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REVIEW ARTICLE

Design and fabrication of airless and tubeless tyre: a review

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Abstract

We are focusing heavily on optimizing tyre design in the next generation of automobiles. Tyres are the only medium that moves a vehicle back and forth while also providing directional stability. Conventional tyres perform admirably and are currently in their prime. Some of the disadvantages of pneumatic tyres are that they all suffer from puncture and pressure maintenance; the operational atmosphere can vary the air density, causing pressure loss, and so on; these issues force the industry to develop new tyres that do not suffer from the same problems. There is always room for improvement in the design procedures. Airless tyres are an option that avoids all of the issues. Airless tyres are rubber structures that support the vehicle's weight while in motion. The structural design of the tyre determines its properties such as stiffness, lateral stiffness, load-bearing capacity, and others. In this paper, the properties of non-pneumatic tyres (NPT), pneumatic tyres, and tubeless tyres were compared, and the NPT tyre was found to be superior due to the quality of material (polyurethane) used on the tyre, which makes it light in weight and strong, and produces less maximum principal stress, which means it does not have permanent deformation and causes the tyre flexible and capable of transferring.
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1. Introduction

For more than 10 decades, vehicles have been running on softened air sheathed in rubber. Sometimes, we have a propensity to get thus accustomed to a valuable product that no such changes are ever created for ever before the years, decades even. Thus begins a commentary discussing the event of stuffy tyres, one thing that comes from additional conquest within the past few years. Many tyre corporations have started experimenting with new styles for non-pneumatic tyres such as Michelin and Bridgestone; however, none of the styles has made it to production.
Creating a replacement non- pneumatic style for tyres has additional positive inference than one would possibly assume. For one factor, their square measure brobdingnagian safety edges. Having a dyspnea tyre suggests that there's no change of a flat which in turn suggests that the quantity of route accidents can become less. Even for things like Humvees within the military' utilizing non-pneumatic tyres contain a nice positive impact on safety. Tyres square measure the liability in military vehicles and square measure usually targeted with explosives. If these vehicles used dyspnea tyres, this might not be a priority.
There is additionally an environmental profit to using this sort of tyre. Since they never go flat and may be retreaded, dyspnea tyres won't ought to be thrown away and replaced nearly as

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usually as gas tyres. This can weigh down lowland mass greatly. Because of the advantages, I feel that it's exceptionally necessary that analysis and production of dyspnea tyres is sustained and raised. This sort of innovation works well in coexistence with many engineering codes of ethics, and therefore ought to be taken up by engineers all over. Cars square measure things that individuals use on a daily basis; thus, any improvement over existing styles would have an effect on the lives of the bulk of individuals.

Learning regarding such a subject, therefore, I feel holds hugely value- particularly for U.S.A freshmen engineering students. In doing analysis into these types of topics that hold importance which means, we are able to see that what we are going to do can create a distinction. The flexible spokes and shear band are the components that support the load acting on an NPT like air in the case of a pneumatic tyre. Several researches are going on to optimize the design of spokes and shear bands of an NPT [1].

A Non-Pneumatic Tire (NPT) appears to have advantages over the conventional pneumatic tyres in terms of flat proof and maintenance free. In this study, the static contact pressure of NPTs with hexagonal honeycomb spokes is investigated as a function of vertical loading and is compared with that of a pneumatic tire. Finite element based numerical simulation of the 2D contact pressure of a NPT is carried out with ABAQUS for varying vertical forces and lattice spoke geometries. A lower contact pressure is obtained with NPTs than with the pneumatic tire due to a high lateral spoke stiffness of NPTs when they are designed to be the same load carrying capability. The NPT with the spoke of a low cell angle, Type A spoke in this study, shows a low contact pressure; Type A in this study. On the other hand, the NPT with Type C spoke shows a lower local stress in the spoke cell struts, associated with the flexible cellular structural property in the uniaxial compression.

The inner ring is made of an aluminum alloy and functions as a rigid hub. The IIEM and OIEM are made of a high strength steel with 1- and 0.75-mm thickness respectively. Without reinforcements, the edges of the spokes over the contact zone with the ground would buckle and cause an undesirable non-linear effect of the honeycombs. Polyurethane (PU) is used as the constituent material of the spokes and shear layer with 10.2 mm thickness. PU composite has both elasticity and stiffness at the same time. PU materials have a relatively low modulus that allows for large strain with low stress. The trend component is made of rubber. The thickness of the tread is set to be 2 mm. In Michelin's Tweel the spokes have a curvature, thickness and also deviate from the radial line. The spokes are paired and placed at equal intervals along the circumference of the Tweel [2].

2. Literature review

Aravind Mohan, et al in 2017 studied about "Design & analysis of non- pneumatic tyre" and concluded the comparison of solid rubber tyre(tubeless tyre) and air filled tyre and discuss the honeycomb structure used in the spokes of NPT tyres having the less stiffness and minimum stress concentration as compare to trigonal, hexagonal, square structured.[1]. Pranav A. Rangdale, et al in 2018 studied about "non-pneumatic tyre" and concluded, the differentiate between pneumatic and non-pneumatic tyre by life, efficiency, cost, air, air valve, puncture and discuss about high quality of NPT tyre are made up of polymer and it can be made cheaper than pneumatic by research on it.[3].S.A Kantorin & S.V Bakhmutov in 2019 studied regarding "providing vehicle running life in case of loss of air pressure in tyre" and ended, that thermoplastic polymers or elastomers, mainly polyurethanes are used as material(durability, lightness, elasticity) high temperature and dynamic load have no effect comes on the functionality support made of these materials testing the properties of polyurethanes [4]. Marcin Zmuda, et al in 2019 studied regarding "numerical research of selected features of the non-pneumatic tyre" and concluded, the characteristics of quasi-static and dynamic(to compare with pneumatic tyre) and prepare a numeric model of NPT tyre by record the data from own experiment on-shapes of spokes, contact areas and deflection through a normal load of 20kn, to find out new material which have to be the similar properties of material used in NPT tyre and author continue the work to improve the model to obtain data for hyper elastic material model [5].

Taoyu Wu, et al in 2020 studied regarding "research on non-pneumatic tyre with gradient anti-tetra chiral structure" and ended, that use of the NPT tyre having the anti-tetra chiral structure was the finest shapes for carrying more load easily than the other structures used for NPT tyres, by analyzed the lateral compression result of different structures (hexagonal, honeycomb, square, trigonal) [6]. Jayanthi srivatsa sharma, et al in 2021 studied about "feasibility of using NPT tyre with re-entrant type auxetic structured spokes in cessno 172 aircraft tyre" Cessna 172 is an American 4 seat, single engine, high wing plane] and ended, that from the testing of the NPT model material of tyre had the maximum principal stress is below the yield point of polyurethane used in spokes, which implies that the structured not undergo damages/permanent deformation and NPT tyre with re-entrant type auxetic structured spokes can be utilized in Cessna 172 aircraft [7]. Sanjit S. Chavan, et al in 2022 studied regarding "tweel non-pneumatic tyre" and concluded, that the different shapes of spokes used in the honeycomb structured in NPT tyres were capable to retreated and the impact of NPT tyres in the upcoming generation because of the conservation of energy and safety of tyre bursts as that of pneumatic tyre [8].

As depicted in Fig. 1, the NPT is made up of three major components: a circular deformable beam, thin elastic collapsible spokes, and a rigid hub. In some designs, such as the Resilient Technologies NPT [9] the polyurethane circular deformable beam can be replaced by rubber. This beam deforms virtually entirely owing to shear, hence its name, and it is made of a low modulus material [10]. A shear layer is sandwiched between an inner inextensible membrane (IIEM) and an outer inextensible membrane (OIEM) in the shear beam (OIEM). This beam acts as a replacement for the inflation pressure, resulting in reduced contact pressure. Inextensible membranes are sometimes known as reinforcements because of their high circumferential stiffness and strength and low radial bending stiffness. This causes shear deformation of the tread rubber. The spokes' edges over the ground contact zone would buckle without the reinforcements, causing an undesired non-linear impact on the spokes [11].

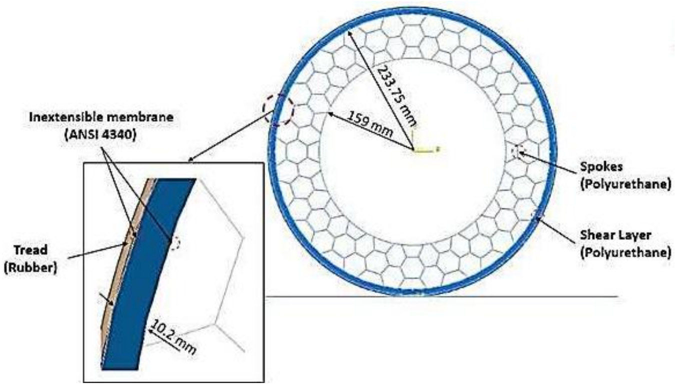

Figure 1: Different parts and dimensions of NPT [12].

The critical properties of the pneumatic tyre, notably mass, stiffness, contact pressure, and rolling resistance, dictate NPT design. Rolling resistance is one of the essential elements to consider because it affects vehicle fuel economy. Stiffness and contact pressure distribution are other significant features to consider while developing an NPT [13]. The goal of modifying the spoke structure during the design phase is to determine the values of design factors to improve the performance of the NPT with given restrictions.

3. Different types of tyres

Pneumatic Tyre Every vehicle deserves the better cure to make it happen the main play role occurs i.e., tyre. The first ever tyre formed is pneumatic tyre which was invented by "john Boyd Dunlop" in 1888 unaware that "Robert Thomson" had already patented a design for a pneumatic tyre in 1846. Pneumatic tyres are available in multiple tread patterns i.e., more variety of tyres is available, offer a more comfortable ride, minimizing the vibration applied to the machine and to the driver. Air gives it a smoother ride, but also has the tendency to get punctures and deflating, it needs to be repaired at a very inconvenient time, while driving, it takes charges on a daily basis to maintain the air pressure. Non-Pneumatic Tyre NPT tyres are the upgrade model in the field of tyres to make a more comfortable ride on any vehicle and take cost reduction factor too, in the field of maintenance. And the first NPT tyre was launched in the late 1990s by "Steve cron" and their fellow "Michelin engineer and co-inventor of the Michelin tweel airless radial tire. The two inventors sketch out a radial tire and the idea of exploring alternatives to the pneumatic tire begins. Neither the possibility of air leakage and tyre blow-outs. It provides more contact surface area due to its flexibility. No maintenance is needed. Once it has been manufactured, it cannot be adjusted again. Not as an economic tyre. NPT tyres are heavier than the pneumatic tyre. Tubeless Tyre Every modification comes for the better and makes another chance to overcome the drawback of the previous one and try to adjust in the compatible market. For the automobile sector the main components are the design, engine efficiency, and the tyre performance, to get the chance from the pneumatic tyre "P.W. Litchfield" of the Goodyear tire company patented the first tubeless tyre in 1903, but it was never commercially exploited until the Packard was used in 1954. Deflation of the air leakage rate is very slow, produces low resistance during the ride, more durable than a pneumatic tyre. It is difficult to fit on the rim. It required skilled labor to fit the tire on the rim. It is much more expensive than the pneumatic tyre as shown in table 1.

Table 1: Properties of different types of tyres

Properties of Tyre	Pneumatic	Non-Pneumatic	Tubeless
Energy-Loss While Rolling	High	Low	Medium
Vertical Stiffness	High	Low	Medium
Contact Pressure	Medium	Low	High
Surface Contact	Low	High	Medium
Mass	High	Low	Medium

4. Results and discussion

4.1 Finite element analysis

When investigating the impact of torques on natural wheel frequency, the models are configured with ground limitations and a vertical load of 5 kN to imitate real-world situations. The graph demonstrates that when torque increases, the first four-order natural frequency expands, but the amplitude of the vibration mode remains constant. The first eight vibration modes are presented in Fig. 2 when there is no load and no ground limitations. The vibration modes are axially symmetric, with the first-order vibration mode being "up-twitch" and the second-order vibration mode being "oval." Tangential vibration mode points are located on the elliptical symmetry axis for the second-order vibration mode. In other cases, the wheel has both radial and tangential deformation, and the deformations in both directions correspond to each other. Different modes are three-directional vibration coupling modes. The first eight vibration modes are presented in Fig. 3 when there is no load and no ground limitations. The figure depicts how the first-order vibration mode differs from that without ground limitations. The vibration mode shifts from "up-twitch" to "elliptical," and the natural frequency increases, indicating that it is in eccentric mode. As a result, the excitation force transmitted from the pavement to the axle is significant, and it is vital for producing pavement noises. Second, vertical loads and torques affect only the amplitude of vibration modes and have minimal effect on the shape of vibration modes. When the wheel carries vertical loads and moments, the vibration modes are not axially symmetric, and the amplitudes shift due to the uniformly distributed loads. As a result, when evaluating the matching of MEW and vehicles, excitation force should be considered [14].

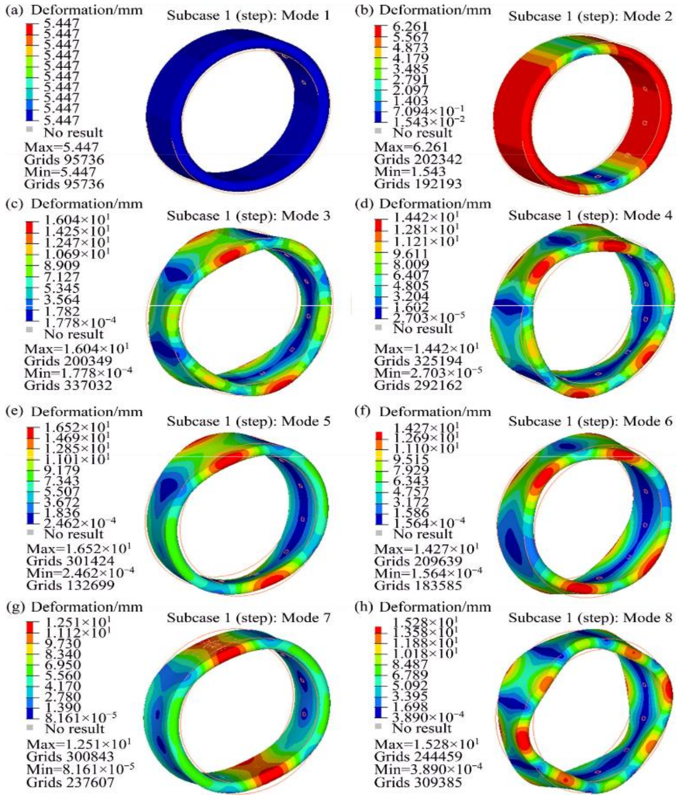

Figure 2: Wheel vibration modes of first-order to eighth-order without ground constraints [14]

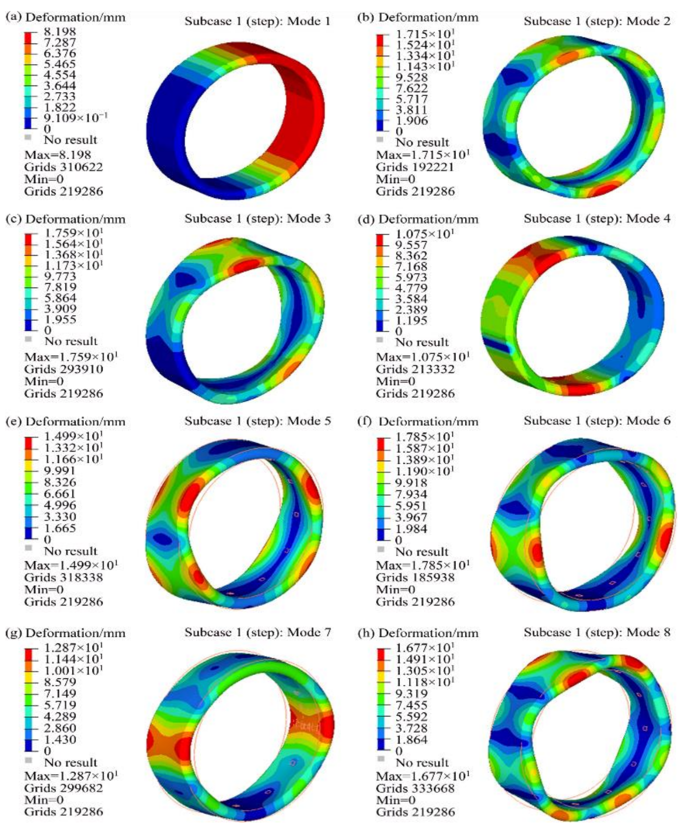

Figure 3: Wheel vibration modes of first-order to eighth-order with ground constraints [14]

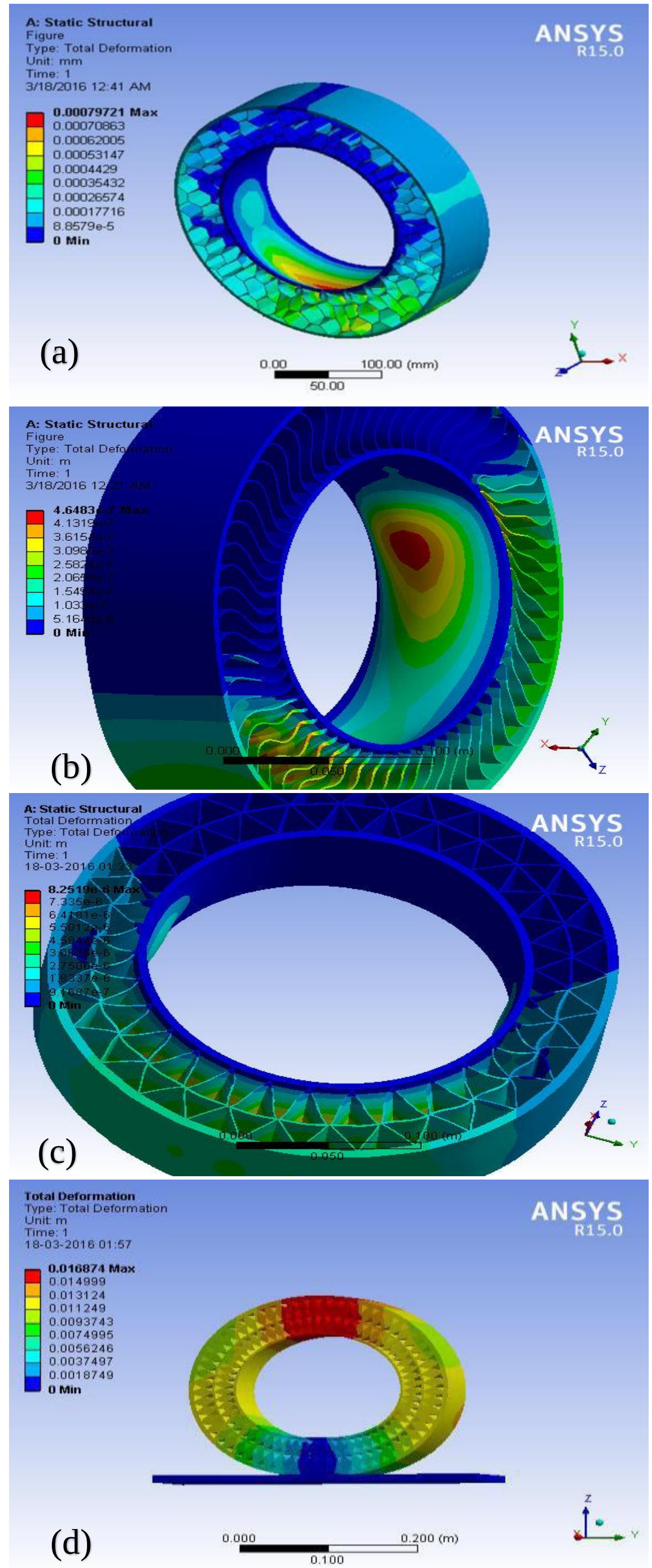

Figure 4: Deflection of air less tyre, (a) Honey Comb Structure, (b) Spoke type Structure, (c) Triangular type Structure, (d) h diamond Structure [15]

Applying a consistently distributed edge force at the tire-rim contact zone results in vertical loading on the wheel. The deflection of the wheel center in the loading direction, and thus the displacement in the lateral direction.

The graphic above depicts the total deformation of the tyre when a load of 1200 N is applied; the load acts on the center of the axle, and the deformation of the entire tyre with stress and strain relationship is depicted. The color representation represents the tyre's deformation when a load is applied. In this construction, the overall deformation of the tyre is 0.00079721. The image above depicts the entire tyre deformation when a load of 1200 N is applied. The standard analysis is performed using polyurethane as spokes and natural rubber as a tyre thread. The inner layer of the tyre is nylon, which is utilized in pneumatic tyres. The hub is made of aluminum, which is the primary material of an airless tyre [15].

Table 2: Vertical stiffness for the four models [12].

Tyre model	First case		Second case	
	Verticle stiffness (N/mm)	Deflection (mm)	Verticle stiffness (N/mm)	Deflection (mm)
Curved spoke	79.76	37.61	48.72	67.57
New curved spoke	158.7	18.9	101	29.7
Honeycomb	263.38	11.39	111.39	26.93
Spoke pairs	608.51	4.93	402.38	7.45

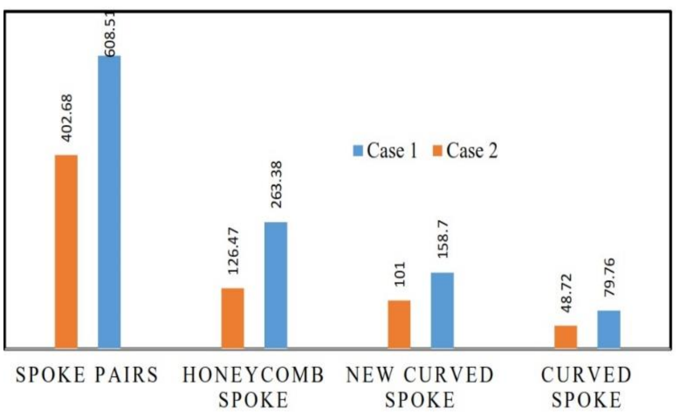

Figure 5: Comparison of vertical stiffness of the four tire models [12].

The Static Load Deflection process measures the displacement of the hub center when a load is applied to evaluate tyre stiffness, where vertical stiffness is defined by Eq (1). Where F is the vertical force (3000 N); δ is the vertical deflection of the hub center.

$$K = F/\delta \tag{1}$$

Because the tyre model is compressed against the ground, the vertical displacement of the hub center is determined.

The vertical stiffness of the four-tire models, sorted from lower to upper values, is given in Table 2 and shown as a column chart in Fig. 5 [12].

In the second situation, the contact pressure and vertical stiffness of the non-pneumatic wheel are decoupled, but they are interdependent in the pneumatic arrangement. Combinations such as high contact pressure / low stiffness and low contact pressure / high stiffness can be accomplished in this proposed structure [16].

5. Conclusions

The best tyre is non- pneumatic tyre due to its less energy loss while rolling, vertical stiffness, contact pressure, and the mass and due to more in surface contact which helps to produce more flexibility in the tyre for spread the vibration around the rim spokes. Ground restrictions, material qualities, loads, torques, and other structural elements all influence a mechanical elastic wheel's inherent frequency and vibration mode. The natural frequency of the wheel increases as the elastic modulus of the flexible rings, loads, and torques increase, and ground restrictions have a notable effect on the shape of the vibration mode. Furthermore, vertical loads and torques primarily affect vibration mode amplitude but have little effect on vibration mode fundamental shape.

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