



Advanced Spoke Design For Non-Pneumatic Tyres: Enhanced Load-Bearing Capacity And Versatile Customization For All Vehicle Types

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Abstract: For more than a century, pneumatic tyres have been an integral part of automobiles. Recently, non-pneumatic (airless) tyres have emerged that offer similar performance but face challenges in stiffness, vehicle safety, compatibility and load capacity. This study presents a new design for non-pneumatic tyres that is superior to honeycomb and diamond-spoked tyres in load capacity, although less complex and adjustable for different types of vehicles, including public transport. This research has two parts. In Part 1, the design is selected from various CAD models using SolidWorks. This includes comparing the parabolic design to previous design studies for honeycomb and diamond surfaces in terms of total deformation, maximum shear stress, uniform (von Mises) stress and maximum elastic strain. using Ansys FEA software. The results show that the Parabola design is superior to diamond and honeycomb tyres in terms of load capacity, The goal is to identify the design that best meets the performance objectives for Phase 2 analysis. In Phase 2, selection and analysis are performed. The purpose is to determine the best polyurethane quality for bus tyres. In this section, the insights from Section 1 are used to enhance the design and select appropriate materials, demonstrating design compatibility from car tyres to bus tyres. Ansys is used to analyse the variation of tyres under a force of 40,000 N, simulating the operating conditions of bus tyres. This paper provides important data on non-pneumatic tyre design, material selection, deformation analysis, design optimisation and standardization, and improving vehicle safety and performance in vehicles and people.

Keywords: Non-Pneumatic tyres, airless tyres, Spokes, Public Transport, Vehicle Safety, Load-Bearing Capacity, Deformation.

I. INTRODUCTION

Non-pneumatic tyres, also known as run-flats, are a new alternative to traditional pneumatic tyres. These tyres are designed to eliminate the problem of flat tyres and provide a more durable, maintenance-free solution for a variety of applications. They are made using rubber polymers, which are light and transparent such as polyurethane and polyether [1]. These polymers create a bond between the core and the tread that also acts as a shock absorber. This helps eliminate the risk of flat tyres and provides a more durable, maintenance-free solution for a variety of applications. The advantages of non-pneumatic tyres include puncture resistance, durability, low maintenance, and environmental benefits, with applications in various vehicles like military vehicles, construction and industrial equipment, bicycles and electric scooters, and agricultural machinery [2]. The transport industry is one of the biggest automotive sectors for vehicles, yet non-pneumatic tyres have yet to make any significant impact on this market. This can be due to several reasons: Higher Initial Costs: Non-pneumatic tyres typically have a higher upfront cost than traditional pneumatic tyres, which can deter large-scale adoption, especially in cost-sensitive markets. Limited Availability and Options: Currently, non-pneumatic tyres are not as widely available in as many sizes and specifications as pneumatic tyres, limiting their applicability across the diverse range of vehicles used in the transport industry. Performance Validation: There is a lack of extensive real-world performance data and validation for non-pneumatic tyres in the

transport sector. This uncertainty is due to uncertainty over time and reliability under various operating conditions. **Weight Considerations** Non-pneumatic tyres weigh more than their pneumatic counterparts, affecting fuel efficiency and overall vehicle handling. This is a major concern for the shipping industry where profitability is paramount. **Heat Dissipation:** The materials used in non-pneumatic tyres may not be as hot as pneumatic tyres. This is a critical issue for high-speed or long-term applications where heat can affect performance and safety. **High Rolling Resistance:** Rolling resistance is the most common problem with non-pneumatic tyres. Due to the absence of compressed air, generally, more polymer material needs to be used as an alternative to air, which adds weight as well as rolling resistance. To address this issue, as we learn in this paper, we can use high-durometer polymer material, which will reduce the contact patch of a tyre with the road resulting in less rolling resistance but will also impact the ride quality. This trade-off can be called a trade-off between impact damping and deformation [3], which needs to be balanced until more research is done regarding polymer materials. However, reducing the rolling resistance in comparison to pneumatic tyres is a challenge that can be achieved through lightweight polymer materials as technology regarding material science advances.

Previous non-pneumatic tyre designs, such as the Michelin X Tweel and the airless Bridgestone, cannot provide a standard design with the ability to increase or decrease the operating weight capacity of the vehicle and maintenance procedures. The only difference, in this case, is Goodyear, but with complex design features.

This study examines non-pneumatic tyres (NPT) and honeycomb structures, and finds that improved designs maximize performance and safety while minimizing environmental impact, and be an alternative to traditional hats [4]. Airless tyres improve wear and safety by eliminating the risk of flats, uniform adhesion and reducing material waste by replacing the outer tube. Finite element analysis of various wing designs shows that the diamond structure is the most durable. Future research will focus on dynamic analysis and composite materials for 3D printing under different load conditions [5]. The article compares three non-pneumatic tyre concepts using Ansys simulations, finding that the honeycomb structure excels in load handling and stress distribution, while Bridgestone's airless design offers superior ride comfort, although further testing is needed to confirm these findings [6]. From the FEM analysis in Section V, the hexagonal lattice structure with hyper-elastic material is suitable for non-pneumatic tyres, being resilient under various loads but needing improved lateral stiffness due to potential fatigue in the inner and outer rings [7]. It underscores the recent advancements in the systematic engineering of metamaterial components, emphasizing the challenges in employing topology optimization for optimizing non-pneumatic tyre components and the identification of the auxetic honeycomb as an optimal geometry for shear layers [8]. The existing tyre designs approach only a handful of organizations, but standardization enables the development of a broader range of application-specific non-pneumatic tyre designs. This is very important to approach different industries, vehicles and countries, and expand the use of non-pneumatic tyres beyond the set of organizations [9]. This research investigates various polyurethane (PU) surfaces for non-pneumatic (NPT) tyres under radial loading conditions, to maintain the same wall thickness and mass. The analysis shows that straight mesh structures such as simple and trapezoidal mesh types show the best load-carrying capacity, while the honey-NPT shows the fatigue life [10]. This paper introduces a bionic petal structure for non-pneumatic tyres (NPTs), demonstrating improved load capacity and stress distribution compared to typical NPTs. A multi-objective optimization method further enhances performance, suggesting promising applications in automotive settings [11]. This work introduces an airless tyre model, substituting natural rubber with synthetic rubber in the tread and polyester for nylon in the carcass, and conducts a comparative study with pneumatic tyres, including material and structural analyses of various airless tyre types, such as honeycomb, spokes, triangular, and diamond structures, using ANSYS software under a 1200N load, revealing that the diamond structure with synthetic materials exhibits minimal deformation compared to other structures [12]. In this numerical analysis, the influence of various internal geometrical parameters on the weight and mechanical behaviour of Non-Pneumatic Tyres with honeycomb structure was assessed through a parametric finite element model subjected to vertical loading, revealing that parameters such as density, thickness, and internal angles of honeycomb cells strongly affect vertical stiffness and stress distribution, with potential implications for fuel efficiency and dynamic properties. In contrast, proper tuning of cell dimensions can mitigate internal stresses and promote a more even distribution of contact pressure [13]. This article focuses on non-pneumatic tyres (NPT), which provide quasi-static and dynamic characteristics comparable to pneumatic tyres without the need for compressed gas or liquid. A numerical model representing a commercially available solution was validated using experimental research results, with simulations conducted to study the contact areas of the NPT under various normal force loadings on rigid ground [14]. Analysed static behaviour of five types of NPTs with 2mm polyurethane wall thickness, finding stress variations due to differences in cell angle and spoke design, with notable load-carrying differences among designs. Investigated stress distribution in NPT treads, revealing variations based on spoke design, with simple spoke structure showing distinct stress patterns

compared to interconnected designs. Evaluated strain energy in NPT spokes, identified design variations and suggested different fatigue life considerations for each design type [15].

This research paper follows the design selection method used by various researchers. Recent studies have found diamond and honeycomb tyre patterns to be common options for non-pneumatic tyres. However, this study presents an innovative design approach with a blade configuration that is capable of outperforming non-pneumatic honeycomb tyres and diamond blade tyres. With the design adopted from this research paper, we can improve the balance between ride quality and carrying capacity. Regarding material selection, there is no current research to identify suitable polyurethane materials based on longitudinal measurements. This study attempts to investigate the effect of length measurement and variation, thus helping to select the right polyurethane material for good handling results.

What is new about this project is a new approach to surface design, preparation and material selection. At the same time, its importance can be seen in its help to overcome the current challenges and limitations and encourage the development of non-pneumatic tyre technologies for the next era. The goal of this project is to create a design that is simple, easy to build and compatible with a variety of vehicles. The surface design can be adjusted to accommodate different loads, and the whole structure exceeds the load capacity of the honeycomb and diamond structures so that it has better durability and performance [16].

II. METHODOLOGY

We use Finite Element Analysis (FEA) to model the tyre models. Based on previous studies, it is clear that vertical load-bearing elements are very important to increase the bursting capacity of non-pneumatic tyres [17]. In addition, studies on honeycomb structures show that the cell angle of the profiles significantly increases the compressive strength of airless tyres [18]. Our goal is to design and analyse new polyurethane surface structures that exhibit low deformation, stress, and weight strength values. Materials for all metal and rubber parts are taken from previous studies, but data for polyurethane materials is only available from industry catalogues. In Part 1, we developed a 127/60 R10 tyre to represent small electric vehicles, including 3-wheelers and other small vehicles. This tyre will be used for the first analysis to determine the best design for phase 2. After receiving the analysis results, we will compare it with the updated 265/70 R17 tyre. In addition, we created a new reference model designed to compare with previous research results and validate our findings. For Part 2, we will use the 10.00 R20 tyre sizes found on commercial and industrial trucks and buses. To ensure that the results are not affected by mass variations, we use a sandwich design model where polyurethane powders are sandwiched between thin polyurethane plates, keeping the weight constant throughout the design. To choose the best surface design, we use a load of 4500 N, which represents a typical SUV. For the material selection step, we use a load of 40,000 newtons (40KN), which represents a bus or truck. These tyres have a load rating of 146, which means a weight capacity of 3000 kg, and the new design exceeds this value with a total capacity of 4078 kg. FEA helps understand how materials and shapes interact in tyres and solve complex manufacturing problems. It is like a virtual test to check the strength of the design and find the weak points. We design a variety of tyres using SolidWorks, then break the tyre structure down into thousands of small elements for analysis. Finally, we run numerical tests with the Ansys desktop to understand how different cap structures perform.

2.1 MATERIAL PROPERTIES

Polyurethane is employed in airless tyres for both the spokes and the shear band, emphasising its suitability for crucial components. Its presence in the spokes ensures flexibility and shock absorption, while its role in the shear band enhances overall durability and structural integrity, making it a fundamental material in the construction of airless tyres. Polyurethane, with its adjustable Shore A and Shore D hardness values, is a mouldable material that lends itself well to the creation of complex-shaped parts in various sizes. The flexibility of Shore A formulations caters to applications requiring elasticity, while the rigidity of Shore D formulations meets the demands of applications prioritizing hardness and durability. Our approach involves leveraging three distinct material data sources, each providing unique material properties, to accomplish our objectives. Property characteristics Tables A, B and C provide specific property sets for phase 2 analysis. The durometer reading indicates the degree of hardness of a material: the A scale is usually used for soft materials, while the D scale is used for hard materials. Polyurethane/polyether materials obtained from Era Elastomers and Redwood Plastic and Rubber provide a reliable, injection-friendly solution to traditional pneumatic tyres in a variety of applications. Table 2 (A) and 3 (B) items are taken from the online catalogue, Era Elastomers 2020, version 8.0, and Table 4 (C) items are from the Redwood Plastic and Rubber brochure.

Table 1. Material Properties Phase 1 [19]

Polymer properties	Hub	Spokes	Tread Band
	AISI 4140	Polyurethane	Synthetic Rubber
Density (Kg/m ³)	7810	1210	1050
Tensile Strength (MPa)	480	145	35
Young's Modulus (MPa)	210000	18.2	14
Poisson's Ratio	0.3	0.48	0.48

Table 2. Material Properties A [20]

Polymer properties	Material properties based on durometer							
	77A	83A	90A	93A	95A	83A (ET83A)	90A (ET90A)	95A (ET95A)
Density (Kg/m ³)	1060	1080	1100	1100	1130	1080	1110	1080
Tensile Strength (MPa)	30	33	42	43	45	33	33	43
Young's Modulus (MPa)	4.8	4.6	9.3	11	13.1	4.8	6.9	6.9
Poisson's Ratio	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48

Table 3. Material Properties B [20]

Polymer properties	Material properties based on durometer								
	70A	85A	90A	93A	95A	60D	65D	75D	80D
Density (Kg/m ³)	1040	1070	1100	1100	1130	1060	1110	1100	1100
Tensile Strength (MPa)	31	38	40	44	44	45	54	50	52
Young's Modulus (MPa)	2.3	7.3	7.2	9.8	13.8	19.9	25	42.5	40
Poisson's Ratio	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48

Table 4. Material Properties C [21]

Polymer properties	Material properties based on durometer										
	75D	60D	55A	57A	60A	62A	70A	80A	85A	90A	95A
Density (Kg/m ³)	1210	1160	1190	1250	1200	1160	1210	1220	1100	1110	1130
Tensile Strength (MPa)	55.1	46.2	37	26.2	37	30.1	45	41	54	50	52
Young's Modulus (MPa)	34.5	24.8	1.6	2.14	2.6	2.1	3.8	7	7.2	7.6	11
Poisson's Ratio	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48

2.2 CONSTRUCTION AND GEOMETRIC PROPERTIES

Unlike traditional pneumatic tyres that are filled with air, PTs are rigidly constructed. This design eliminates the need for gas, injection, and compression. Solid construction features a tread pattern made from lightweight polymers, while the tread is rubber. To ensure constant mass and avoid results influenced by weight variations, a sandwich design model has been used [22]. Polyurethane screens are placed between thin sheets of polyurethane and remain in all designs as shown in Figure 1. Table 1 shows the geometric properties for the Phase 1 analysis of the 10-inch wheel and Table 5 shows the measurements for Figures 1 and 4.

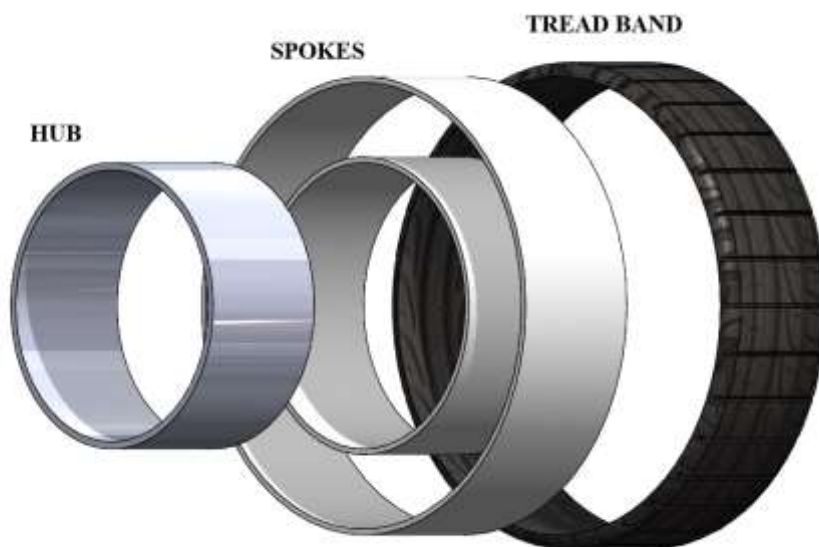
**Figure 1.** Representation of Non-Pneumatic Tyre Structure.

Table 5. Dimensions of Phase 1 and Phase 2 Tyre Structure

Structure	Phase 1			Phase 2		
	Innermost Diameter (mm)	Outermost Diameter (mm)	Thickness (mm)	Innermost Diameter (mm)	Outermost Diameter (mm)	Thickness (mm)
Tread Band	406	431	12.5	950	1016	33
Spokes Support	264	406	5	508	950	20
Hub	264	254	5	508	476	16

2.3 Phase 1 analysis

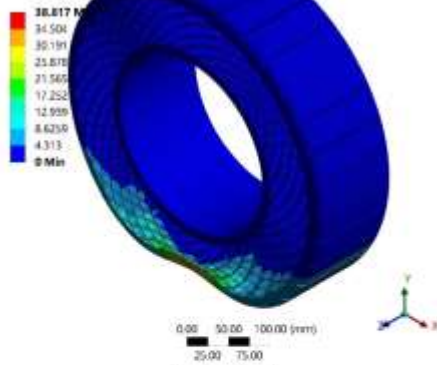
Boundary Condition Set-Up:

Correct mesh settings and geometry are important for accurate finite element analysis. Assuming that the vehicle is stationary, only vertical conditions are considered and analysed, so local conditions were assumed to be quasi-static for all subsequent analyses. Changes to boundary conditions are specified before each analysis. Assuming that the tyre is attached to the wheel, the post is set as a permanent support. A force was applied to generate the reaction force for the weight of the vehicle, and the weight of the ground (9.81 m/s) using a function in Ansys. For the analysis of Phase 1, a force of 4500 N is applied from below, as shown in Figure 3, using grooves to isolate the force and reconstruct the tyre contact surface.

Mesh Set-Up and Material Assignment:

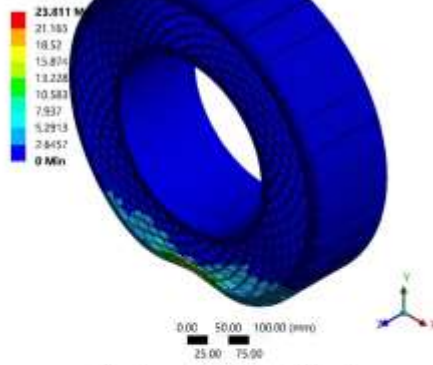
Polyurethane was used as the surface material, AISI 4140 as the floor material and synthetic rubber as the tread. The combination was applied to the total modification with a difference of 10%. For all Part 1 analyses, Figure 2 and Figure 3 show the surface produced using the tetrahedral method, with a body size of 6 mm for the blades and tread.

A: Static Structural
Total Deformation
Type: Total Deformation
Unit: mm
Time: 1 s
13-07-2024 13:20



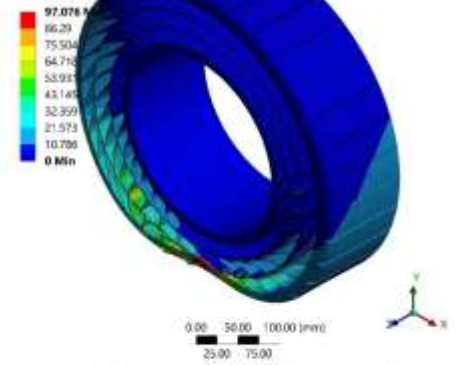
A. Spiral

A: Static Structural
Total Deformation
Type: Total Deformation
Unit: mm
Time: 1 s
13-07-2024 13:26



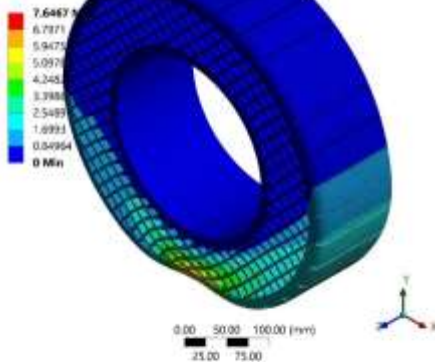
B. Constricting Spiral

A: Static Structural
Total Deformation
Type: Total Deformation
Unit: mm
Time: 1 s
13-07-2024 14:31



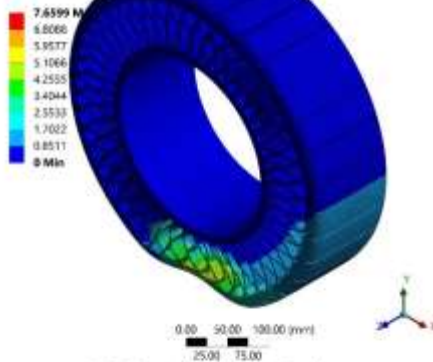
C. Spiral with 2 supports

A: Static Structural
Total Deformation
Type: Total Deformation
Unit: mm
Time: 1 s
13-07-2024 13:39



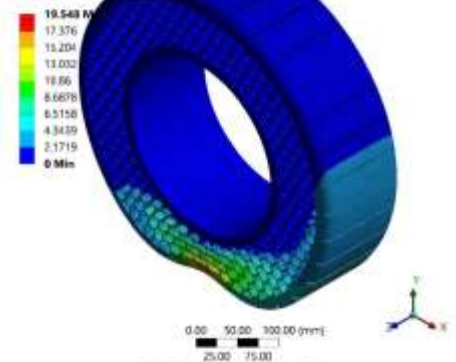
D. Diamond

A: Static Structural
Total Deformation
Type: Total Deformation
Unit: mm
Time: 1 s
16-07-2024 14:39



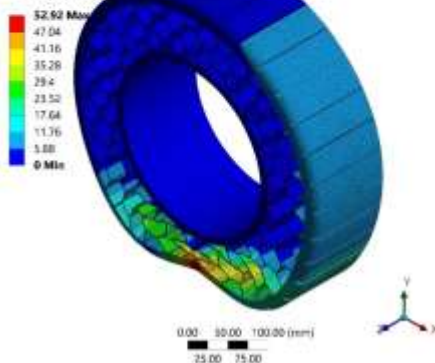
E. Parabola 48 Spokes

A: Static Structural
Total Deformation
Type: Total Deformation
Unit: mm
Time: 1 s
13-07-2024 13:50



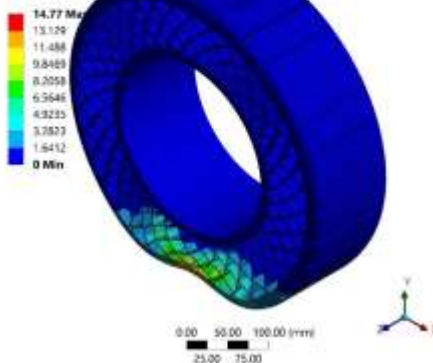
F. Honeycomb

A: Static Structural
Total Deformation
Type: Total Deformation
Unit: mm
Time: 1 s
13-07-2024 13:00



G. Honeycomb 2.0

A: Static Structural
Total Deformation
Type: Total Deformation
Unit: mm
Time: 1 s
13-07-2024 13:08

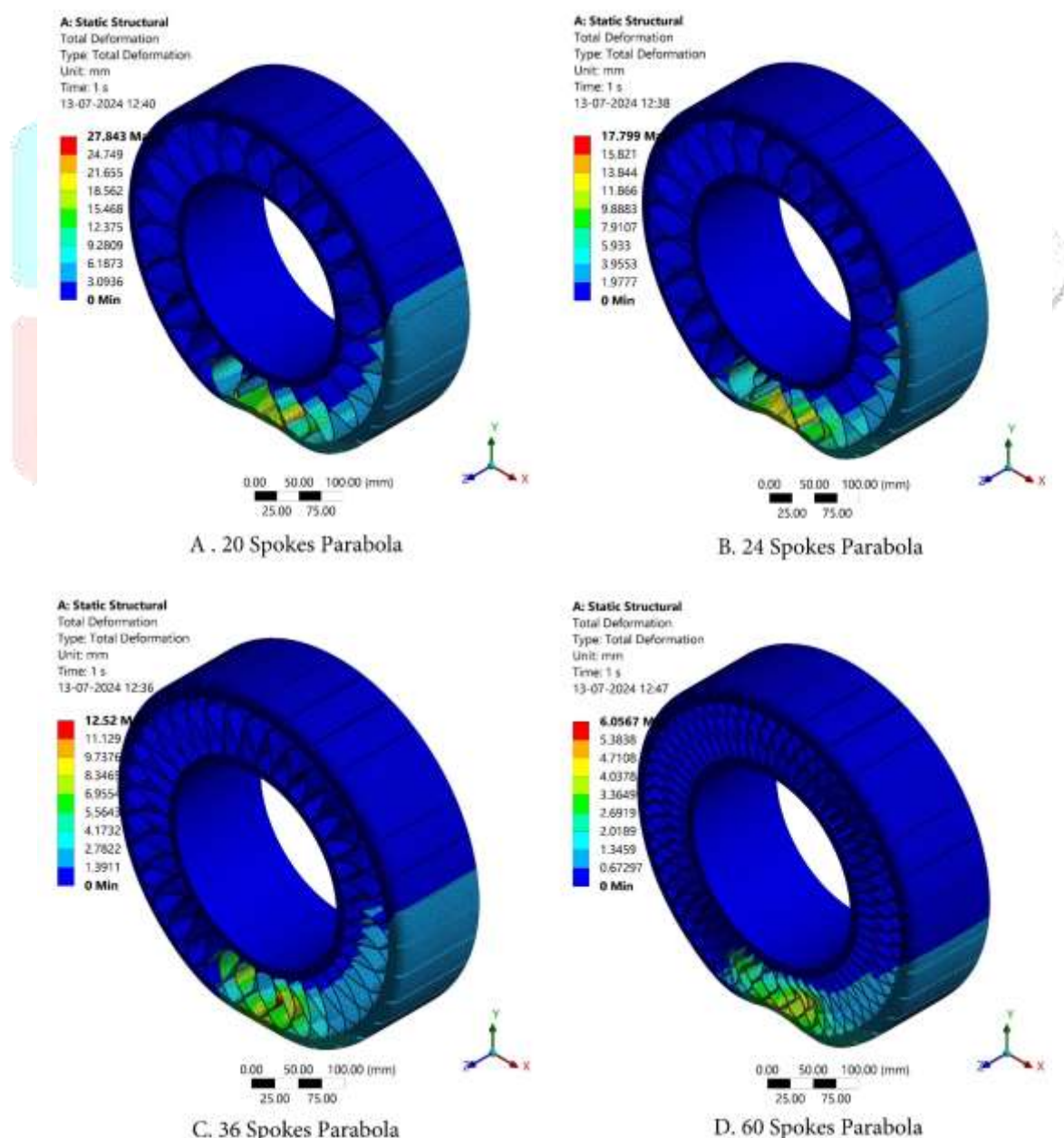


H. Diamond 2.0

Table 6. Analysis results for CAD models

Figure 2	Total Deformation(mm)	Mass (kg)	Maximum Shear Stress (MPa)	Equivalent (Von-Mises) Stress (MPa)	Maximum Principal Elastic Strain(mm)
A	38.81	3.45	8.08	14.23	0.3030
B	23.81	5.30	8.62	15.05	0.3322
C	97.07	3.00	17.9	31.56	0.6610
D	7.64	5.63	1.54	2.78	0.0694
E	7.65	4.21	2.77	4.96	0.0978
F	19.54	3.78	4.98	8.74	0.1883
G	52.92	2.85	10.27	17.86	0.4033
H	14.77	3.50	4.63	8.13	0.1752

Table 6 shows that the construction of diamond blades, honeycomb, honeycomb 2.0, diamond 2.0 and parabolic blades show the best results. However, it is important to consider that changes in the weight difference of materials affect the overall design perspective [23-24]. The parabolic diagram in Figure 2 (E) has 48 points. Due to the adaptability of this design for different weight classes, we create four other variations



of the sandblasting design with 20, 24, 36 and 60 details to compare with the honeycomb and diamond mesh structures.

Figure 3. 20, 24, 36 and 60 Spokes Parabola design**Table 7.** 20, 24, 36 & 60 spokes parabola tyre analysis results.

Figure 3	Spokes	Total Deformation (mm)	Mass (kg)	Maximum Shear Stress (MPa)	Equivalent (Von-Mises) Stress (MPa)	Maximum Principal Elastic Strain(mm)
A	20	27.84	2.83	9.00	15.72	0.3480
B	24	17.79	2.94	7.42	12.98	0.2811
C	36	12.52	3.54	3.88	6.87	0.1483
D	60	6.05	4.77	1.81	3.28	0.0651

The fossil structure was drawn using the eclipse draw command. The parabolic design is 2.5 mm thick. To avoid complex geometry, the design is built into the tread. Figure 3 examines the correct number of spokes for a load of 4500 N, showing that the 48-spoke design is a good choice for cars and SUVs. In comparison, the 36-inch design is ideal for small, lightweight electric vehicles, and the 60-inch design can be used for trucks and buses. The curvature of the tread is applied to a large weight, preventing sudden changes in geometry to allow for efficient load transfer. A comprehensive analysis of the deformation, maximum shear stress, equivalent stress (von Mises) and ultimate elastic strain from the data presented in Table 6-7 shows the diamond designs and parasites in all situations [25-26].

But for adaptation to various load capacities. Although the diamond design is not uniform, the Parabola design with its different surfaces offers a practical solution. In particular, the Parabola 60 mesh design is the first for Phase 2 analysis and is not only flexible but also has the same stress and wear resistance as the diamond design. The Parabola design can be retrofitted to existing tyre requirements to reduce the need for modifications to the vehicle itself. In summary, the Parabola design, especially with the 60 blades, turns out to be the best part due to the better performance, the strength of the preparation and the lightweight, which is suitable for exploring the part later analysis [27-28].

2.4 Phase 2 Analysis

For the analysis of the upscaled design version intended for transport buses or similar vehicles, we will use the 60 spokes parabola design to maximise compressive strength.

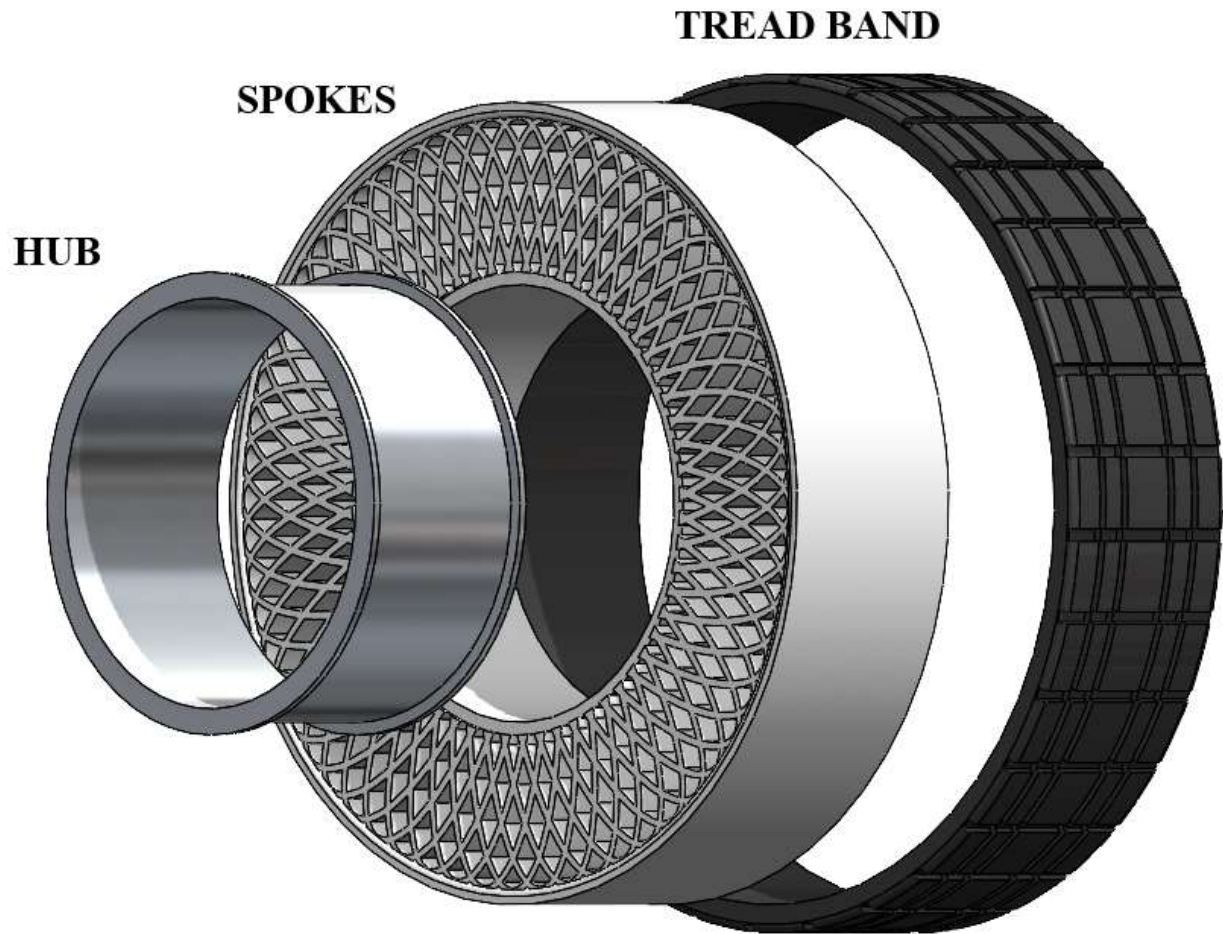


Figure 4. Representation of Upscaled Tyre

Boundary Condition Set-Up:

Accurate finite element analysis requires appropriate mesh and geometry settings. Figure 4 shows a modified non-pneumatic Parabola 60 Spokes tyre to be used for further analysis. The wheel is mounted and a force of 40,000 N is transmitted from below and distributed to the contact point of the tyre through the paths shown in Figure 4. This setting produces a heavy reaction force on the vehicle. The ground pressure (9.81 m/s) is applied using Ansys. For analysis, tyre sizes of 10.00 R20 tyres are used on commercial and industrial trucks and buses. To ensure a constant mass and avoid the effects of weight variations, a sandwich design model is used. During the design selection phase, a force of 4500 N was applied to the tyre model from bottom to top, a fixed point, representing a typical load for an SUV. For the material selection step, a higher force of 40,000 N is used to simulate the loading conditions of a bus or truck.

Mesh Set-Up and Material Assignment:

For the Phase 2 analysis, the surface was constructed using the tetrahedron method, with a body size of 10 mm for the blades and tread. Polyurethane/polyether was used as raw material, AISI 4140 as base material and synthetic rubber as tread material. Material data A, B and C from Tables 2, 3 and 4 were used for these analyses.

Figure 5 gives us a visual representation of the analysis with Table A

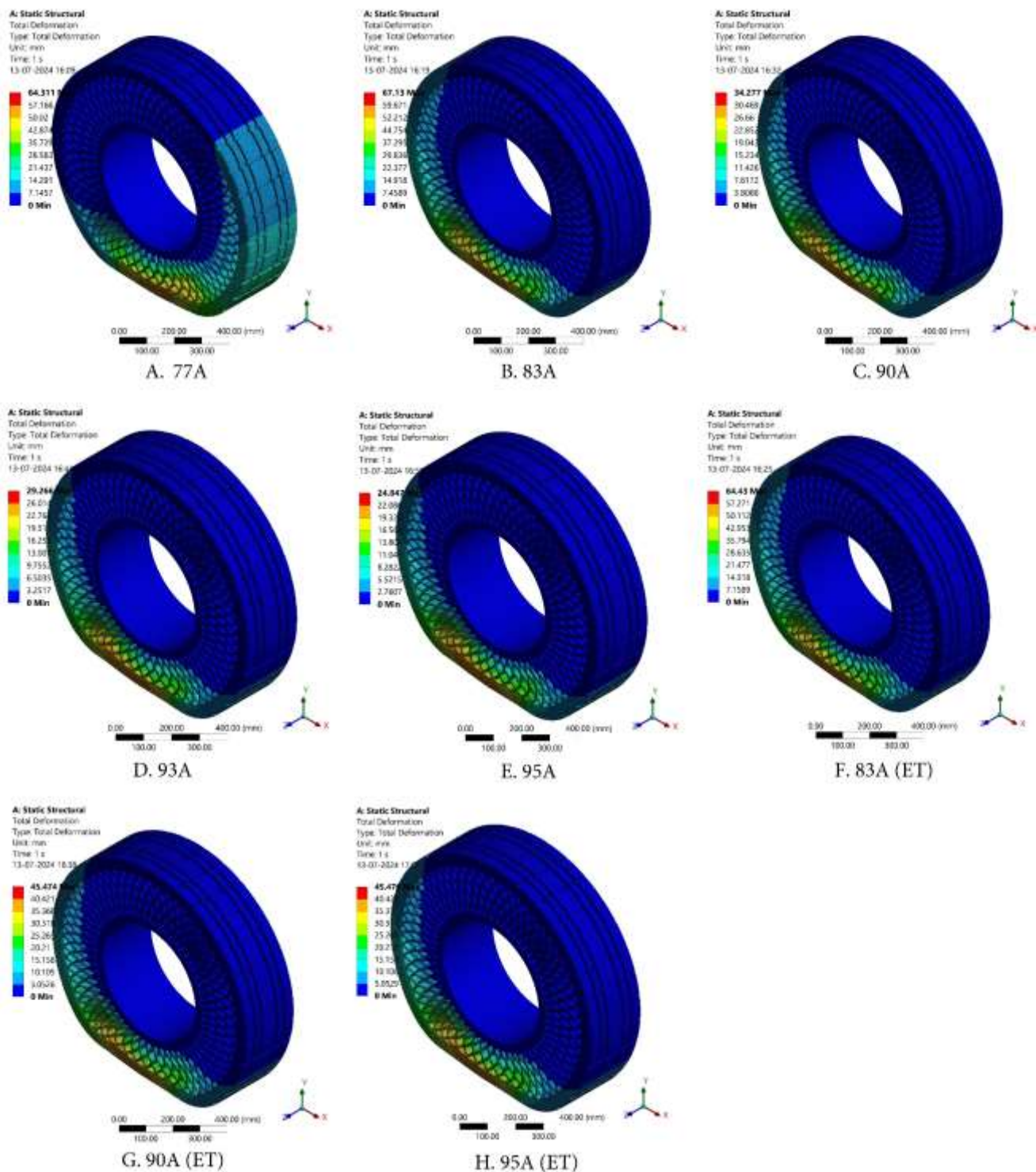


Figure 5. Analysis with Table A materials

Figure 6 gives us a visual representation of the analysis with Table B

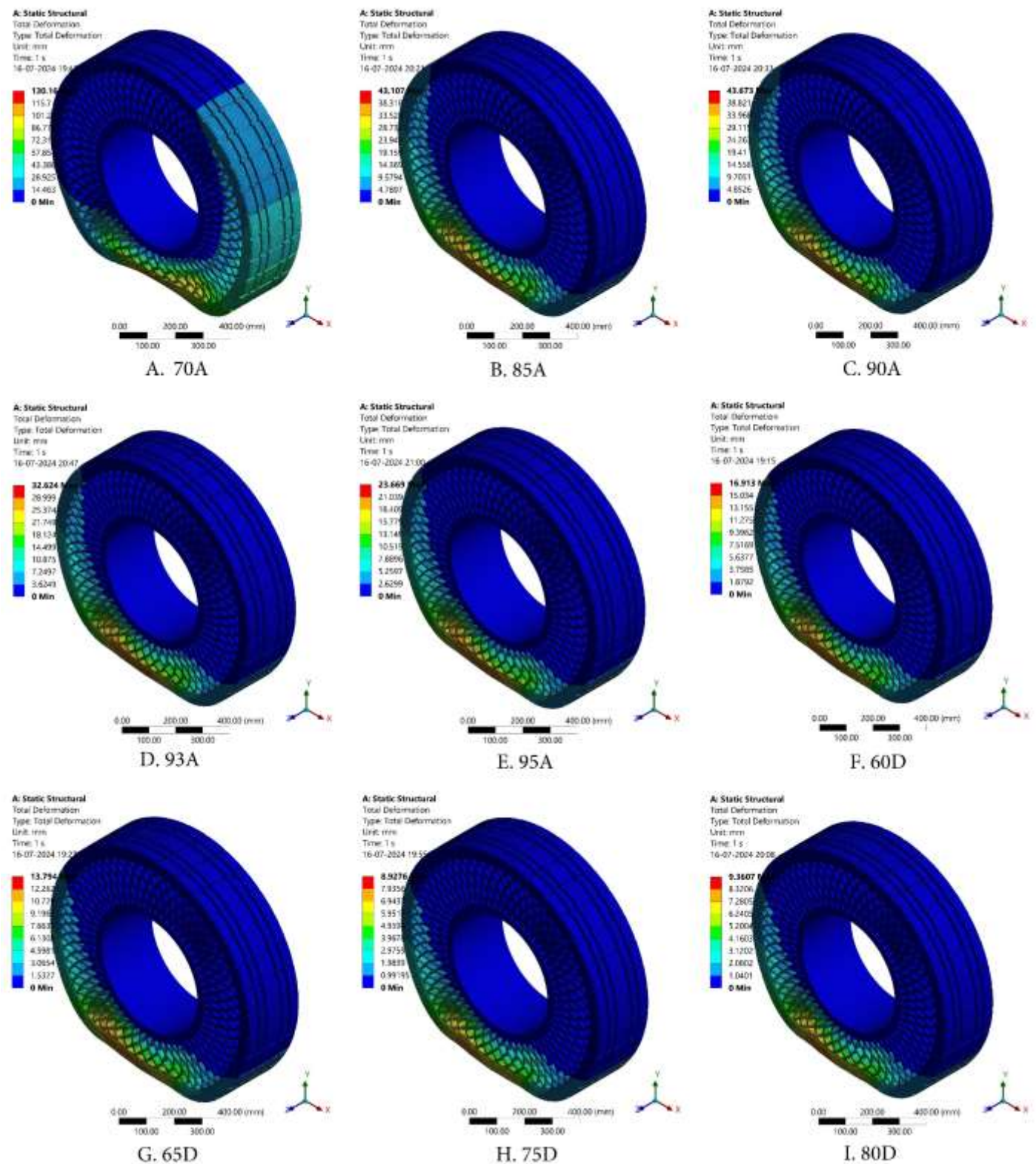


Figure 6. Analysis with Table B Materials

Figure 7 gives us a visual representation of the analysis with Table C

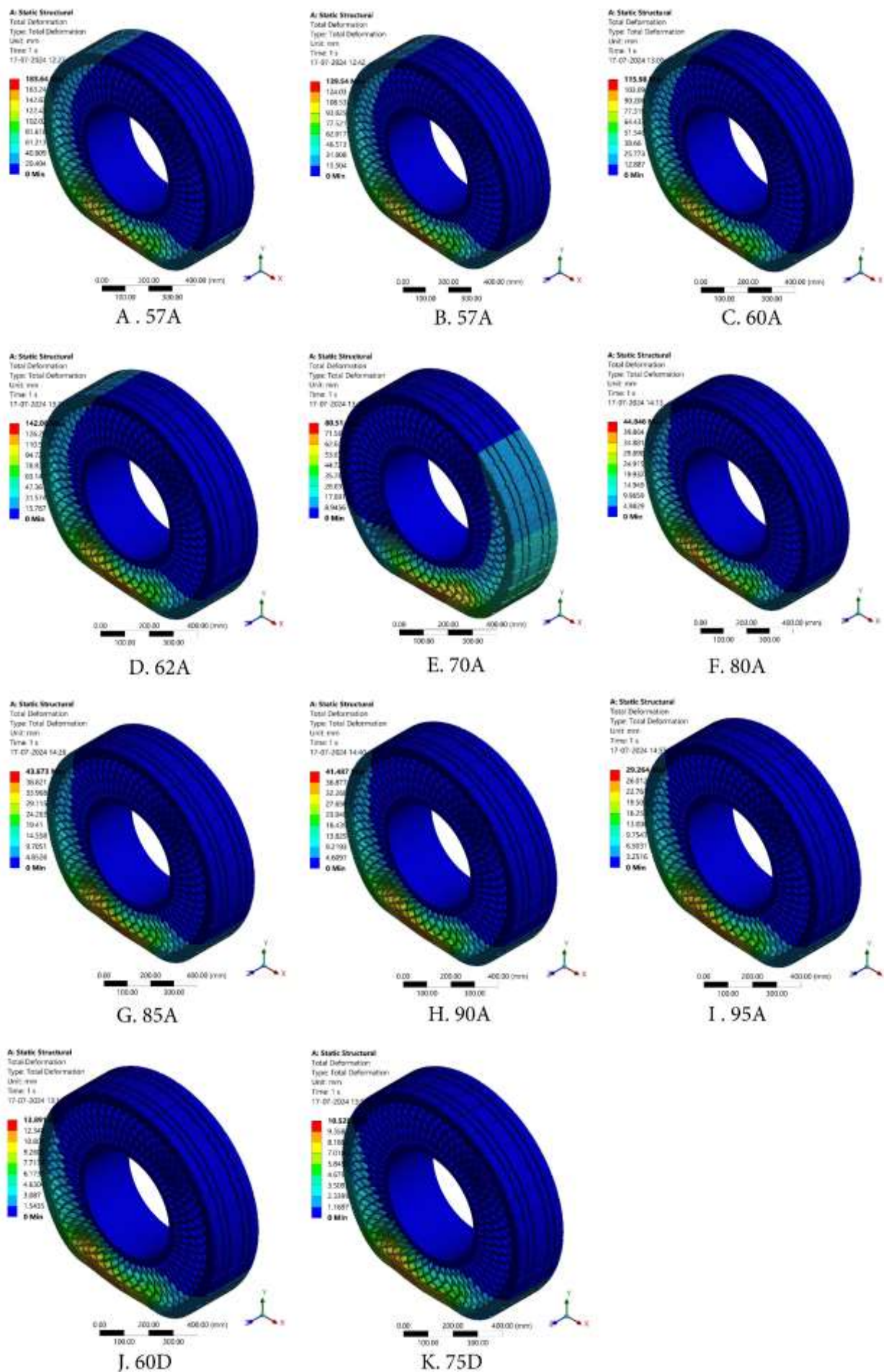


Figure 7. Analysis with Table C Materials

Table 8. Total Deformation of Material A**Table 9.** Total Deformation of

Material B

Figure 5	Durometer	Total Deformation (mm)
A	77A	64.31
B	83A	67.13
C	90A	34.27
D	93A	29.26
E	95A	24.84
F	83A (ET83A)	64.43
G	90A (ET90A)	45.47
H	95A (ET90A)	45.47

Figure 6	Durometer	Total Deformation(mm)
A	70A	130.16
B	85A	43.10
C	90A	43.67
D	93A	32.62
E	95A	23.66
F	60D	16.91
G	65D	13.79
H	75D	8.92
I	80D	9.36

Table 10. Total Deformation of Material C

Figure 7	Durometer	Total Deformation(mm)
A	55A	183.64
B	57A	139.54
C	60A	115.98
D	62A	142.08
E	70A	80.51
F	80A	44.64
G	85A	43.67
H	90A	41.48
I	95A	29.26
J	60D	13.89
K	75D	10.52

Based on the data collected from Tables 8, 9 and 10 and Figures 5, 6 and 7, the Polyurethane D shows a higher compressive strength. However, it is noted that this substance can transfer several road imperfections to the passengers and the driver. On the other hand, polyurethane with a Shore hardness of 75A to 95A provides the benefit of seeding while showing a different appearance than Shore D. These materials create a space for the helmet, it can remove the stress of the road [29-30].

III. RESULTS AND DISCUSSIONS

3.1 Stress Comparison Under Static Conditions:

Total Deformation: - The deformation analysis data indicates that the load-carrying capacity of designs Diamond, Parabola, and Honeycomb is excellent. Furthermore, upon comparing with the diamond spokes, Parabola designs even surpass the diamond design with 60 spokes while being 859 grams lighter. The deformation analysis results show that even within lower weight classes, the Parabola design in Figure 2 (E) exhibits superiority. Compared with diamond and honeycomb as we can see parabola design can be customized with spokes, which can improve their compressive strength, The design with enough spokes resembles a diamond structure however even with 20 spokes it still surpasses the conventional honeycomb and diamond patterns. Since the deformation and impact-damping trade-off needs to be balanced, going with the design that offers less deformation can lead to human discomfort but with parabola design. We can guarantee good ride quality with special speakers that increase or decrease the handling load of the vehicle by changing the tyre.

Maximum Shear Stress: - This refers to the maximum value of shear stress that occurs in a material or structure due to an external force. The peak shear stress analysis data from Tables 6 and 7 show the shear

stresses shown in the diagrams under tensile strength. Here, the diamond and ruby design has the lowest concentration of high shear stress, so it can be said that the diamond and ruby design is better.

Equivalent (von Mises) Stress: - When a material is subjected to multiple stress, that is, stress from multiple directions, different stress components act on it simultaneously. Von Mises stress is a single uniform stress value that describes the effect of these different stresses. Equivalent (von Mises) analysis data from Tables 6, and 7 show that von Mises stresses occur in designs under tensile strength. Here, the diamond and slag designs have the lowest equivalent (von Mises) stress concentration, so it can be said that the diamond and slag designs are better.

Maximum Principal Elastic Strain: - It is the maximum deviation a material experiences in the direction of principal stress. Strain indicates how much a substance reacts to an external force. The major principal load occurs along the axis as the material is stretched or compressed. The analysis data for the ultimate elastic strain from Tables 6, and 7 shows that the diamond and diamond designs have the lowest ultimate elastic strain concentration.

3.2 Phase 1 Results:

On Ansys software, three-dimensional finite element analysis was performed on different surface structures, compared with honeycomb and diamond surface models, the results of parabolic design analysis related to the change all, high shear stress, and equivalent (von Mises) expression. Stress, maximum elastic strain. The tested designs follow the general principle of reducing stiffness and increasing the applied force. The choice of the parabolic nail design was justified by careful comparison with honeycomb and diamond nail designs, the analysis showed that the parabolic design performed better in terms of total variation, stress high shear, uniform stress (von Mises) and very high Although elastic. the tape is lighter in design, we see that the amount of vertical stiffness continues to decrease and the strength increases.

3.3 Phase 2 Results:

This section focused on material selection, specifically to determine the best polyurethane gauge grade for bus tyres. Using the materials in Tables 2(A), 3(B) and 4(C) provides a comprehensive understanding of the impact of various polyurethanes on tyre performance under stress. The results of the FEA simulations using Ansys showed that the 60-story beam design not only resists the applied forces but also shows promising compatibility for large and heavy vehicles. Based on the data shown in Tables 8, 9 and 10, it is clear that the Shore D polyurethane shows a higher compressive strength. However, this material is bad at transferring road imperfections to the passengers and the driver, making the ride more comfortable.

In contrast, polyurethane with a Shore hardness of 75A to 95A, as it has a lower shape than Shore D, has great advantages in the room. These materials create a space for the tyre to better absorb the shock of the road. This ability to change and absorb energy helps to smooth the ride, reduce the transmission of road imperfections and increase the comfort of the passengers. The combination of a parabolic tread design with a choice of polyurethane materials and Shore hardness from 75 amps to 95 amps represent major advances in non-pneumatic tyre technology. These products pave the way for the development of tyres that not only offer greater load capacity and durability but more importantly passenger comfort and safety. The analysis concludes that non-pneumatic tyres are more suitable for light military vehicles with uniform designs and more material options depending on specific applications.

3.4 Limitations and Future Work:

The analysis reveals that the parabola spoke structure exhibits superior compressive strength compared to both pneumatic and non-pneumatic tyres tested in earlier studies. Notably, the true advantage of this spoke structure lies in its customization potential, allowing for adjustments to the vertical stiffness of the tyre by modifying the spoke design.

While the proposed experimental model could provide valuable insights, its scope and scale may be limited, potentially impacting the generalizability of the findings. While dynamic analysis can provide valuable insights, it may introduce additional complexities and uncertainties that need to be carefully addressed. The proposed design may face challenges in terms of manufacturability and scalability, which could impact its feasibility for large-scale production and deployment. Further research should focus on optimizing the parabolic vane design for different loading conditions and exploring other materials to increase the thrust without compromising structural integrity. Combining these results ensures comprehensive validation and widespread use of the non-pneumatic tyre design.

As a way forward for this project, we plan to make test models using polyurethane materials. This model is used to perform a comparative analysis with existing commercial tyres. In addition, the introduction of dynamic analysis methods allows for more accurate comparisons between experimental data and theoretical predictions.

IV. CONCLUSIONS

The analysis performed in this study has significantly improved the design and material selection of non-pneumatic tyres, especially focusing on the use of polyurethane/polyether and innovative parabolic mesh design. These findings are important to optimize performance in a variety of vehicle applications, from small cars to passenger cars and trucks. The results obtained from this study are as follows:

1. The parabolic design, identified through the analysis of Part 1, is better in terms of the overall variation than honey and diamond formations, and showing better performance, indicating increased load-bearing capacity.
2. The analysis in Part 2 provided quantitative readings for polyurethane and guidance for the selection of non-pneumatic tyre materials based on vehicle use and operating weight. The recommendations suggest 75A-85A for small vehicles and 85A-95A for buses and trucks.
3. Shore D polyurethane has a very good load capacity, but the road will be rougher due to its higher stiffness. In contrast, polyurethane with a hardness range of 75A to 95A provides good adhesion even with slight deviations.
4. It is recommended to adapt the parabolic design with different modifications to meet different load requirements. It includes variations with 20, 24, 36, 48 and 60 details, which allow for built-in solutions.
5. The latest version of the design using a 60-spoke parabolic design has been optimized for compression strength in large vehicles, such as buses and public transport trucks.

The project is a thorough understanding of tread design, the selection of appropriate polyurethane materials, and design optimization for specific load classes, and provides advice on airless tyre applications in small cars, and SUVs, including crossover buses and trucks. These findings suggest that the parabolic design could be a game-changer in the standardization of non-pneumatic tyres with the potential for widespread use across industries.

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