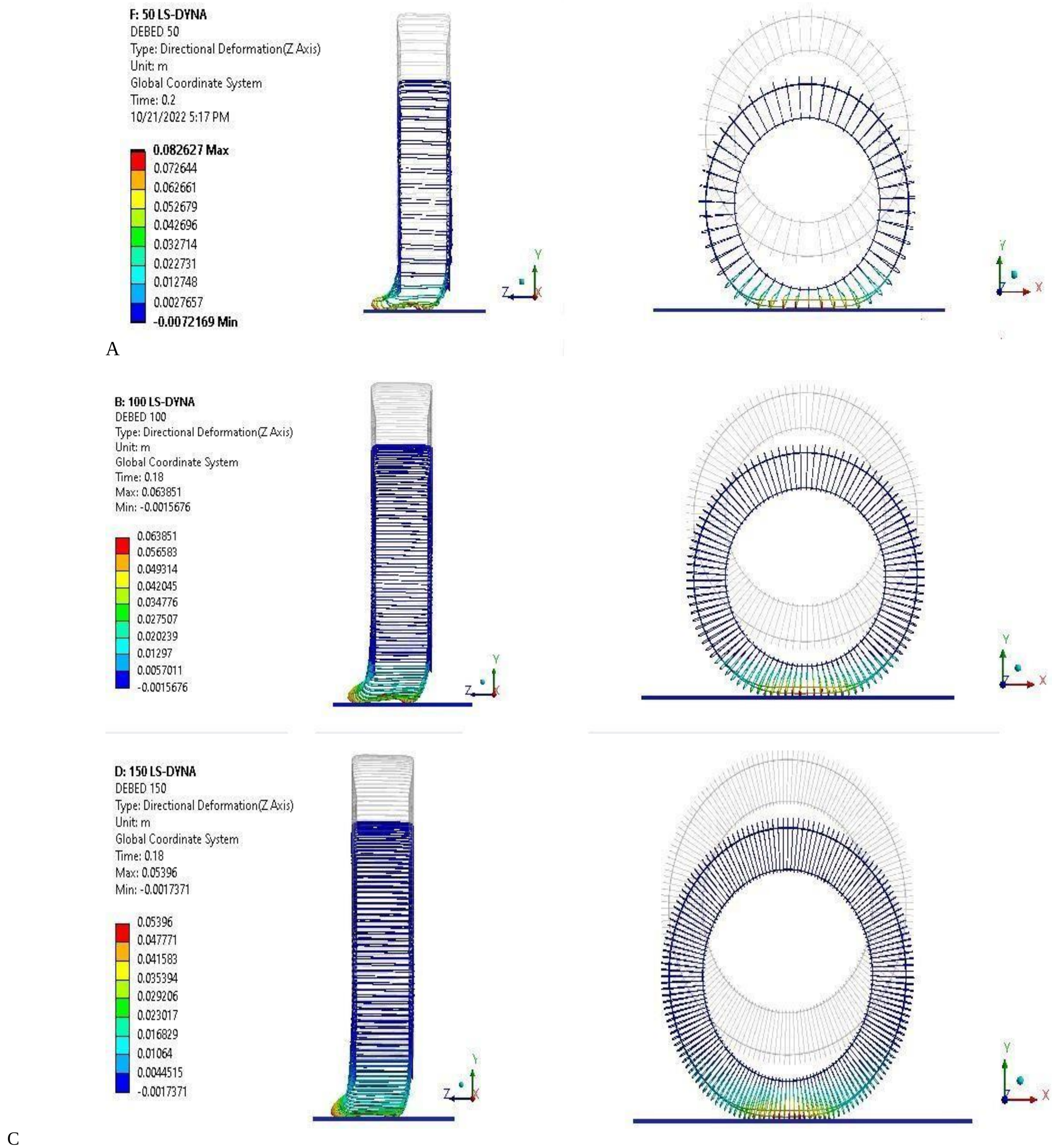


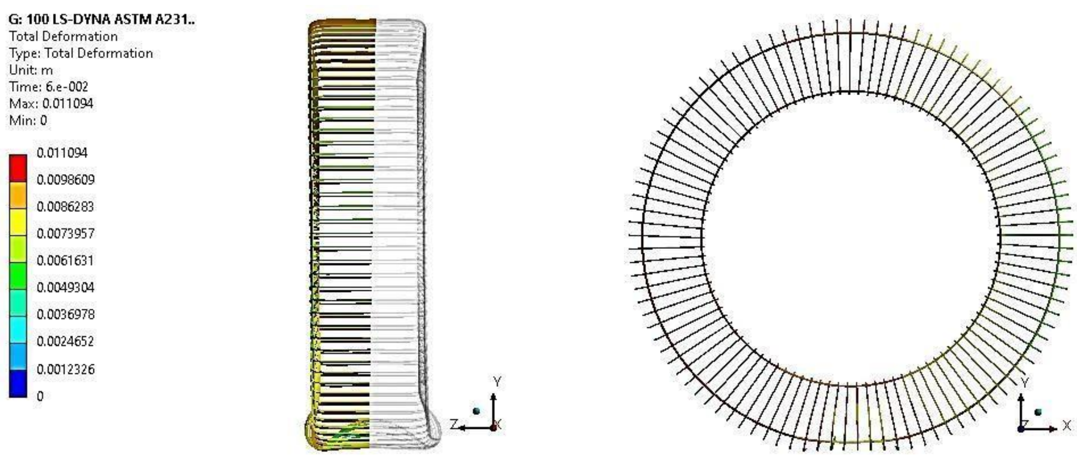
Figure 4.8 (a) 50,(b) 100 (c) 150. With Guidance Contour plot debbed Deformation

Rubber mass is 14.27 kg and wheel rime mass of aluminum alloys is 1.61kg. Therefore the totalweight of the existing tire or tubeless tire is 15.88kg. There the percentage of mass change can beestimated by adding the number of sprigs mass with Rubber and wheel rim. The following table shows the difference between their mass and energy change. The researcher has decided to select the number of springs for the designed spring tire model should be 100 based on the rim circumference of selected vehicle model, spring weight and load resisting capacity. The decision is made by comparing the % of weight change and resilient energy change of arrayed springs from numerical simulation case studies. The 50 spring and 150 sprig tire model is rejected for large deformation and heavy mass increase which is 6.73% respectively. Because if the mass change is above 5%, it doesn't found in the confidence interval range for low weight is better for any vehicle because internal energy is an extensive property, so it depends on mass and volume, hence it depends on molecular weight..

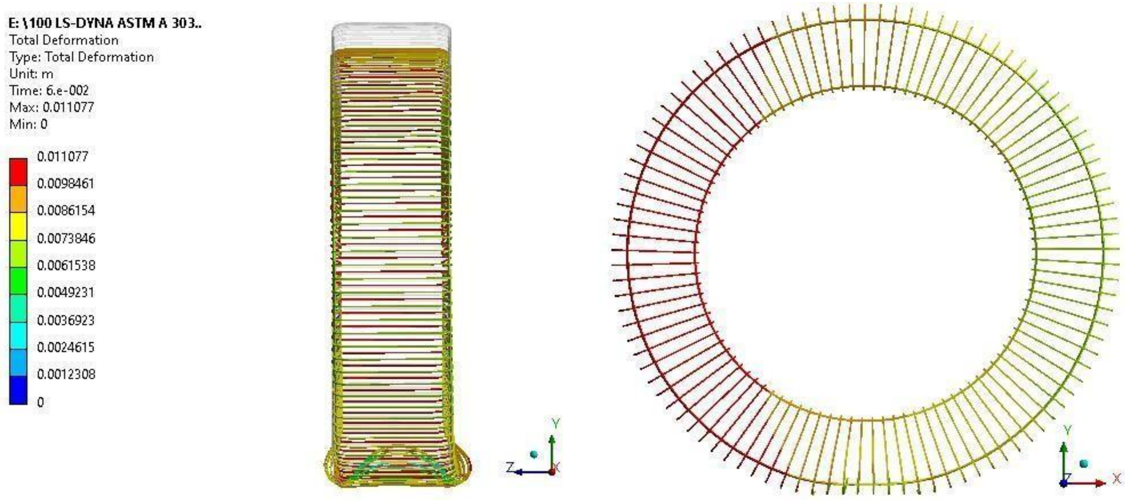
Table 4.3.Summary of Weight in (kg) ad Internal energy (J)

S/N	Diameter of Spring Wire (2mm)	Weight (kg)	Maximum Internal Energy (J)	Weight (%kg)	Energy (%J)
1	Number of Spring 50	16.65	1311.4	-	-
2	Number of Spring 100	17.21	1148.4	3.36	12.4
3	Number of Spring 150	17.77	996.89	6.73	24.0

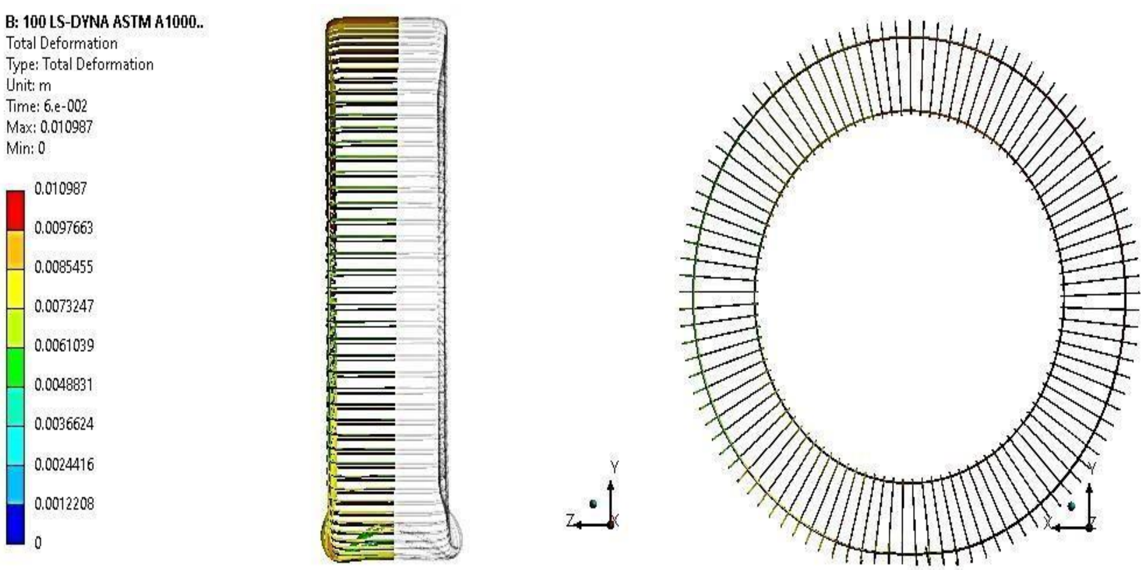
Simulation-based on spring material properties



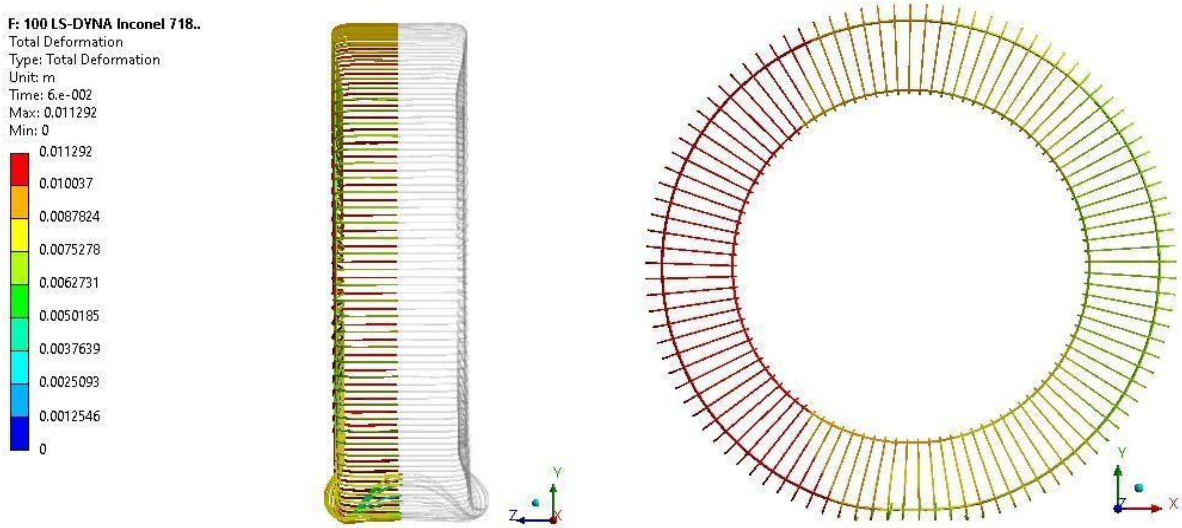
(a)


E: \100 LS-DYNA ASTM A 303..
Total Deformation
Type: Total Deformation
Unit: m
Time: 6.e-002
Max: 0.011077
Min: 0
0.011077
0.0098461
0.0086154
0.0073846
0.0061538
0.0049231
0.0036923
0.0024615
0.0012308
0

(b)


B: 100 LS-DYNA ASTM A1000..
Total Deformation
Type: Total Deformation
Unit: m
Time: 6.e-002
Max: 0.010987
Min: 0
0.010987
0.0097663
0.0085455
0.0073247
0.0061039
0.0048831
0.0036624
0.0024416
0.0012208
0

(c)



(d)

Figure 4.9 (a) ASTMA1000, (b) AMS 7233 (c) ASTMA 303 (d) ASTMA679, (e) Inconel (d) ASTMA 231. With Guidance Contour plot material based

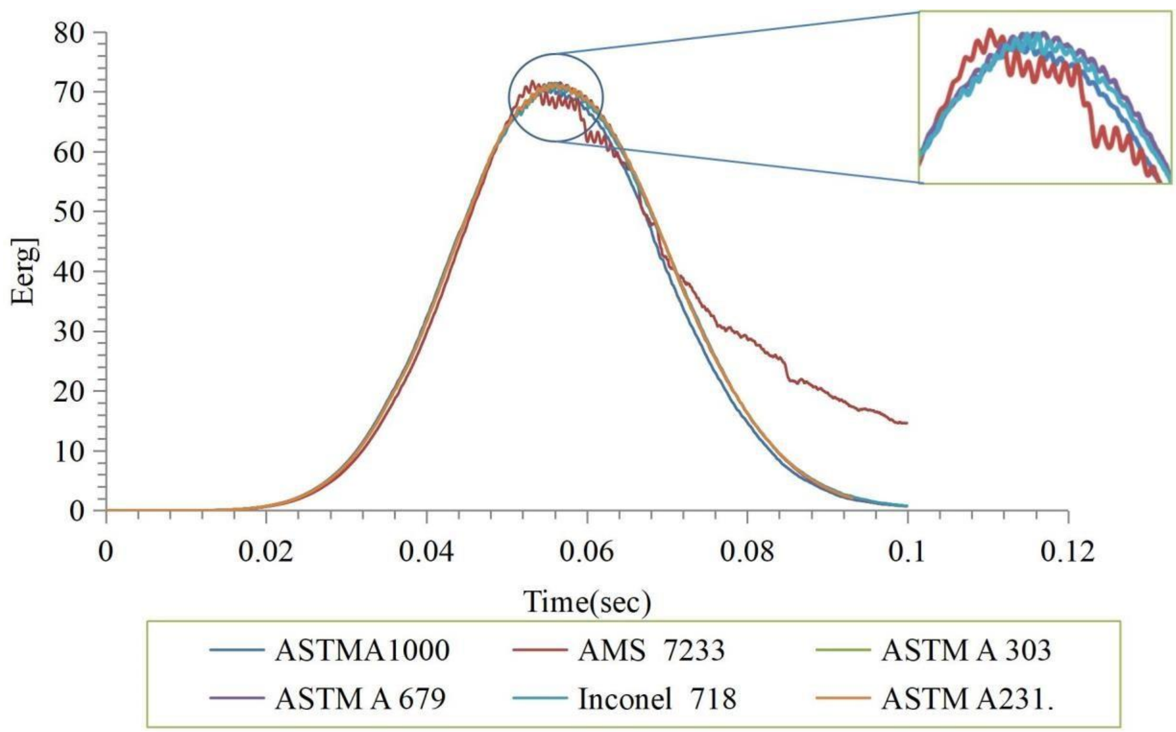


Figure 4.10 Result of internal energy graphic plot material properties based

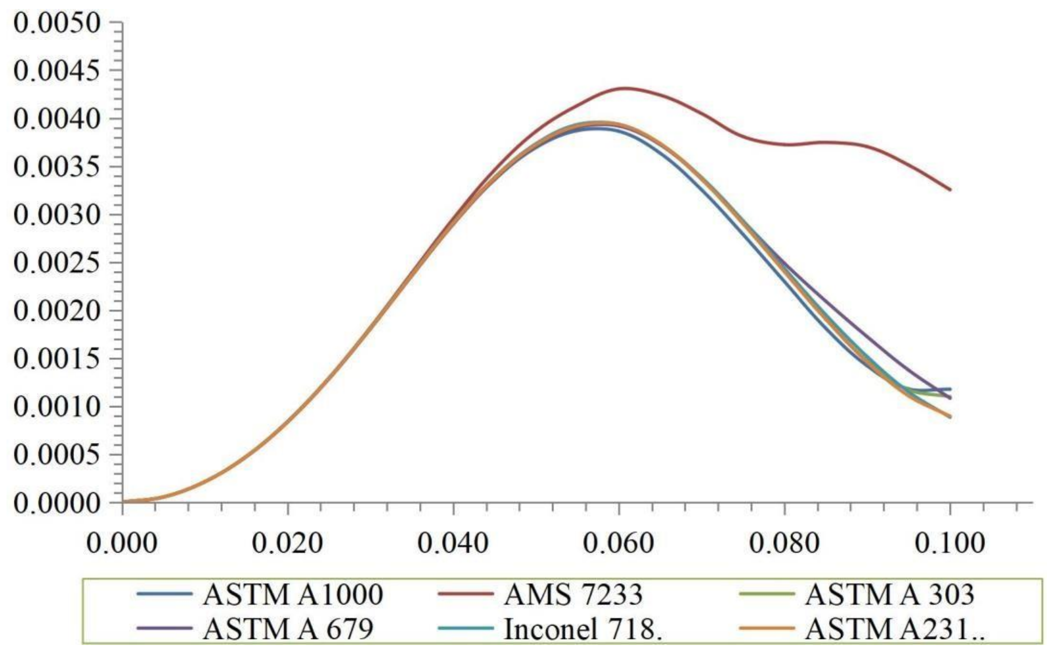


Figure 4.11 Result of Deformation graphic plot material properties based

From the above two graphs, the elastic potential energy and deformation are used to show the loss of sprigging effect. The energy regains after compression of the spring under a gravity load of 1000kg analyzed based on material properties. AMS 7233 materials are subjected to large deformation which is 4.3mm and the resilience energy over the respective time didn't regain. This makes AMS 7233 Material rejected from the others. ASTM A 679 and ASTM A231 have overlapped and completely regained energy levels from the rest. But also ASTM A 1000, ASTM 303, Inconel 718 and have the behavior of complete energy gain except they have big dynamic fluctuation.

Spring assembled with rubber and existing tire performance

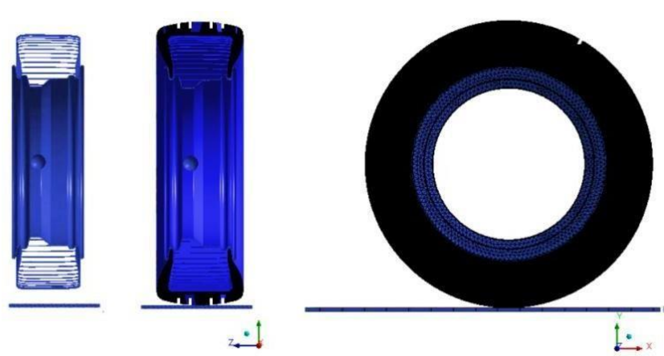


Figure 4.12 spring assemble with rubber

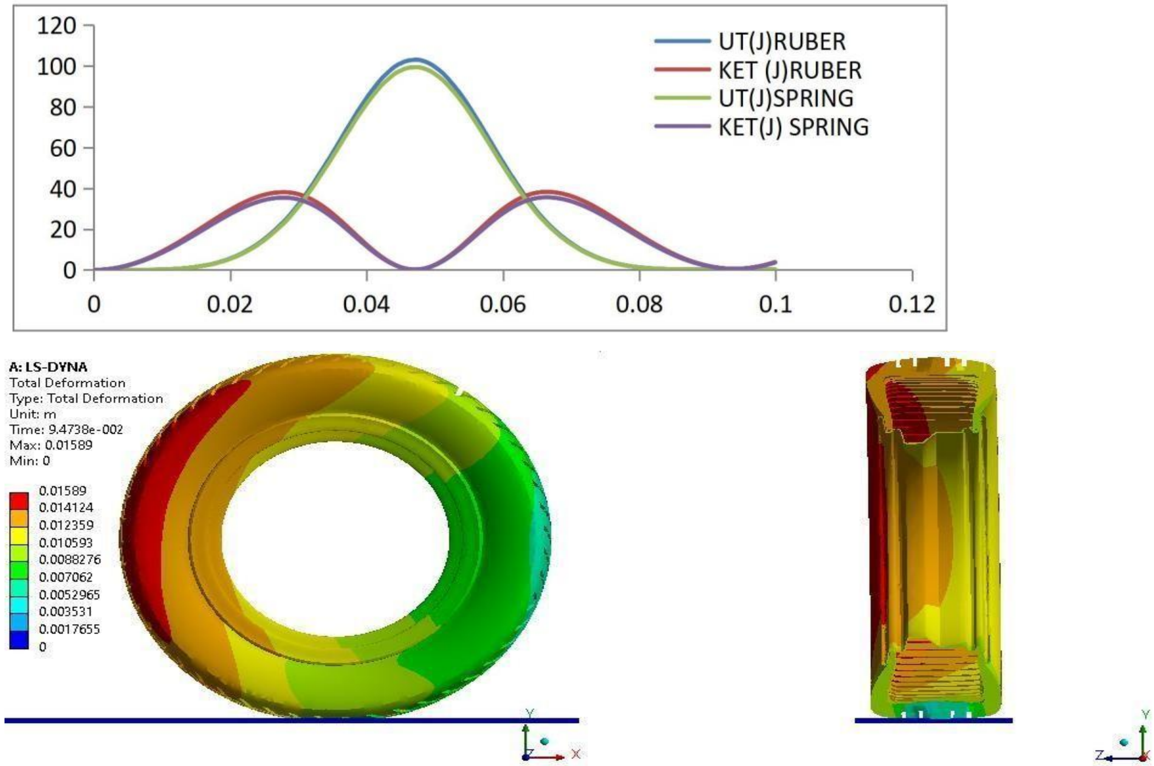


Figure 4.13 Result of spring assemble with rubber

S/N	Tyre Type	Weight (kg)	Maximum Internal Energy (J)	Weight (%kg)	Energy (%J)
1	Air Spring(Rubber Tire)	16.65	103	-	-
2	Metal Spring(100 Spring with Rubber)	17.21	99.9	3.36	-3

Pneumatic air-filled tires provide anyone with a more comfortable ride and a more enjoyable driving experience. When traveling over potholes, obstacles, and bumps, the air helps to absorb the jolts, making the ride for operators much more comfortable using the springing effect of air which gives resilient energy. And also, in this thesis spring tire mode that has the same behavior as a pneumatic tire in which air is replaced with multiple metal springs has been designed and simulated dynamically. The selected material of the proposed spring is simulated with 100 number of spring shielded by the original tire rubber and their deformation and resilient energy is compared with a pneumatic tire. This gives the pneumatic tire maximum internal energy of 103J and metal type spring tire 99.9J. The pneumatic tire resilience is only 3 % better than the spring model.

CHAPTER FIVE

SUMMARY AND CONCLUSION

Summary

From the content of this thesis, the results come after each concept followed by design and numerical analysis of spring tires for good performance improvement and lifetime is designed. The method used in this thesis is the model becomes developed by 3dmodeling software Ansys Space Claim a n d analyzed by Ansys LS Dyna Software. A comparative study has been carried out on existing and designed models of spring tires. From four cases of numerical analysis, (1) spring shape design,(2) wire type spring numbered tire design without guidance,(3)wire type spring numbered tire with guidance,(4)wire type spring based on material properties.

- From the analysis of flat spring, cylindrical and C cross-section wire type result shows that a single cylindrical wire spring has good energy absorption mode which is 28% better than flat spring and 4% better than C section cross-section. The C-section cross-section is 24% better than flat springs.
- The full tire has also been tested based on the number of wires used and the circumferential radius of the wheel rim. The analysis is carried out for the safety rich of designed spring tires with internal energy. The result from the analysis is based on the Rubber mass being 14.27 kg and the wheel rime mass of aluminum alloys is 1.61 kg. The total weight of the existing tire or tubeless tire is 15.88kg. The percentage of mass change is estimated by adding the number of sprigs mass with Rubber and wheel rim.
- The researcher selected several springs for the designed spring tire model 100. The decision is made by comparing the % of weight change and resilient energy change of arrayed springs from numerical simulation case studies. The 50 spring and 150 sprig tire model is rejected for large deformation and heavy mass increase which is 6.73% respectively. Because if the mass change is above 5%, it doesn’t found in the confidence interval range for low weight is better for any vehicle.
- From the material properties based, the elastic potential energy and deformation are used to show the loss of sprigging effect. The energy regains after compression of the spring under a gravity load of 1000kg analyzed based on material properties. AMS 7233

materials are subjected to large deformation which is 4.3mm and the resilience energy over the respective time didn't regain.

- This makes AMS 7233 Material rejected from the others. ASTM A 679 and ASTM A231 have overlapped and completely regained energy levels from the rest. But also ASTM A 1000, ASTM 303, Inconel 718 and have the behavior of complete energy gain except they have big dynamic fluctuation.
- For the comparison, the selected material of the proposed spring is simulated with 100 number of spring shielded by original tire rubber, and their deformation and resilient energy is compared with pneumatic tires. This gives the pneumatic tire maximum internal energy of 103J and metal type spring tire 99.9J. The pneumatic tire resilience is only 3 % better than the spring model. But the spring tire is better than pneumatic tire by service duration, better maintenance cost, better maintenance time and good strengthness.

Conclusion

The result shows that single wire cylindrical has a good energy absorption mode which is 28% better than flat spring and 4% better than C-section cross-section. The full tire has also been tested based on the number of wires used and the circumferential radius of the wheel rim. The analysis is carried out for the safety rich of designed spring tire with overall energy and compared with exiting tubeless tire. This makes the performance of the designed tire is also can be equal to a pneumatic tire. The decided number of springs for the designed spring tire model is become100. The decision is made by comparing the % of weight change and resilient energy change of arrayed springs from numerical simulation case studies. The 50 spring and 150 sprig tire model is rejected for large deformation and heavy mass increase which is 6.73% respectively. The analysis carried out based on material properties makes AMS 7233 Material rejected from the others for it is big dynamic fluctuation energy loss and large deformation. ASTM A 679 and ASTM A231 have overlapped and completely regained energy levels from the rest. But also ASTM A 1000, ASTM 303, Inconel 718 and have the behavior of complete energy gain except they have big dynamic energy loss fluctuation. Finally, the selected material for the spring tire is ASTM A231 for its good in deformation than ASTM A 679. And the selected material of the proposed spring is simulated with 100 number of spring shielded by the original tire rubber and their deformation and resilient energy is compared with a pneumatic tire. This gives the pneumatic tire maximum internal energy of 103J and metal type spring tire 99.9J. The pneumatic tire resilience is only 3 % better than the spring model.

Recommendation

This type of tire is recommended for any type of vehicle that uses the same size of pneumatics tire and airless tire to be capable of the performance of both tires. The spring wire should mount properly with a screw-like thread. Balancing during spring mounting should be checked. After the spring is assembled on the rim rubber-like structure should shade the external part.

Future scope

- The researcher reflected to investigate experimental analysis for different spring cross sections and spring tire assembly for further study.
- Further, the researchers should carry out performance investigations of spring tires assembled with vehicles in driving conditions.
- The researchers can also carry out the details mathematical modeling of spring tires based on analytical skills.

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APPENDIX I

Spring material properties

High Carbon Spring Wire		Min. Tensile Strength (psi x 103)	Modulus of Elasticity (psi x 106)	Design Stress % Min. Tensile	Modulus in torsion (psi x 106)	Density
Music Wire ,ASTM A228	ASTM A228	230-399	30[207]	45	11.5 [79.3]	7860
Hard Drawn	ASTM A227	CLI 147-283	30 [207]	40	11.5 [79.3]	7860
High Tensile Hard Drawn	ASTM A679	238-350	30 [207]	45	11.5 [79.3]	7860
Carbon & Alloy-Specialty Spring Grade						
Grade B Carbon	ASTM A1000	195-276	30 [207]	45	11.5 [79.3]	7860
Grade C Chrome Vanadium	ASTM A1000	210-270	30 [207]	45	11.5 [79.3]	7860
Grade A Chrome Silicon	ASTM A1000	231-305	30 [207]	45	11.5 [79.3]	7860
Alloy Steel Wire						
Chrome Vanadium	ASTM A231	190-300	30 [207]	45	11.5 [79.3]	7860
Chrome Vanadium Valve	ASTM A232	205-290	30 [207]	45	11.5 [79.3]	7860
Chrome Vanadium Valve Modified	ASTM A878	205-290	30 [207]	45	11.5 [79.3]	7860
Stainless Steel Wire						
AISI 302/304	ASTM A 313	110-245	28 [193]	35	10 [69.0]	7860
AISI 316	ASTM A 313	110-245	28 [193]	40	10 [69.0]	7860
17-7 PH	ASTM A 303	235-335	29.5 [203]	45	11 [75.8]	7860
Non-Ferrous Alloy Wire						

Phosphor Bronze Grade A	ASTM B 159	105-145	15 [103]	40	6.25 [43.1]	7860
Beryllium Copper	ASTM B197	150-230	18.5 [128]	45	7.0 [48.3]	7860
Monel 400	AMS 7233	145-180	26 [179]	40	9.5 [65.5]	7860
High-Temperature Alloy Wire						
A286 Alloy	A286	160-200	29 [200]	35	10.4 [71.7]	7860
Inconel 600	Inconel 600	100-230	31 [214	40	11.0 [75.8]	7860
Inconel 718	Inconel 718	210-250	29 [200]	40	11.2 [77.2]	7860

APPENDIX II

InnovaCrysta Tire Load and Unloaded Pressure

InnovaCrysta Variant(s)	Front Tyre		Rear Tyre		Tyre Size
	Unloaded	Loaded	Unloaded	Loaded	
2.4 G Plus 7 STR	33	33	33	36	205/65 R16
2.4 G Plus 8 STR	33	33	33	36	205/65 R16
2.4 GX 7 STR	33	33	33	36	205/65 R16
2.4 GX 8 STR	33	33	33	36	205/65 R16
2.4 VX 7 STR	33	33	33	36	205/65 R16
2.4 VX 8 STR	33	33	33	36	205/65 R17
2.4 ZX 7 STR	33	33	33	36	215/55 R17
2.7 GX AT 7 STR	33	33	33	36	215/55 R17
2.7 GX AT 8 STR	33	33	33	36	205/65 R16
2.7 GX MT 7 STR	33	33	33	36	205/65 R16
2.7 GX MT 8 STR	33	33	33	36	205/65 R16
2.7 VX 7 STR	33	33	33	36	205/65 R16
2.7 ZX AT 7 STR	33	33	33	36	215/55 R17
2.4 GX AT 7 STR	32	32	34	34	215/55 R17
2.4 GX AT 8 STR	32	32	34	34	205/65 R16
2.4 ZX AT 7 STR	NA	NA	NA	NA	215/55 R17
2.8 GX AT 7 STR	33	33	33	36	205/65 R16
2.8 GX AT 8 STR	33	33	33	36	205/65 R16
2.8 ZX AT 7 STR	33	33	33	36	215/55 R17
Touring Sport 2.4 VX 7 STR	33	33	33	36	205/65 R16
Touring Sport 2.7 ZX AT 7 STR	32	36	32	36	215/55 R17
Touring Sport 2.7 VX 7 STR	32	34	32	34	205/65 R16
2.7 GX (-) MT 7 STR	32	32	34	34	205/65 R16
2.7 GX (-) MT 8 STR	32	32	34	34	205/65 R16