Design and analysis of the application of 3D-printed composite sandwich structures for use in an airless tyre

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Aim

The aim of this dissertation is design and analyse an airless tyre using the concept of sandwich structures.

Introduction

With the increasing necessity for the use of sustainable composite materials for the use in many industries especially automotive, lightweight, composite sandwich structures have various application depending on the properties needed such as strength, vibration resistant, load bearing, shock absorbing and enhanced performance over solid core structures.

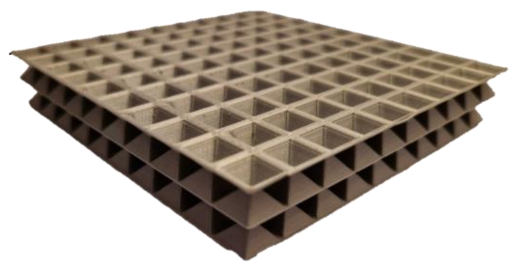

Figure 1: 10mm Pyramid sandwich structure

Why is there a need for Airless Tires ?, Why is it worth changing from a classic pneumatic tyre and what makes Airless tyres better.

- Tyre waste, **25%** of tires are wasted each year which is approximately **10,940 tonnes.**
- **280 million** tires are discarded each year in America alone.
- Tire particles account for **5-10%** of ocean plastic pollution.
- Use of sandwich structures to reduce that waste and reduce the cost of owning an automobile for consumers.

Objectives

- Conduct a critical literature review on airless tyres and the application of composite sandwich structures in their design and investigate market trends for new developments in sustainable composite materials and already available solutions.
- Make design changes to airless tyre models
- In dept static structural analysis on spoke geometry and Michelin airless tyre geometry and carry out mesh-based parametric study within Ansys for spoke models.
- Result comparison between all spoke model configurations
- Carry out a cost and sustainability analysis for the proposed airless tyre design.

Literature Review

The academic literature review presented and compared the findings of published works relating to

- An overview of pneumatic tyres.
- Evolution of airless tyres and their operational principles.
- Advantages and disadvantages, the use of composite materials and the use of composite sandwich structures.

To begin with saying that the **tyre** is one of the most **vital** and **fundamental** components of a vehicle as it is the only point of contact between the vehicle the driving surface. A pneumatic tyre consists of an airtight rubber ring filled with pressurized air that provides a cushioning effect for the tyre between the vehicle and the driving surface. The first iteration of an airless tyre was in **1982** by Goodyear and a Swedish engineer Hans Erik Hansson

Figure 2: "The Composite wheel (CW)" (Sandberg, 2022)

More recent iterations include designs from **Michelin** and **Hankook in 2022.**

Figure 3: Michelin Airless Tyre (Michelin, 2022)

Figure 4: Hankook Airless Tyre (Hankook, 2022)

The use of composite sandwich structures has been advances and developed majorly in recent years with honeycomb shape sandwich structures providing excellent mechanical performance when paired with hyper elastic material such as polyurethane provides high lateral and vertical stiffness, high fatigue resistance, and high out of plane stiffness.

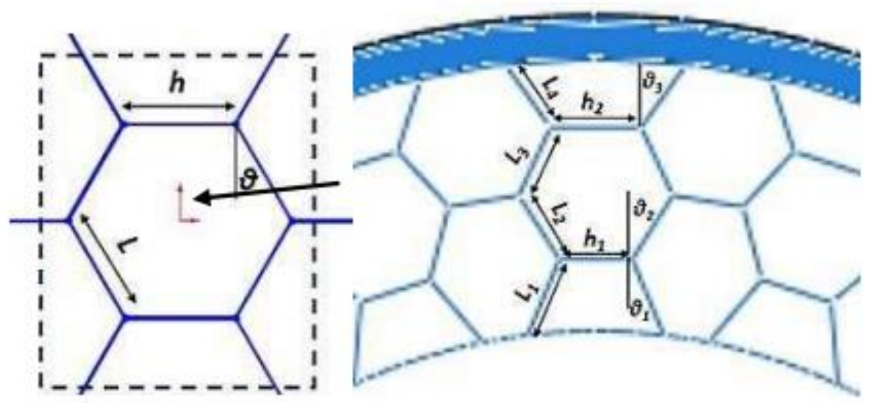

Figure 5: Honeycomb sandwich structure Aboul-Yazid *et al.*, (2015)

Final Design

The airless tyre design incorporates some of the main features of the makeup of other airless tyre designs such as an alloy hub, metal shear band, flexible and deformable polyurethane spokes and a tread, but also includes extra outer spokes and an outer shear band to enhance its mechanical performance.

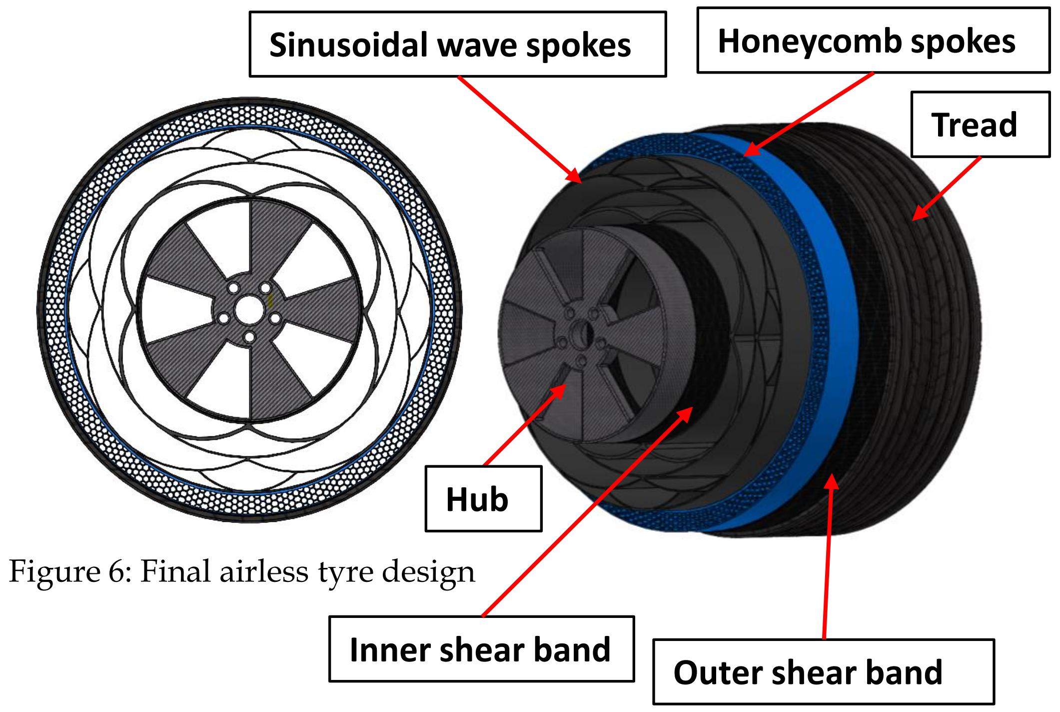

Figure 6: Final airless tyre design

Design Components

The main features of this design are the two unique spoke configuration which are the sinusoidal wave spokes and the outer honeycomb spokes which work in conjunction with each other to provide the necessary stiffness to bear the load of the vehicle but also allow for elasticity to prove shock absorption and smooth driving. These spokes will be made from TPU CFRP 30% (Thermoplastic Polyurethane Carbon fibre reinforced 30%)

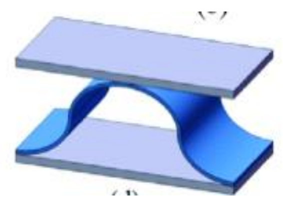

Figure 7: Sinusoidal wave sandwich structure

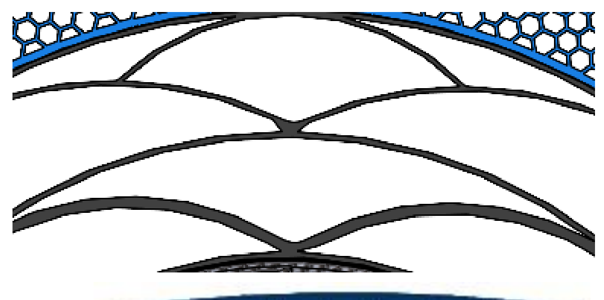

Figure 8: Honeycomb Config 1

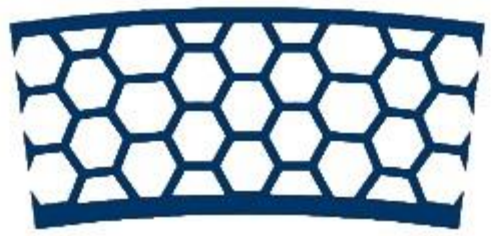

Figure 9: Honeycomb config 2

The sinusoidal wave spokes work as a compression and suspension component, combined with the elastic properties of polyurethane. The honeycomb sandwich structure will prove the load and shock bearing properties of the airless tyre. For the static structural analysis both a section of both honeycomb configurations as well as a section of the Michelin "Uptis" airless tyre will be analysed as shown in **Figure 3.** As can be seen in the results section all the analysis models are a viable design as they are well below the yield strength of the material however, the 10mm Honeycomb is most optimum design as it has the lowest displacement.

Analysis

A static structural analysis was carried out using Ansys Workbench/Mechanical on three models which were the 18.1mm honeycomb section, 10mm honeycomb section and the Michelin "Uptis" airless tyre section. Each analysis used a mesh size of 0.8mm which was determined as optimum from the parametric study and a load of 4000 Newtons was applied in the –Y direction (Downwards). The two result outputs that were analysis were the von mises stress and total displacement.

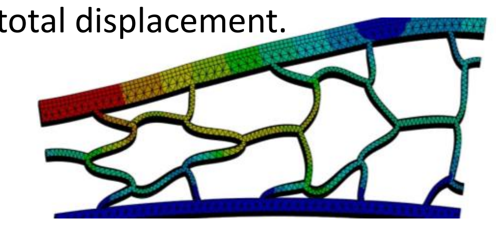

Figure 9: Honeycomb Config 1

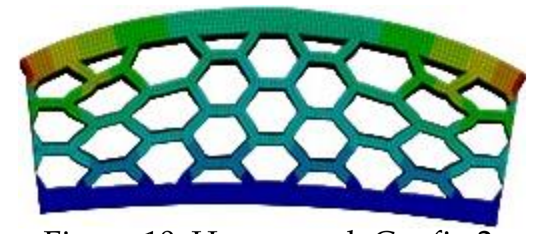

Figure 10: Honeycomb Config 2

Figure 11: Michelin airless tyre section

Results

	Michelin airless tyre	10mm Honeycomb section	18.1mm Honeycomb section
Max Stress (Mpa)	12.966	53.291	41.863
Max Displacemnt (Microns)	147.83	29.295	89.455

Figure 12: Max stress and displacement analysis results

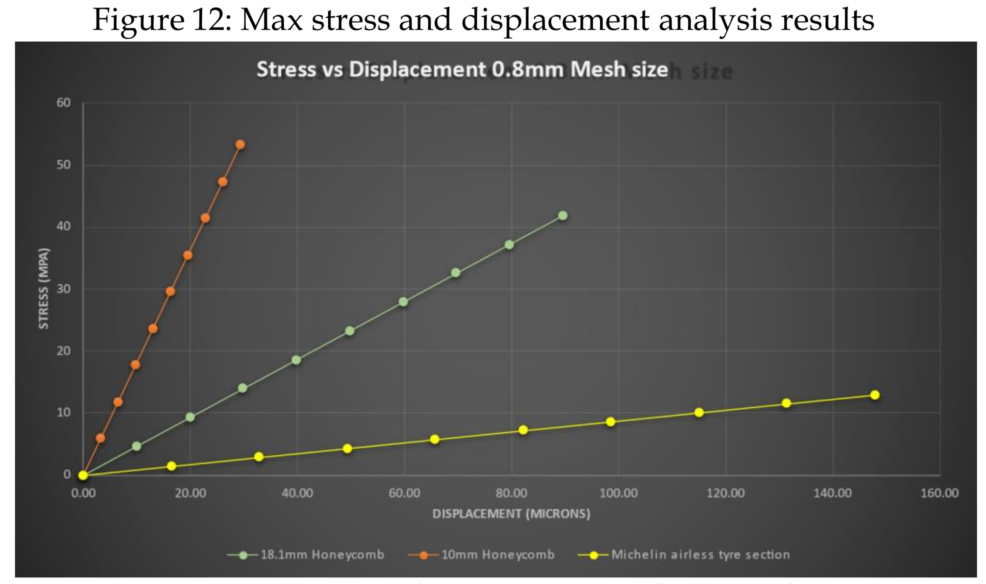

Figure 13: Stress vs displacement analysis results

Conclusion and future implications

For further advancements to made for airless tyres

- Further research and analysis is needed on the application of sandwich structures and sustainable composite materials.

However, recent developments show a promising future for the application of airless tyres which boast many advantages such as

- No flat tyres, lower maintenance costs, the ability for them to be re-treaded, sustainable use and manufacture, one step closer to autonomous driving which shows a bright and impactful future for airless tyres.

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