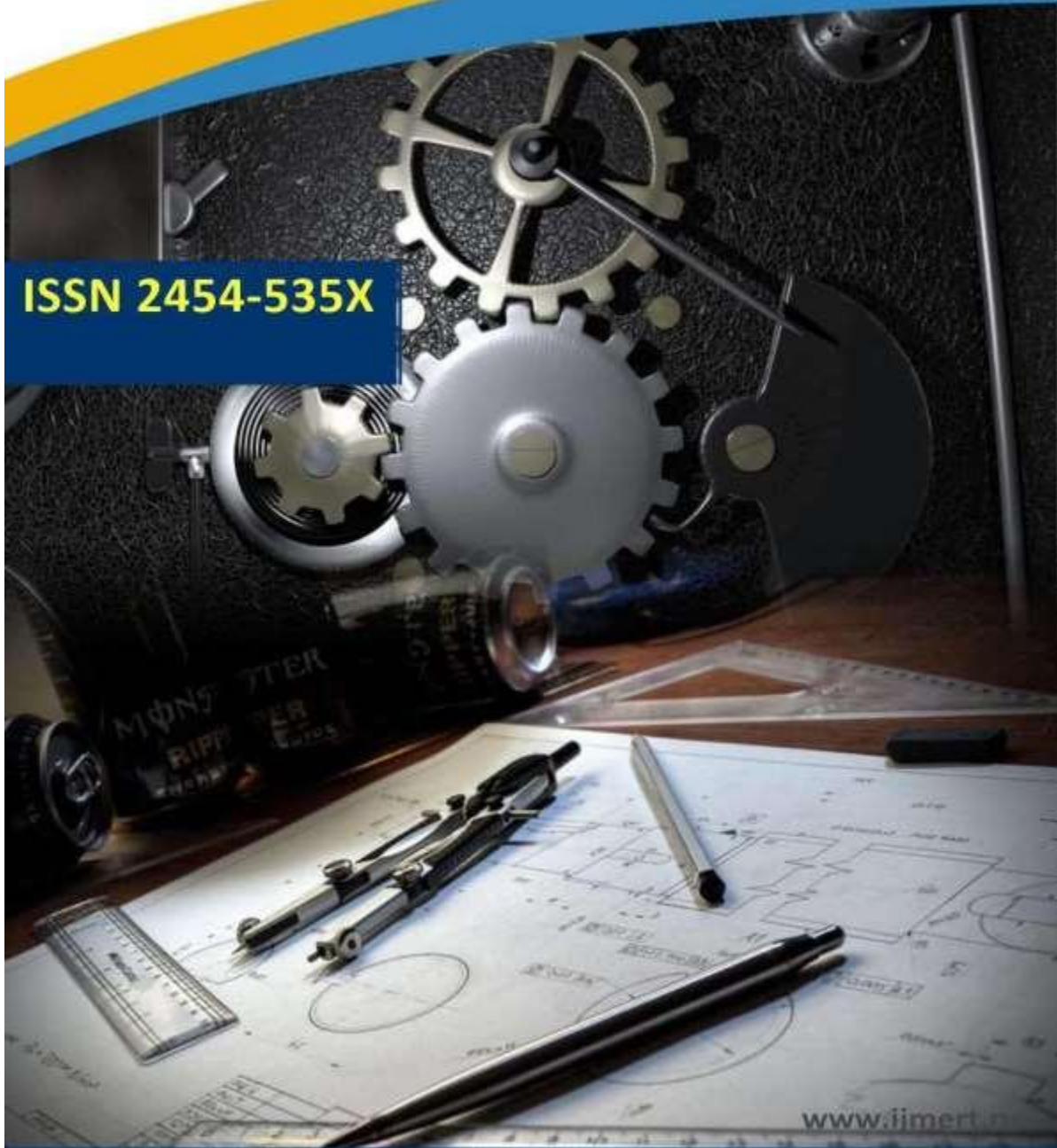




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STRUCTURAL EVALUATION OF HONEYCOMB-BASED WHEEL DESIGN UNDER LOAD CONDITIONS

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Abstract

Lightweight is one of the primary goal for the development of wheels. A new type of automobile wheel is proposed in the present work. The wheel is divided into tread, spoke and wheel hub. The spoke layout is designed based on the honeycomb structure by considering load bearing performance of wheel. The analysis is carried out by the varying material of core wall of honeycomb structure. Structural steel, aluminum alloy, carbon fiber and polyethylene are used as a core material. The mechanical performances are analyzed and results shows that maximum stress and deformation which can meet design requirements like strength and stiffness of the wheel.

Keywords: honeycomb structure, ANSYS, temperature distribution, strength-to-weight ratio, light weight and structural integrity.

1. Introduction

Weight reduction is a critical factor in automotive design. Wheels significantly

influence unsprung mass, fuel efficiency, and dynamic performance. Traditional solid



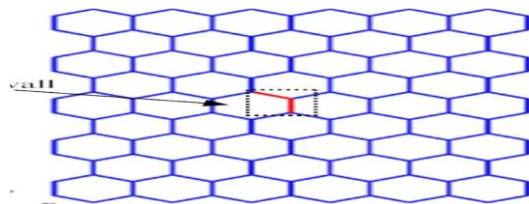
spoke wheels increase weight and may not fully utilize material efficiency.

Honeycomb structures are known for:

- High strength-to-weight ratio
- Excellent energy absorption
- Orthotropic stiffness behavior
- Efficient load transfer

Inspired by natural honeycomb geometry, this research integrates a hexagonal cellular structure into an automobile wheel spoke system and evaluates its structural performance under mechanical and thermal loading.

A honeycomb is a mass of hexagonal prismatic wax cells built by honey bees in their nests to contain their larvae and stores



of honey and pollen.

Figure 1.1 One D view of hexagonal honeycomb structure

2. Honeycomb Structure Fundamentals

Honeycomb structures consist of thin-walled hexagonal cells arranged in a repeating lattice pattern.

Thermoplastic honeycomb cores

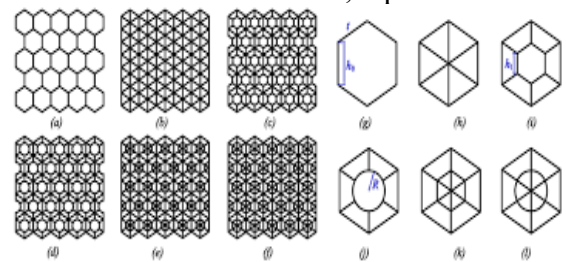
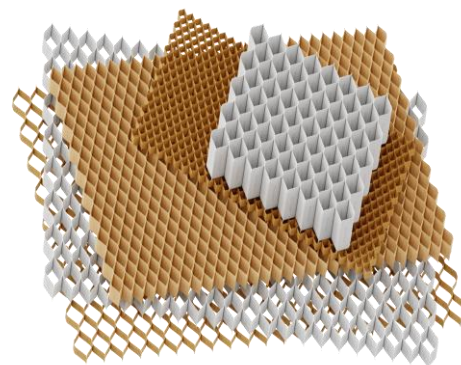


Figure 1.2 Hybrid honeycomb structure

3. Industrial Applications of Honeycomb structures

Honeycomb structures, inspired from bee honeycombs, had found widespread applications in various fields, including architecture, transportation, aerospace,



mechanical engineering, chemical engineering, Nano-fabrication, and recently bio-medicine.

Figure 1.3 Manufactured honeycomb sheet of different materials



Properties

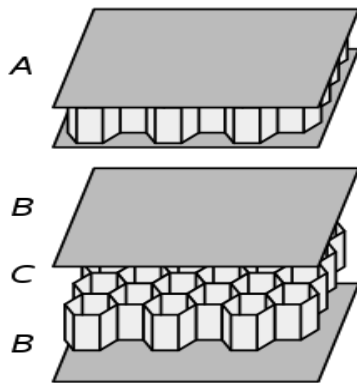


Figure 1.4 A composite sandwich panel (A) with honeycomb core (C) and face sheets (B)

Natural Examples of Honeycomb Structures

Beehives: Honeybees create hexagonal wax cells in their hives to store honey and eggs. The hexagonal shape provides maximum storage space and strength for the structure of the hive. The bees instinctively build these cells to be uniform in size and shape, using the minimum amount of wax necessary.

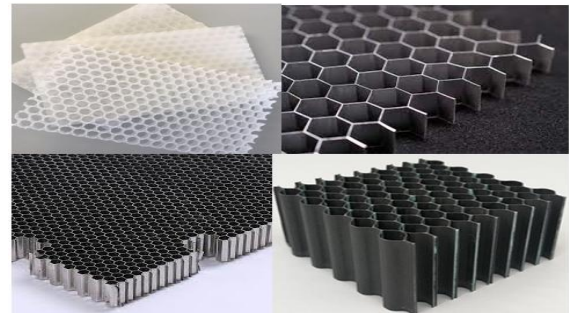
Basalt columns: Certain types of volcanic rocks, such as basalt, can form hexagonal columnar structures as they cool and solidify. These columns are often seen in volcanic areas, such as the Giant's Causeway in Northern Ireland.

Coral reefs: Some types of coral reefs have a honeycomb-like structure that provides support for the organisms living within the reef. The intricate network of tunnels and channels in the reef also allows for water flow and nutrient exchange.

Bone structure: The internal structure of certain types of bones, such as bird bones, can resemble a honeycomb. This structure provides strength and support while also keeping the bone lightweight.

Classification of Honey comb structure

Material: Honeycombs can be made from a variety of materials, such as metals, plastics, or composites. The choice of material depends on the specific application of the



honeycomb, and each material may offer different mechanical properties.



Fig 1.5 Honeycomb structures with different materials

Key Mechanical Characteristics:

- High out-of-plane compression strength
- Orthotropic behavior
- Strength proportional to relative density
- Failure modes: buckling, yielding, crushing



Table 3.1 Elemental Properties for Aluminium

In-plane modulus:

$$E \propto (t/L)^3$$

Out-of-plane modulus:

$$E \propto (t/L)$$

Where:

- t = wall thickness
- L = cell length

3. Materials Considered

Four materials were selected based on availability and engineering relevance.

3.1 Aluminium Alloy

- Density \approx 2700 kg/m³
- Young’s Modulus \approx 70 GPa
- Good corrosion resistance
- High strength-to-weight ratio

Element Properties	
atomic number	13
atomic weight	26.9815384
melting point	660 °C (1,220 °F)
boiling point	2,467 °C (4,473 °F)
specific gravity	2.70 (at 20 °C [68 °F])
valence	3
electron configuration	1s ² 2s ² 2p ⁶ 3s ² 3p ¹

3.2 Structural Steel

- Density \approx 7850 kg/m³
- Young’s Modulus \approx 200 GPa
- High stiffness
- High yield strength

3.3 Carbon Epoxy

- Density \approx 1600 kg/m³
- Young’s Modulus \approx 70–140 GPa
- Very high tensile strength
- Lightweight composite

3.4 Polyethylene

- Low density
- Low stiffness
- High ductility
- Suitable for low-load applications

4. Geometry Modeling

The wheel was modeled using ANSYS Space Claim.

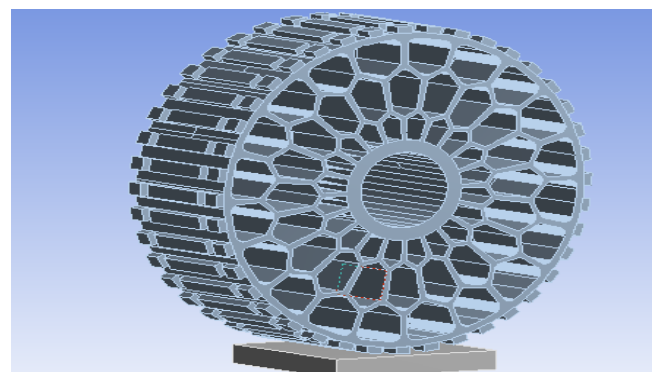




Fig 4.3 Side view of the wheel with dimensions of cell

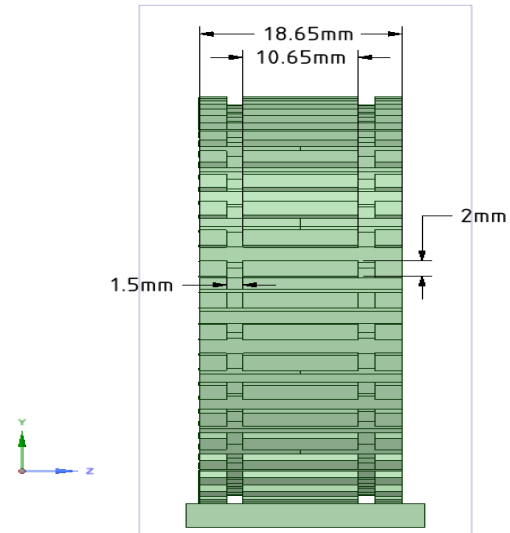


Fig 4.1 Geometric model of the wheel

Dimensions:

- Wheel Diameter: 50 mm
- Wheel Width: 18.5 mm
- Hub Diameter: 12 mm
- Hub Thickness: 2 mm
- Tread Thickness: 1 mm
- Cell Thickness: 1 mm

The honeycomb cells are arranged radially between hub and rim.

Fig 4.2 Front view showing dimensions of wheel

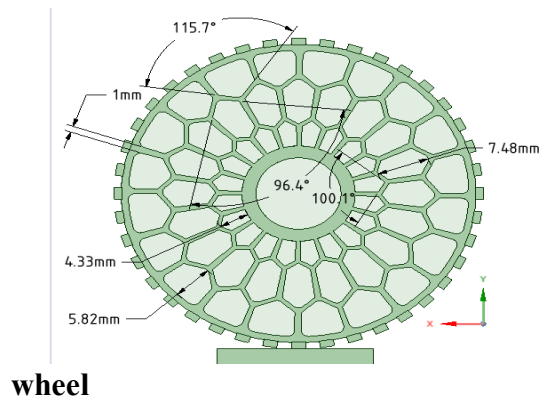


Fig 4.4 front view of the wheel

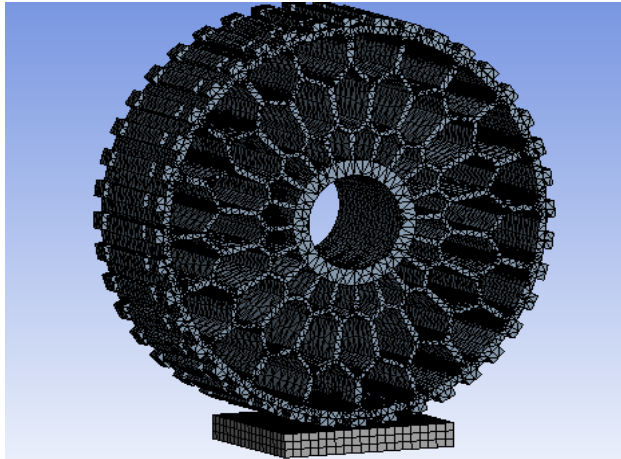
5. Finite Element Modeling

5.1 Meshing

- Unstructured tetrahedral mesh
- Refined mesh near hub and cell intersections
- Convergence ensured



Mesh generation is the practice of creating a mesh, a subdivision of a continuous geometric space into



discrete geometric and topological cells.

Fig 4.5 Image showing the meshing of the wheel

A major distinction is between structured and unstructured meshing. In structured meshing the mesh is a regular lattice, such as an array, with implied connectivity between elements. In unstructured meshing, elements may be connected to each other in irregular patterns, and more complicated domains can be captured. This page is primarily about unstructured meshes.

5.2 Governing Equation

$$[K]\{u\} = \{F\}$$

Where:

- K = stiffness matrix
- u = displacement vector
- F = applied load vector

6. Boundary Conditions

Static Structural Analysis

- Base plate fixed
- 1000 N load applied on inner hub surface

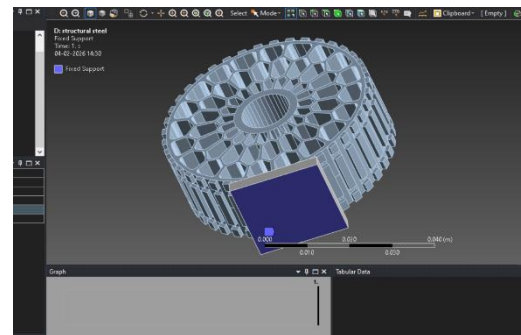
Transient Analysis

- Fixed support on base, front and back
- Rotational velocity applied at center

Thermal Analysis

- Initial temperature: 220°C
- Inner hub temperature: 800°C
- Convection coefficient: 10 W/m²°C

Boundary conditions for Static Structural Analysis

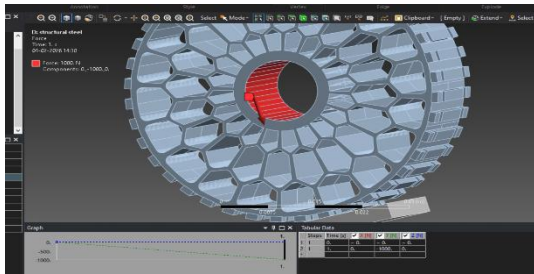




Boundary conditions for Thermal Analysis

Figure 6.1 Fixed support (fixed face of a base plate)

Figure 6.2 Load of 1000 N on the inside face of the hub



Boundary conditions for Transient Structural Analysis

Figure 6.3 Fixed support three faces (base, front and back face)

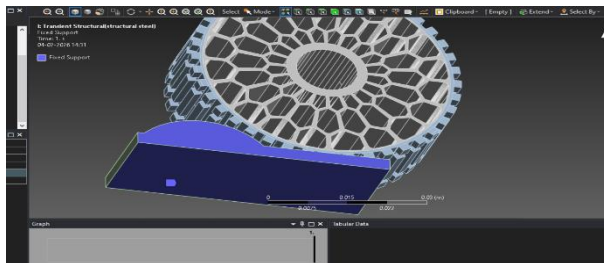
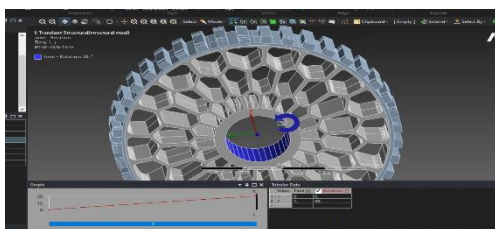
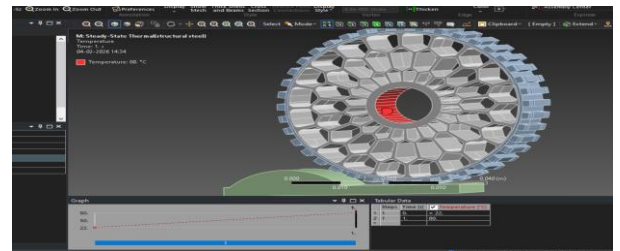


Figure 6.4 Rotation around center 30°



- First, we establish initial temperature to uniform and an assign a value, Here the value is 22⁰ c.
- Then apply a temperature to observe temperature distribution



- Figure 6.7 Temperature assigned at the inner surface of wheel hub of 80⁰C

The ambient temperature is set to 22⁰c and film coefficient = 10W/M² °C

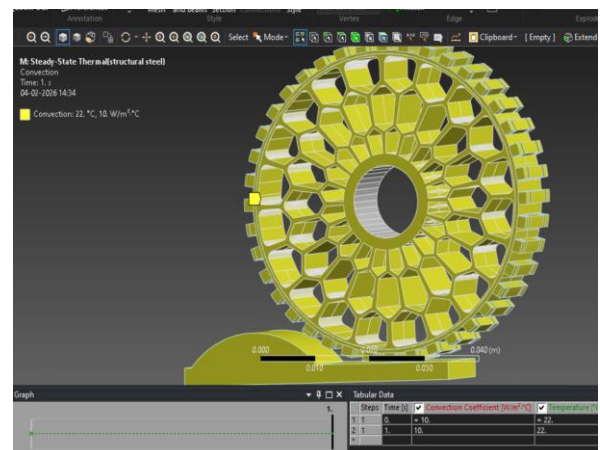


Figure 6.8 Convection applied over all the 3750 faces of the wheel.



7. Results and Discussion

7.1 Static Structural Analysis

Aluminium Alloy

- Max Deformation: 3.0496×10^{-5} m
- Avg Stress: 3801.78 Pa
- Strain: 3.25×10^{-3}

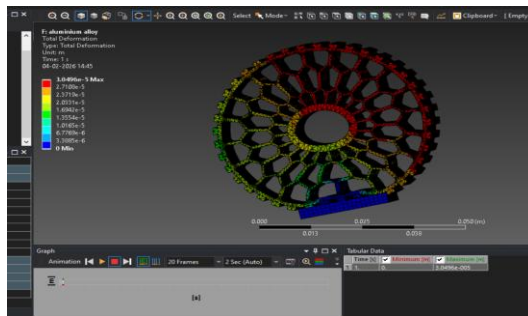
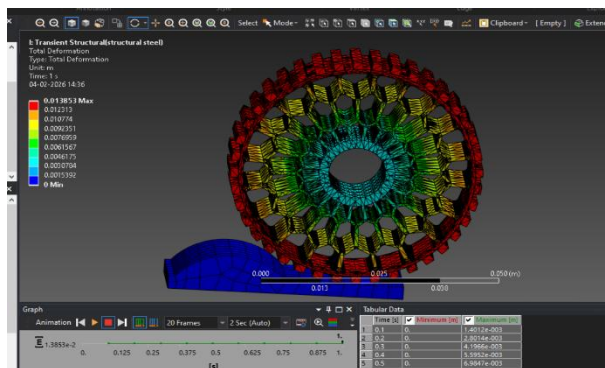


Figure 7.1 Total Deformation for the Honeycomb wheel of Aluminium Alloy

Structural Steel

- Max Deformation: 1.199×10^{-5} m
- Avg Stress: 5575.61 Pa
- Strain: 3.06×10^{-4}



• Figure 7.16 Total Deformation for the Honeycomb wheel of Structural Steel

Lowest deformation observed

Carbon Epoxy

- Max Deformation: 1.29×10^{-4} m
- Avg Stress: 8230.94 Pa
- Strain: 1.23×10^{-2}

Highest stress concentration.

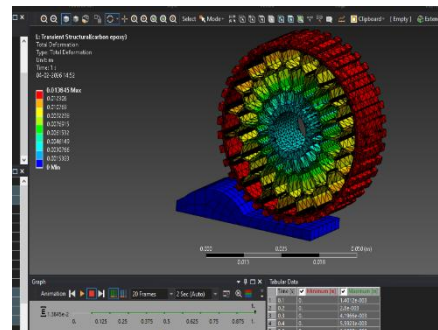


Figure 7.19 Total Deformation for the Honeycomb wheel of Carbon Epoxy

Polyethylene

- Max Deformation: 0.001811 m
- Avg Stress: 5262.12 Pa
- Strain: 1.87×10^{-1}

Excessive deformation observed.

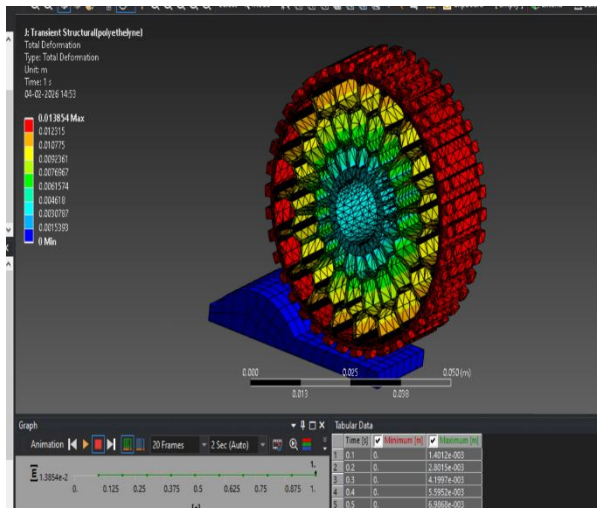


Figure 7.22 Total Deformation for the Honeycomb wheel of Polyethylene

7.5 Data obtained from the Analysis

7.5.1 Static Analysis

By comparing the static analysis results from the table 1 we can observe that polyethylene has more elastic strain as compared to the other materials; that means polyethylene is used at places where there will be more damping will be there i.e. at off road condition.

Material	Equivalent Elastic Strain	Equivalent (von-Mises) Stress	Total Deformation
Aluminium Alloy	3.25E-03	3801.780186	0.015068609

Structural Steel	3.06E-04	5575.611967	0.013229994
Carbon Epoxy	1.23E-02	8230.943712	0.016213346
Poly Ethylene	1.87E-01	5262.118735	0.00140864

Table 7.1 Results of Static Structural Analysis

7.5.2 Transient Analysis

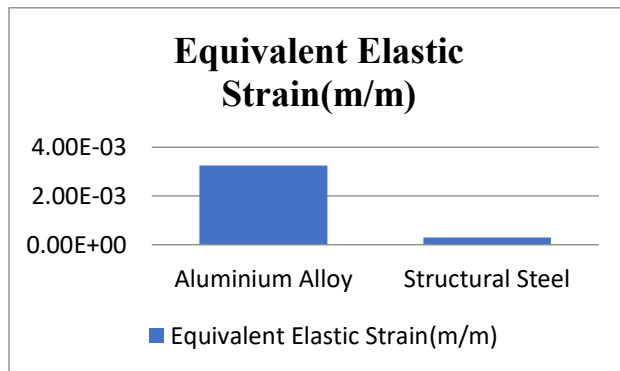
Here in the transient analysis by taking the time into consideration aluminium alloy is the better choice for the continuous cycle as the stress distribution is taken uniformly as compared to the other materials.

Material	Equivalent Elastic Strain(m/m)	Equivalent (von-Mises) Stress (Pa)	Total Deformation(m)
Aluminium Alloy	0.000512044	196.8466667	0.009203367
Structural Steel	0.001958467	11511.56546	0.008465367
Carbon Epoxy	0.006380867	5676.739904	0.008460567
Polyethylene	0.008717044	995.155	0.009203367

Table 7.2 Results of Transient Analysis



7.5.3 Thermal Analysis (Steady state)



state)

For thermal analysis independent of the time, aluminum alloy and the structural steel are better choices as both are metals and metals are good conductors of heat, therefore better distribution of heat energy is done.

Table 7.3 Results of Steady state

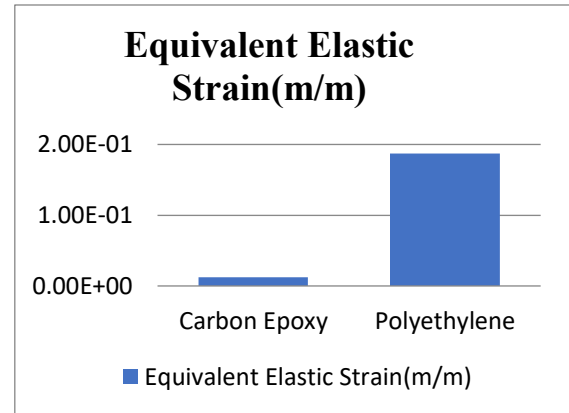
Thermal Analysis

Material	temperature (°c)	Total Heat Flux (w/m ²)
Aluminium Alloy	76.74275	47614.66667
Structural Steel	71.6225	46874
Carbon Epoxy	71.46475	39547
Polyethylene	54.222	2262.28

7.6 Graphical representation the results

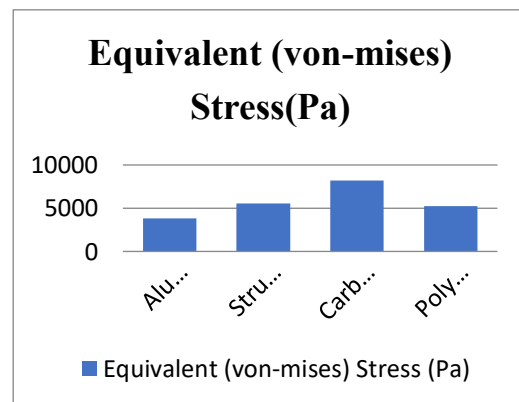
7.6.1 Static Structural Analysis

Graph 7.1 Equivalent Elastic Strain

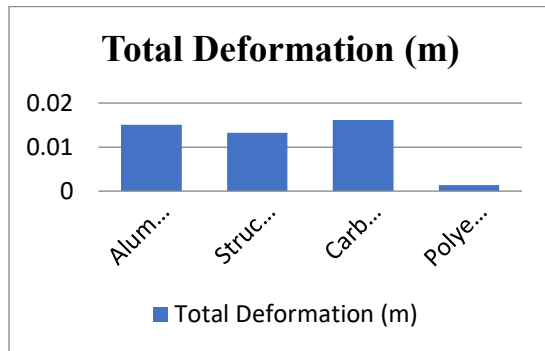


Results in the Static Structural Analysis

Graph 7.2 Equivalent Elastic Strain in the Static Structural Analysis

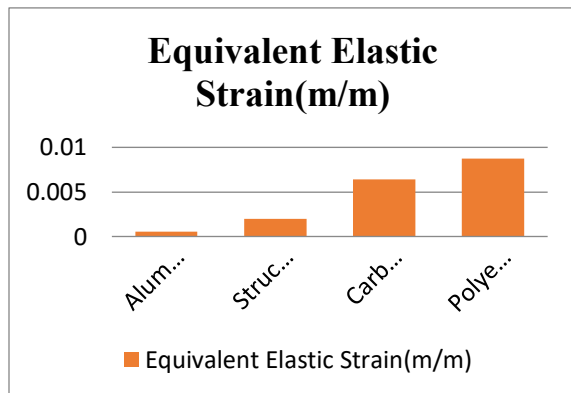


Graph 7.3 Equivalent (von-Mises) Stress in the Static Structural Analysis

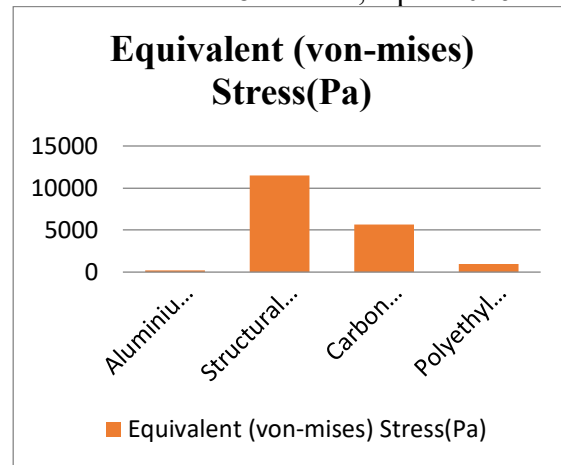


Graph 7.4 Total Deformation Results in the Static Structural Analysis

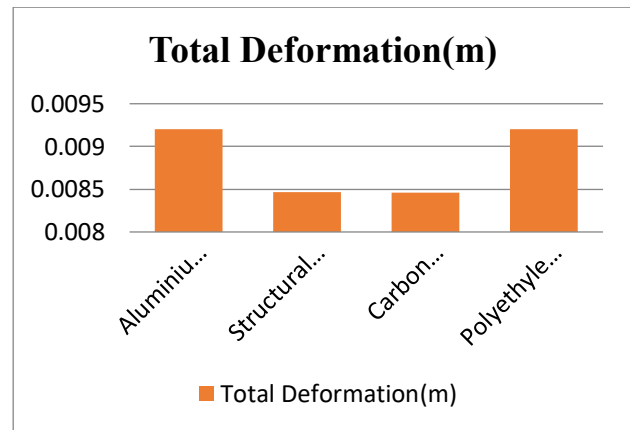
7.6.2 Transient analysis



Graph 7.5 Equivalent Elastic Strain Results in the Transient Analysis



Graph 7.6 Equivalent (von-Mises) Stress Results in the Transient Analysis



Graph 7.7 Total Deformation Results in the Transient Analysis

7.6.3 Thermal Analysis (Steady state)



- **Polyethylene:** Not suitable for load-bearing wheels.

Considering automotive applications where weight reduction is essential, **Aluminium Alloy is recommended.**

8. Conclusion

A honeycomb-based wheel design was analyzed using FEA.

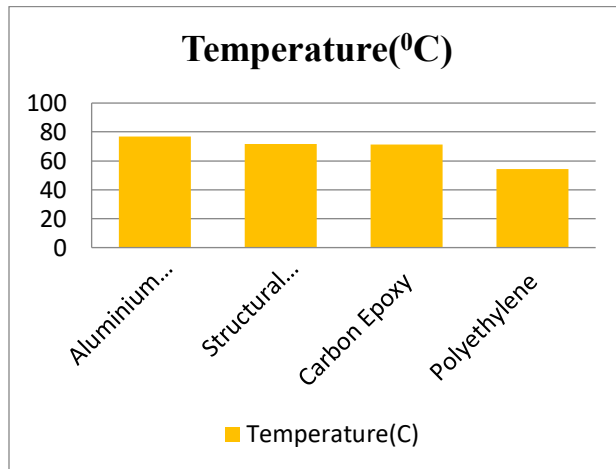
Major conclusions:

1. Honeycomb structure improves load distribution.
2. Structural Steel shows minimum deformation.
3. Carbon Epoxy shows highest stress concentration.
4. Polyethylene unsuitable for structural wheel.
5. Aluminum Alloy provides optimal strength-to-weight ratio.
6. Honeycomb design is structurally feasible for automotive applications.

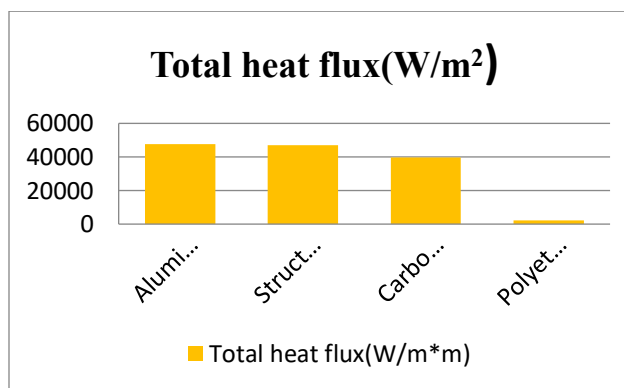
The study confirms that honeycomb cellular geometry enhances stiffness while reducing material usage.

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Graph 7.8 Average surface temperature Results in the Thermal Analysis



Graph 7.9 Total Heat Flux Results in the Thermal Analysis

7.3 Material Selection Discussion

- **Structural Steel:** Best stiffness but heavy.
- **Aluminium Alloy:** Best strength-to-weight compromise.
- **Carbon Epoxy:** Lightweight but stress concentration critical.



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