Static analysis of different spoke structure of airless and conventional tyre

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Abstract. An airless tyre is known as non-pneumatic tyres which are not advocated by air pressure. The major issues related to pneumatic tyre are puncture and flatness due to wear and tear, which lead to the development of airless tyres. The aim of this work is to conduct static analysis of airless tyre, considering various 3D printing materials with different spoke structures. The spoke structures like honeycomb, triangular and diamond and the 3D printing materials such as Acrylonitrile Butadiene Styrene + Polycarbonate (ABS+PC), Polyethylene Terephthalate (PET) and High Impact Polystyrene (HIPS) are considered for modelling of airless tyre. For conventional tyre, Neoprene rubber is considered. The static analysis is conducted using ANSYS workbench 19.2, and the total deformation, equivalent elastic strain, equivalent von-Mises stress and strain energy are compared and evaluated for conventional and airless tyre.

Keywords: Airless tyre, Static analysis, 3D printing materials, ABS+PC, PET, HIPS

1. Introduction
Robert William Thomson is the inventor of first pneumatic tyre or conventional tyre. The pneumatic tyre is made up of composition of butadiene rubber, styrene butadiene rubber and natural rubber which encloses air to reduce vibration and improve traction. The main disadvantage of these tyres is that it flattens due to wear and tear or due to sudden deformations consecutively within a short duration and is needed to be replaced. But, an airless tyre doesn’t get flattened due to wear and tear and they need not to be replaced often. So, the pneumatic tyres are replaced with airless tyres and these tyres are known as Tweel that is blend of the words tyre and wheel. So, Tweel doesn’t have standard wheel hub assembly and was initially developed by a French Company Michelin in 2005. The Structure of Tweel consists of a cable-reinforced band of conventional tyre rubber with molded thread; shear band creates a compliant contact patch with the surface, polyurethane spokes which absorbs energy (i.e.) it provides spring action and wheel hub which connects with axle. The spokes in wheel acts as shock absorbers in airless tyre instead of compressed air in conventional tyre which doesn’t use an inner tube filled with compressed air is a significant advantage of airless tyre over conventional tyre and thus, it will not burst, leak pressure wear or tear due to sudden deformations. Currently, most airless tyre on the market are made of solid rubber or plastic. Due to its ability in not flattening it is used in space rovers for space exploration missions. So, it is used for heavy load carrying and transporting applications.
2. Literature review

Aramian studied the different additive manufacturing techniques used for cermets [2]. Domingues et al fabricated a composite material by blending the used tyre granules with plastic waste. Also the possible additive manufacturing processes are explored for the utilization of the fabricated composites [3]. Kaufui and Hernandez conducted a detailed review of additive manufacturing process. The need and possible methodologies used in additive manufacturing are explored [4]. Kucewicz et al performed finite element simulation of non-pneumatic tyre. Static radial deflection test was conducted and the different parameter like stress distribution, contact pressure and displacement are studied at constant load conditions [5]. Aboul yazid et al conducted quasi static two dimensional analysis on Michelin’s Tweel. Tyre with and without composite ring are investigated. The outcome shows that the spokes have more impact on tyre’s behaviour [1]. Periyasamy and Vijayan generated models of airless and conventional tyre for a car and analysed the parameters like deflection, Von-misses stress and strain energy [9]. Prajwal and Seetharama developed the airless and air tyre by considering the rubber as the material and conducted the FEA with static compressive load [10]. Vinay et al developed a model of airless tyre with aluminium alloy for hub, polyurethane for spokes, AISI 4340 for outer ring and rubber for thread. They also considered three different type of honeycomb structures and conducted the analysis to find the deformation and stress developed [11]. Libin Rajan et al studied the airless tyre for a tractor. Three types of tyre namely Michelin Tweel, honeycomb structure and Bridgestone airless tyre are considered and static analysis were conducted. The effects of thickness of spoke and reinforcement layer on total deformation are studied [6].

3. Problem Definition

The design and manufacturing related issues of airless tyre are recent areas of the research. Many academicians and industrialist are working on development of new materials and 3D printing methods for airless tyre. The objective of this paper is to conduct finite element analysis of airless tyre with different spoke structures and different 3D printing materials. The spoke structures considered for this study are honeycomb, diamond and triangular. The various 3D printing materials such as ABS + PC, PET and HIPS are selected for analysis. The finite element analysis of conventional tyre with neoprene rubber is also conducted. Finally the total deformation, equivalent stress, equivalent elastic strain and strain energy are compared for different models. The three dimensional models were constructed in CATIA V5 and finite element analysis is carried out in Ansys workbench 19.2.

4. Design parameters

The various parameters considered for modelling and analysis of airless tyre are described in this section. Three different materials were considered for model generation. They are Acrylonitrile Butadiene Styrene + Polycarbonate (ABS+PC), Polyethylene Terephthalate (PET) and High Impact Polystyrene (HIPS). The boundary conditions such as load of 3193 N and mesh element size of 50mm are considered. For airless tyre, hub is considered as fixed support. The rim is considered as the fixed support for conventional tyre.
Table 1. Tyre dimensions for modelling.

| Airless tyre dimensions | Conventional tyre dimensions |
|-------------------------|-----------------------------|
| Outer diameter of Tyre  | 540 mm                      |
| Inner diameter of Tyre  | 500 mm                      |
| Outer diameter of Hub   | 340 mm                      |
| Inner diameter of Hub   | 320 mm                      |
| Outer diameter of Tyre  | 500 mm                      |
| Inner diameter of Tyre  | 420 mm                      |
| Outer diameter of Rim   | 420 mm                      |
| Inner diameter of Rim   | 400 mm                      |

4.1. CAD Model of tyre

The CAD model of the airless tyre with different spoke structures are created using CATIA V5 software and shown in the Figure 2.

**Figure 2(a).** Honey Comb Structure

**Figure 2(b).** Diamond Structure

**Figure 2(c).** Triangular Structure

**Figure 2(d).** Conventional Tyre
5. Results and discussions

5.1. Total Deformation

5.1.1. Honeycomb structure. The honeycomb spoke structure model is taken for statistic structural analysis. The three different material properties namely ABS+PC, PET and HIPS are attached to the model. The following figure shows the total deformation for different materials.

![Figure 3(a). ABS+PC](image1)

![Figure 3(b). PET](image2)

![Figure 3(c). HIPS](image3)

5.1.2. Diamond structure. The diamond spoke structure model with three different material properties namely ABS+PC, PET and HIPS are analysed to find the total deformation. The following figure shows the total deformation for different materials.
5.1.3. Triangular structure. The triangular spoke structure model with three different material properties namely ABS+PC, PET and HIPS are analysed to find the total deformation. The following figure shows the total deformation for different materials.
5.2. Equivalent elastic strain.

5.2.1. Honeycomb Structure. The honeycomb spoke structure model with three different material properties namely ABS+PC, PET and HIPS are analysed to find the equivalent elastic strain. The following figure shows the results of equivalent elastic strain for different materials.
5.2.2. **Diamond structure.** The diamond spoke structure model with three different material properties namely ABS+PC, PET and HIPS are analysed to find the equivalent elastic strain. The following figure shows the results of equivalent elastic strain for different materials.

![Figure 7(a). ABS+PC](image1)

![Figure 7(b). PET](image2)

![Figure 7(c). HIPS](image3)

5.2.3. **Triangular structure.** The triangular spoke structure model with three different material properties namely ABS+PC, PET and HIPS are analysed to find the equivalent elastic strain. The following figure shows the results of equivalent elastic strain for different materials.

![Figure 8(a). ABS+PC](image4)

![Figure 8(b). PET](image5)
5.3. Equivalent (Von-mises) Stress

5.3.1. Honeycomb structure. The honeycomb spoke structure model with three different material properties namely ABS+PC, PET and HIPS are analysed to find the equivalent (von-mises) stress. The following figure shows the result of equivalent (von-mises) stress for different materials.
5.3.2. **Diamond structure.** The diamond spoke structure model with three different material properties namely ABS+PC, PET and HIPS are analysed to find the equivalent (von-mises) stress. The following figure shows the results of equivalent (von-mises) stress for different materials.

![Figure 10(a). ABS+PC](image1)

![Figure 10(b). PET](image2)

![Figure 10(c). HIPS](image3)

5.3.3. **Triangular structure.** The triangular spoke structure model with three different material properties namely ABS+PC, PET and HIPS are analysed to find the equivalent (von-mises) stress. The following figure shows the results of equivalent (von-mises) stress for different materials.

![Figure 11(a). ABS+PC](image4)

![Figure 11(b). PET](image5)
5.4. Strain energy

5.4.1. Honeycomb structure. The honeycomb spoke structure model with three different material properties namely ABS+PC, PET and HIPS are analysed to find the strain energy. The following figure shows the results of strain energy for different materials.
5.4.2. **Diamond structure.** The diamond spoke structure model with three different material properties namely ABS+PC, PET and HIPS are analysed to find the strain energy. The following figure shows the results of strain energy for different materials.

![Figure 13(a). ABS+PC](image)

![Figure 13(b). PET](image)

![Figure 13(c). HIPS](image)

5.4.3. **Triangular structure.** The triangular spoke structure model with three different material properties namely ABS+PC, PET and HIPS are analysed to find the strain energy. The following figure shows the results of strain energy for different materials.

![Figure 14(a). ABS+PC](image)

![Figure 14(b). PET](image)
5.5. Conventional tyre

The conventional tyre is modelled with aluminium alloy for rim, neoprene rubber for tyre and air is used in place of inflated tubes. The finite element analyses were conducted and the results for total deformation, equivalent elastic strain, equivalent von-mises stress and strain energy are shown in figure.
5.6. Consolidated results.
The following table shows the consolidated results of total deformation, equivalent elastic strain, equivalent von-Mises stress and strain energy of airless and conventional tyre. It also gives a comparative analysis of all three materials used for airless tyre.

| S. No | Materials Used | Type of Analysis       | Spokes structure |
|-------|----------------|------------------------|------------------|
|       |                |                        | Honeycomb | Diamond   | Triangular |
| 1     | ABS +PC        | Total Deformation (mm) | 0.286     | 0.053686  | 0.053703   |
|       |                | Equivalent Elastic Strain | 0.002904 | 0.000857  | 0.001128   |
|       |                | Equivalent (Von-mises) Stress (MPa) | 7.2855 | 1.9575 | 2.8193 |
|       |                | Strain energy (mJ)     | 2.7747    | 0.45238   | 0.55302    |
|       |                | Total Deformation (mm) | 0.24998   | 0.046625  | 0.046627   |
| 2     | PET            | Equivalent Elastic Strain | 0.002545 | 0.000724  | 0.000980   |
|       |                | Equivalent (Von-mises) Stress (MPa) | 7.3763 | 1.9676 | 2.8308 |
|       |                | Strain energy (mJ)     | 2.4106    | 0.39311   | 0.48016    |
|       |                | Total Deformation (mm) | 0.41301   | 0.078062  | 0.78137    |
| 3     | HIPS           | Equivalent Elastic Strain | 0.004185 | 0.001248  | 0.001639   |
|       |                | Equivalent (Von-mises) Stress (MPa) | 7.193  | 1.947 | 2.8079 |
|       |                | Strain energy (mJ)     | 4.0323    | 0.65731   | 0.80406    |
| 4     | Conventional tyre | Equivalent Elastic Strain | 0.4981    | -         | -         |
|       |                | Equivalent (Von-mises) Stress (MPa) | 0.88103 | -       | -         |
|       |                | Strain energy (mJ)     | 10.049    | -         | -         |
|       |                | Total Deformation (mm) | 102.13    | -         | -         |

From the tabulation, we understand the diamond spoke structure model gives better results than the other spoke model. Similarly in different material constraints, for all three materials the diamond spoke structure yields better result. So for the given boundary conditions and applied load, the diamond spoke structure airless tyre is more rigid and durable.

6. Conclusion

Use of air-less tyre eliminates disadvantages faced by pneumatic tyres. Air-less tyre provides uniform adhesion and uniform wear while absence of air. The airless tyres need not to be replaced very often and if it wears out and needed to be replaced the outer band of the airless tyre is replaced which saves material in manufacturing point of view. In pneumatic tyres, there was a high possibility of the flatten which can cause more number of accidents. Using airless tyres it's an outsized impact on safety. If the vehicles with airless tyres are used then one needn't worry about safety. Another benefit is that they're going to be reused and earlier tyres go flat and wish to be thrown away so there was the need for the event of airless tyres. Driving these vehicles reduces mind-stress. In this work there dimensional
model of airless tyre with different spoke structures are generated and finite element analysis is carried out. From the FEA results of different structures, the airless tyre with diamond structure proves to be more durable than other structures and the conventional tyre.

In future the dynamic analysis of the same model will be performed and the outcomes are to be studied. The composite materials for 3D printing will be developed and by applying these material properties the model will be further studied for static and dynamic load conditions.

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