MODELING AND ANALYSIS OF NON-PNEUMATIC TYRES WITH DIFFERENT DESIGN STRUCTURES USING FEM METHOD

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***Abstract*: A conventional tyre is made up of air enclosed rubber packed by means of compressed air. Conventional tyres over period have been dominating the world marketplace because it exhibits ride excellence and robustness. But it has a disadvantage such as burst out while driving, compound manufacturing method, the necessity to keep interior pressure. An innovative technology is under advancement to exploit only one of its kind blends of materials and geometry that does not need compressed air to hold up the load. Hence Non-pneumatic tyres were introduced.**

Non-pneumatic tyre is a submissive of cellular flexible spoke component which acts as air of a traditional tyre. In this project we replace conventional alloy wheel by flexible spoke structure. We investigated different spokes structure i.e. Honeycomb spokes structure, Triangle spokes structure, Plate spokes structure and Curved spokes structure for Non-pneumatic tyre by applying uniaxial load and rotational velocity. The spokes experience tension as well as compression while they are rolling. Non-pneumatic tyres are designed in CATIA workbench and analysis is done using ANSYS workbench and finally carried out the equivalent stresses, strains, deformations, shear stresses. Model analysis is also carried out and then finding out the suitable design for Non - pneumatic tyres.

***Keywords*: Finite Elemental Method, Non-Pneumatic Tyres, Honeycomb Spokes, Triangular Spokes, Plate Spokes, Curved Spokes, CATIA V5, ANSYS**

1. INTRODUCTION:

The NPT tyre is an airless one-piece wheel-and-tyre combination with a rubber tread bonded to a wheel hub with polyurethane spokes. The NPT tyre aims at performance levels beyond those possible with conventional pneumatic technology because of its shear band design, added suspension, and decreased rolling resistance. It delivers pneumatic-like load-carrying capacity, ride comfort, and as it has no pressurized air cavity, it cannot fail by loss of air pressure. Eventually it may be able to outperform conventional tires since it can be designed to have high lateral stiffness for better handling without a loss in comfort. However, it is unclear what environmental impact this radical new design will have. Currently there are environmental issues all throughout a tire's lifespan. The traditional tire is replaced with the NPT which has reduced weight compared to conventional tyres so this will reduce the vehicle and helps by improving efficiency of the engine. Non-pneumatic tyres are also expected to have a positive environmental impact. As of now, tyre companies must address the growing mountain of bald tyres defiling the landscape and find a way to recycle or find something that lasts longer and can be recycled. Because airless tires mostly use composite materials. Since the tread life of most models is longer than that of pneumatic tyres, the rubber does not have to be replaced very often. Currently automobile companies are taking into account every potential alternative to decrease the overall weight of the automobile to accomplish the fuel economy standards set by government. The focus study is mainly towards the option to reduce the weight of the tire. This will contribute to the reduction of overall weight of the vehicle.

2. LITERATURE SURVEY:

Mohammad Fazelpour et al, [1] stayed considered about the evolution of meso-structures in the development of the shear band of non-pneumatic tyre and he concluded as follows below. To increase fuel efficiency in NASA manned exploration system. They replaced elastomeric material with shear of shear band with materials which can tolerate harsh temperatures and shear loads or to replace the materials with linear elastic low-hysteretic loss materials. Topologies were created such as honeycombs; new shapes like s-type meso-structures and the structural analysis were carried out of shear band of non-pneumatic tyre with meso-structure was investigated through shear flexure, shear strain, and contact pressure. At the end of research, they set up guidelines on custom-designing meso-structures for challenging applications such as non-pneumatic tyre and passive morphing airfoils which will be addressed in future research. A.M. Abdul-Yazid et al, [2] examined three dissimilar structures of the Tweel, resistant technologies, and NPT by seeking yielding spoke structures. He conducted the quasi-static, 2D analysis on contact pressure, vertical tire stiffness and stress which are affected by spoke structures and shear band by creating two NPTs, a tire with a composite ring and another without composite ring. The results showed that shape and size of spokes has effect on tire behavior and the shear layer reduces the impact of the deformed spokes shape in contact pressure distribution. Bert Bras et al, [3] discussed about the ecological effect of the Tweel tyre amid its lifecycle from assembling, through use and transfer. Since the Tweel tyre is as of now still in the examination stage and is most certainly not made and utilized on a vast scale, there are instabilities as for end-of-life situations and rolling resistance evaluates that will influence the LCA.

3. PROBLEM IDENTIFICATION:

Non-pneumatic tyres generally have higher rolling resistance and provide much less suspension than similarly shaped and sized pneumatic tyres. Other problems for airless tyres include dissipating the heat buildup that occurs when they are driven. NPT's are often filled with compressed polymers (plastic), rather than air. Considering the NPT structure, the spokes undergo tension–compression cyclic loading while the tyre rolls. Therefore, it is important to minimize the local stresses of spokes that is, the spokes should be fatigue resistant. In this project, we designed different types of NPT's structures that are: honeycomb, plate, triangle and curved shape. Triangular, Plate, and Curved shapes. Hexagonal cell structures are known to be flexible in both axial and shear loadings. The spokes of an NPT are required to have both stiffness and resilience under cyclic tension–compression loading. In general, stiffness and resilience are conflicting requirements if a material has a high modulus, it shows a low elastic strain limit, and vice versa. The challenge, then, is to design materials that have both high stiffness and high resilience. Finite element analysis (FEA) has been utilized extensively in the simulation of tyre models due to its capability to solve complicated structural behaviors combining the nonlinearity of a material and geometry and is often used to verify design integrity and identify critical locations on components. The different types of NPT geometry are created using CATIA WORKBENCH. The analysis is done by modeling the structure into thousands of finite elements. In this study, ANSYS WORKBENCH is used for a numerical experiment with NPT's of different structures.

A. MATERIAL PROPERTIES:

The materials used in this analysis for honeycomb tire are aluminum alloy, polyurethane, steel, syntactic rubber. The main reason for selecting these materials is because they pose wide range of mechanical properties like high stiffness and resilience, high flexibility, hyper elastic, high temperature resistance etc. The selected material properties are tabulated below

Material properties table

Part	Hub	Spokes	Outer Ring	Shear Band
Material	UNS A97075	POLY URETHANE	AISI 4340	SYNTHETIC RUBBER
Yield Strength(Mpa)	503	140	470	16
Elastic Modulus(Mpa)	72000	32	210000	11.9
Poison's Ratio	0.33	0.49	0.29	0.49
Density(kg/m^3)	2180	120	7800	1043
Shear Modulus(Mpa)	32000	10810	80000	4

B. GEOMETRICAL ASPECTS:

- The wheel size is 24.6" ×6.5" ×9.8"
- The hub or rim diameter is = 250 mm.
- Inner hub diameter =200mm
- Hub thickness is = 25 mm.
- The outer ring diameter is = 605 mm.
- The outer diameter of the wheel is =625 mm.
- The width of the wheel is = 165.1 mm.

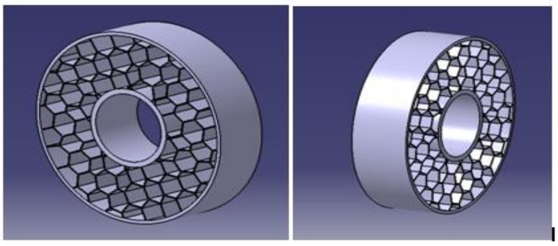
4. INTRODUCTION TO CATIA V5R20:

Welcome to CATIA (Computer Aided Three Dimensional Interactive Application) developed by this Dassault Systems, and is a completely re-engineered, Next-generation family of CAD/CAM/CAE software solutions for Product Lifecycle Management. Through its exceptionally easy-to-use and state-of-the-art user interface, CATIA V5 delivers innovative technologies for maximum productivity and creativity, from the inception concept to the final product. CATIA V5 reduces the learning curve, as it allows the flexibility of using feature-based and parametric designs.

A. DESIGN PROCEDURE OF THE MODELS IN CATIA V5:

I.HONEYCOMB SPOKES STRUCTURE:

While designing the honeycomb structure, whole structure is divided in to cell. The single cell is created first and mirrored to create entire structure. By considering the cell configuration dimensions i.e. cell angle θ, height h, and length l that were mentioned above in the geometrical dimensions and geometrical aspects, the following model of Honeycomb spokes structure tyre is developed which is shown below

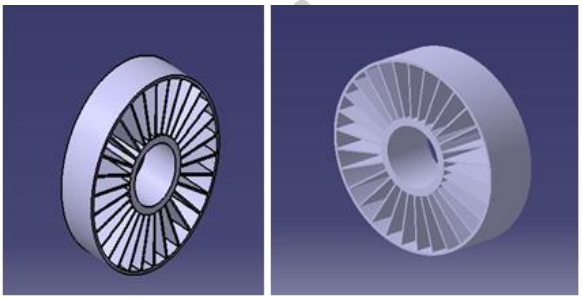


Honeycomb spokes structure

II.PLATE SPOKES STRUCTURE:

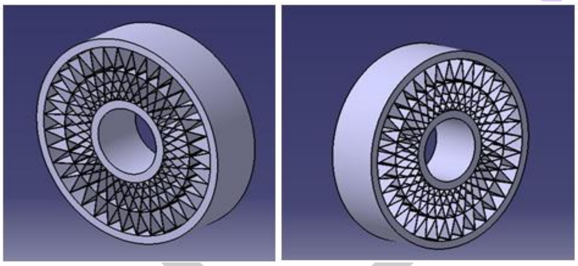
While designing the plate spokes structure, the hub which carries the entire structure is created first with the required dimensions there after plate spoke of mentioned dimension is created on it and by using rotation command, giving the spacing required thereby created an entire structure with the following dimensions of the tyre which is shown below

Plate spokes structure



III.TRIANGLE SPOKES STRUCTURE:

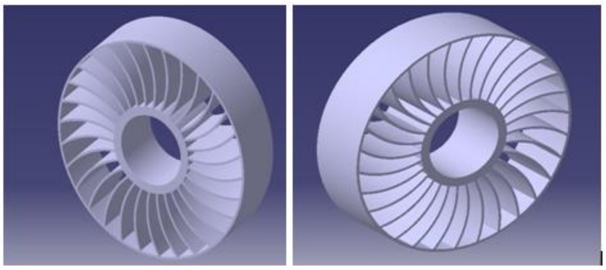
The design procedure is similar to the honeycomb spokes structure. While designing this structure, whole structure is divided in to cell. The single cell is created first and mirrored to create entire structure. And thereby following the geometric aspects and dimensions, the following model is developed which is shown below



Triangle spokes structure

IV.CURVED SPOKES STRUCTURE:

While designing the curved spokes structure, the hub which carries the entire structure is created first with the required dimensions there after curved spoke of mentioned dimension is created on it and by using rotation command, giving the spacing required thereby created an entire structure with the following dimensions of the tyre which is shown below



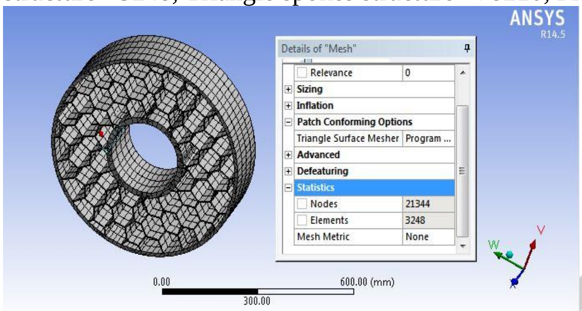
Curved spokes structure

5. INTRODUCTION TO ANSYS:

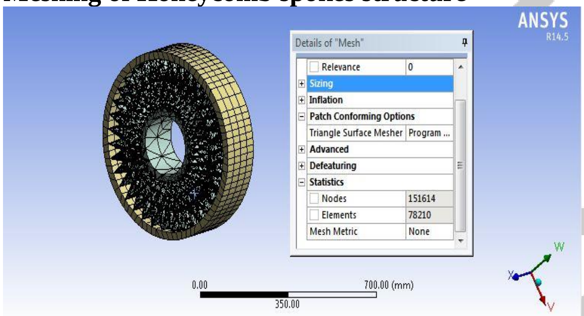
ANSYS is a general purpose software, used to simulate interactions of all disciplines of physics, structural, vibration, fluid dynamics, heat transfer and electromagnetic for engineers. So ANSYS, which enables to simulate tests or working conditions, enables to test in virtual environment before manufacturing prototypes of products. Furthermore, determining and improving weak points, computing life and foreseeing probable problems are possible by 3D simulations in virtual environment.

A. MESHING:

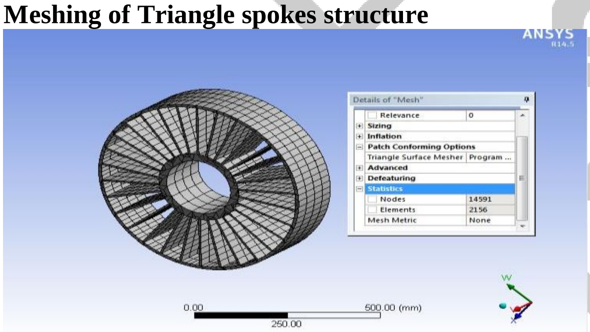
The Meshed model of honeycomb spokes structure, triangle spokes structure, plate spokes structure and curved spokes structure tyre are shown below. Meshing is carried out using ANSYS software. Here, we used tetrahedral element for meshing. The total number of nodes in the meshed models i.e., Honeycomb spokes structure= 21344, Triangle spokes structure =151614, Plate spokes structure=14591 and Curved spokes structure=16849. The total number of elements in the meshed models i.e., Honeycomb spokes structure= 3248, Triangle spokes structure =78210, Plate spokes structure=2156 and Curved spokes structure=2428.



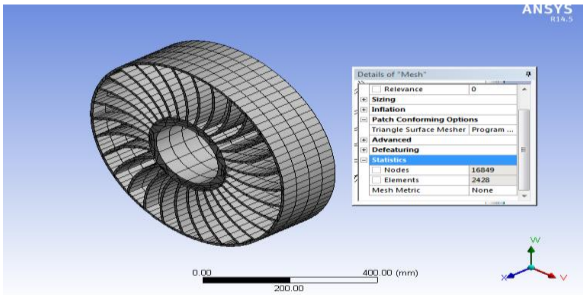
Meshing of Honeycomb spokes structure



Meshing of Triangle spokes structure



Meshing of Plate spokes structure

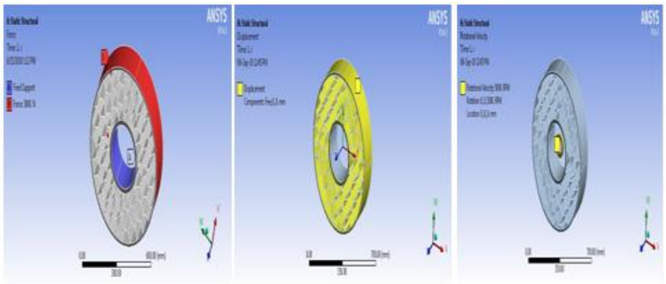


Meshing of Curved spokes structure

B. BOUNDARY CONDITIONS:

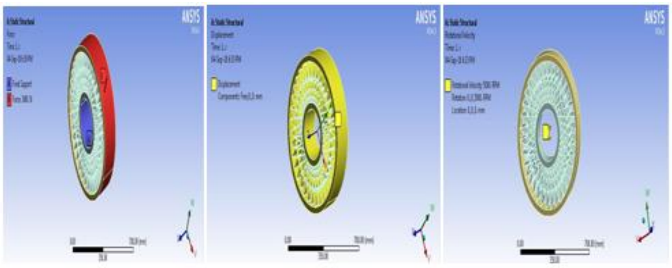
The Load applied on top surface of every tyre structure i.e., 3000 N is applied and considering the center of the wheel is fixed(hub). Applied displacement in the Negative y-direction at the inner surface of the wheel.

I. HONEYCOMB SPOKES STRUCTURE:



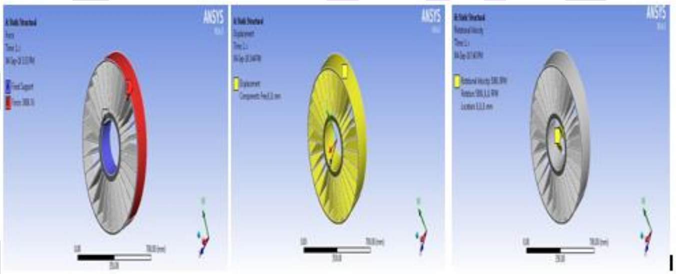
Load applying on Top surface 3000N and Rotational velocity 5000rpm

II.TRAINGLE SPOKES STRUCTURE:



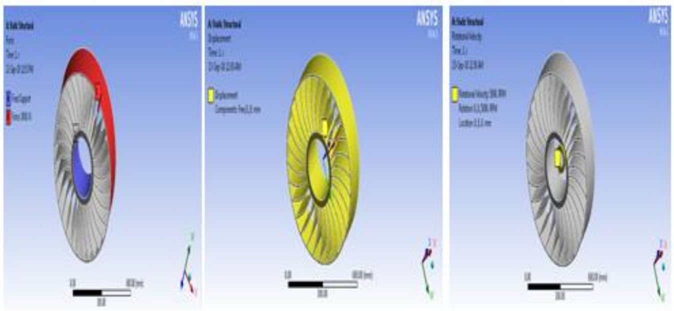
Load applying on Top surface 3000N and Rotational velocity 5000rpm

III.PLATE SPOKES STRUCTURE:



Load applying on Top surface 3000N and Rotational velocity 5000rpm

IV.CURVED SPOKES STRUCTURE:

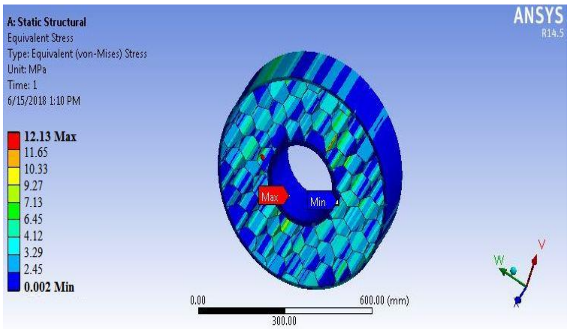


Load applying on Top surface 3000N and Rotational velocity 5000rpm

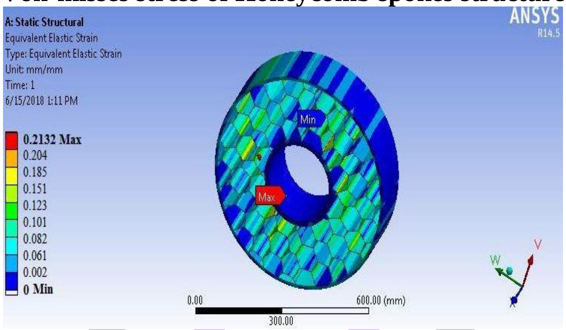
6. RESULTS AND DISCUSSIONS: The constructed wheels of different tyre structures which are Honeycomb spokes structure, Triangle spokes structure, Plate spokes structure, Curved spokes structure in CATIA were statically analyzed using ANSYS 14.5. On the contrary, we found the following results based on the application of boundary conditions i.e., load on the top surface 3000N and rotational velocity 5000rpm.The results deduced here are stresses, strains, shear stresses, total deformations as shown in below figures

A. HONEYCOMB SPOKES STRUCTURE:

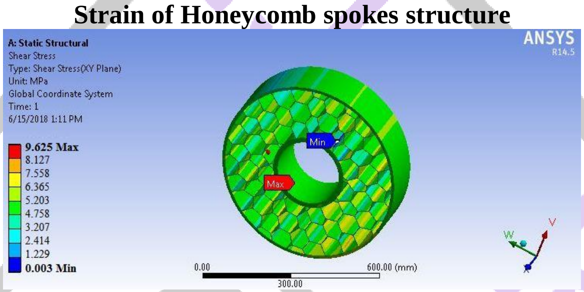
I.FOR THE LOAD ON TOP SURFACE 3000N



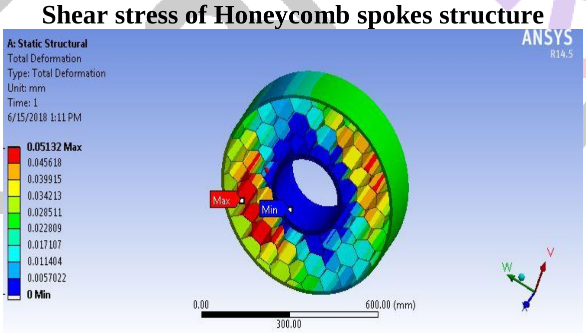
Von-misses stress of Honeycomb spokes structure



Strain of Honeycomb spokes structure

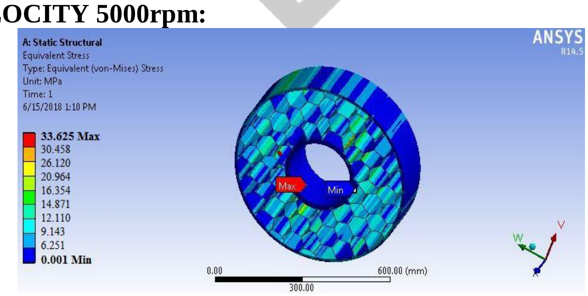


Shear stress of Honeycomb spokes structure

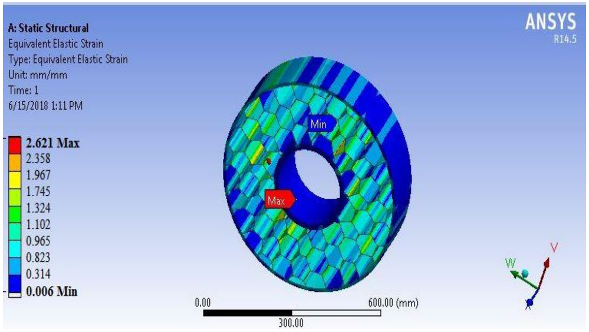


Total deformation of Honeycomb spokes structure

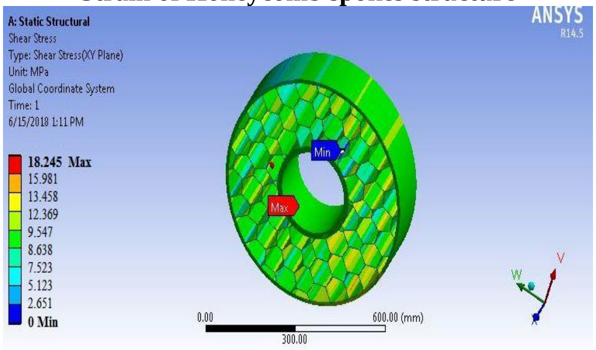
II.FOR THE ROTATIONAL VELOCITY 5000rpm:



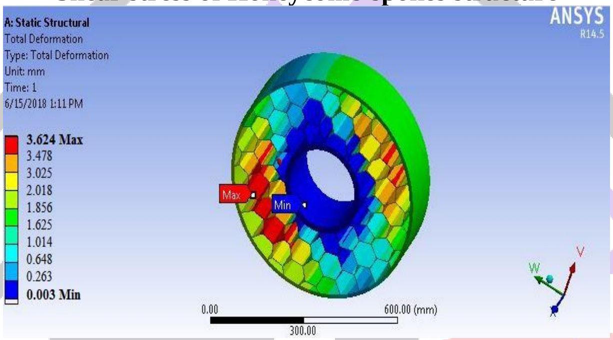
Von-misses stress of Honeycomb spokes structure



Strain of Honeycomb spokes structure

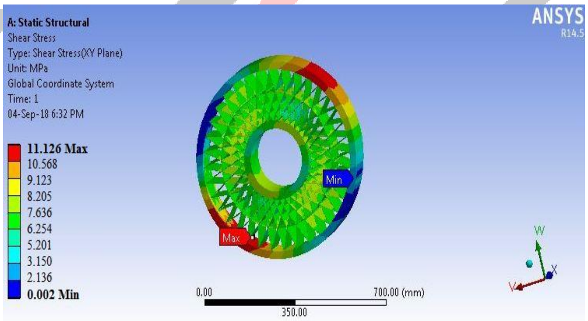


Shear stress of Honeycomb spokes structure

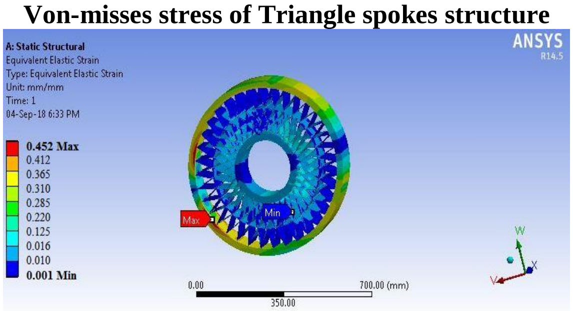


Total deformation of Honeycomb spokes structure

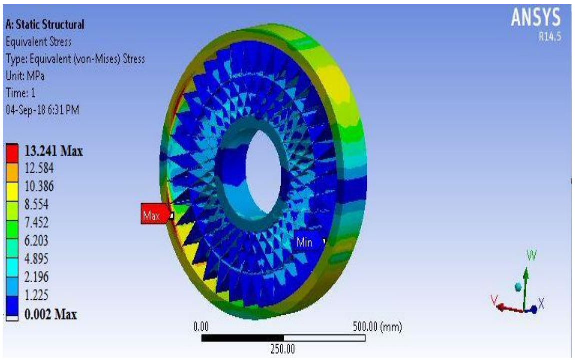
B. TRAINGLE SPOKES STRUCTURE:
I.FOR THE LOAD ON TOP SURFACE 3000N



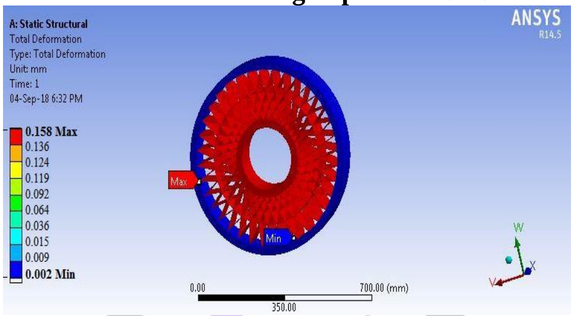
Von-misses stress of Triangle spokes structure



Strain of Triangle spokes structure

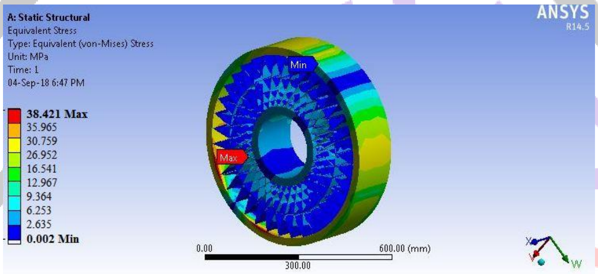


Shear stress of Triangle spokes structure

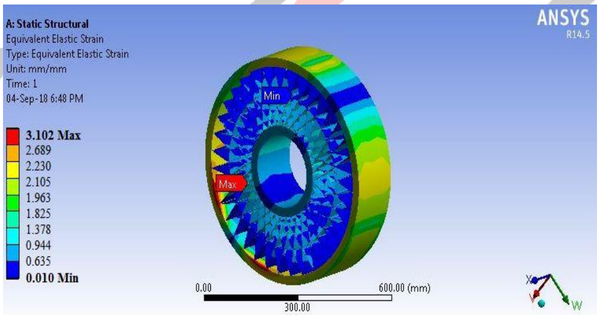


Total deformation of Triangle spokes structure

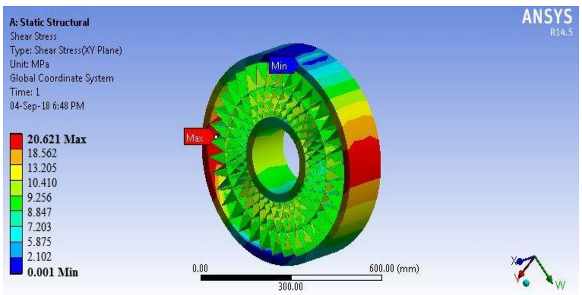
II.FOR THE ROTATIONAL VELOCITY 5000rpm



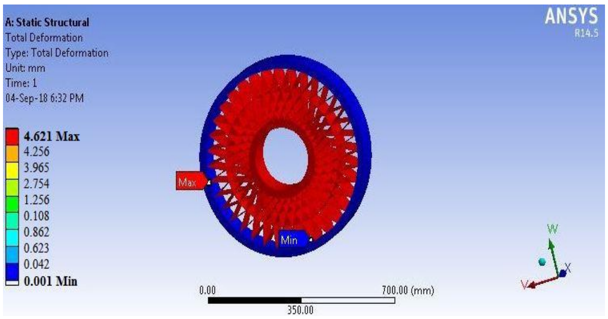
Von-misses stress of Triangle spokes structure



Strain of Triangle spokes structure



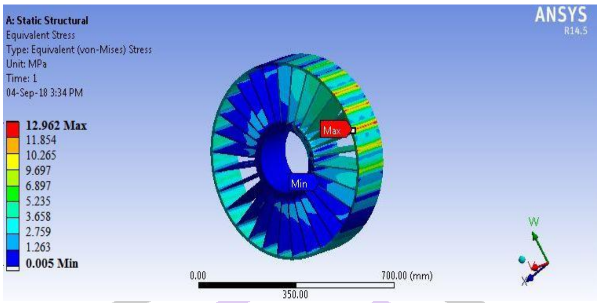
Shear stress of Triangle spokes structure



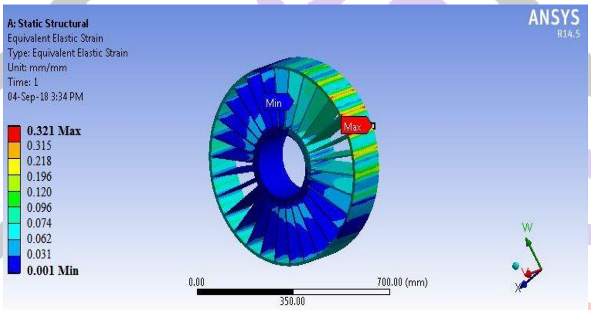
Total deformation of Triangle spokes structure

C. PLATE SPOKES STRUCTURE:

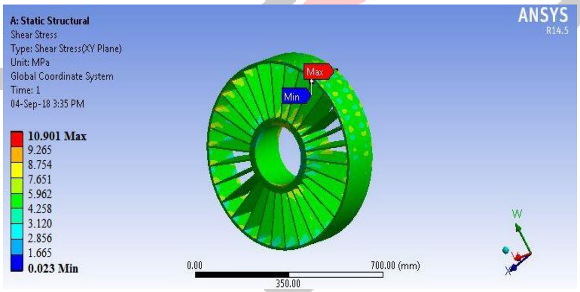
I.FOR THE LOAD ON TOP SURFACE 3000N



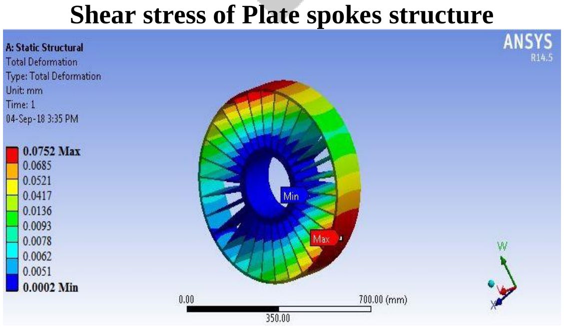
Von-misses stress of Plate spokes structure



Strain of Plate spokes structure



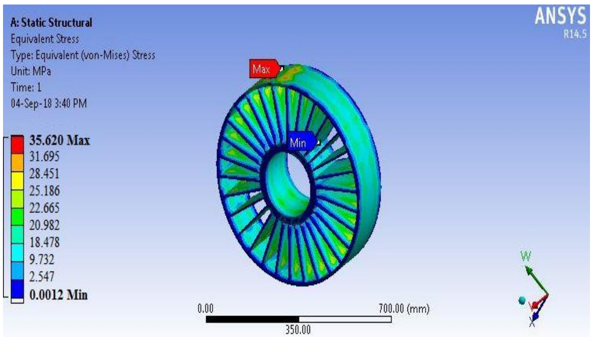
Shear stress of Plate spokes structure

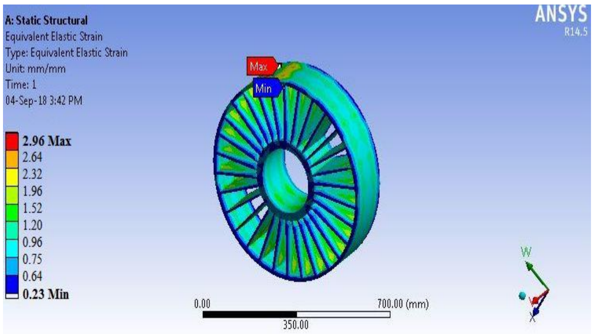


Total deformation of Plate spokes structure

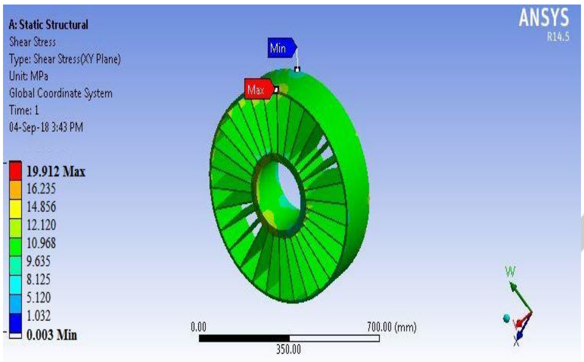
II.FORTHE ROTATIONAL VELOCITY 5000rpm

Von misses stress of Plate spokes structure

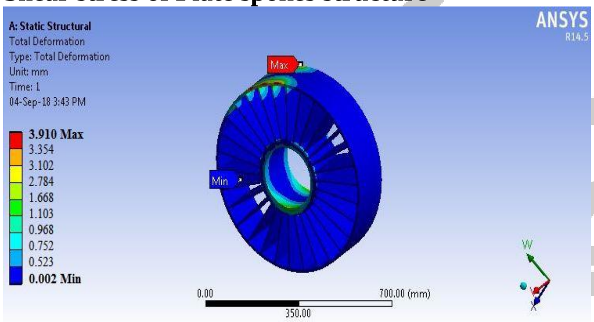




Strain of Plate spokes structure



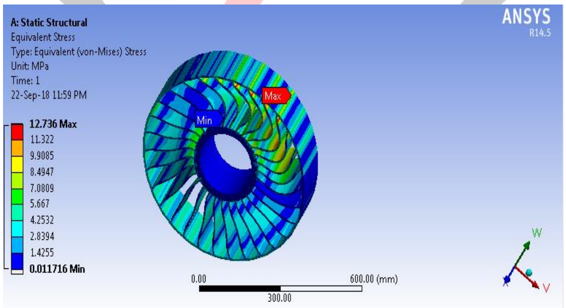
Shear stress of Plate spokes structure



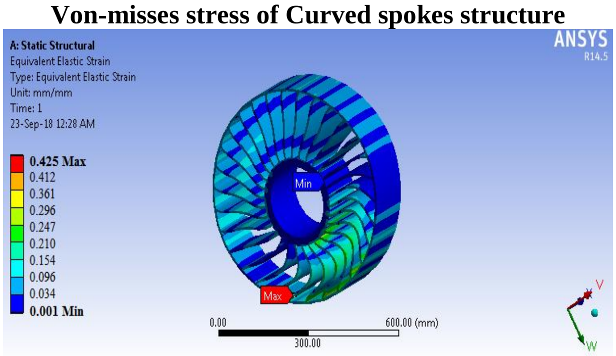
Total deformation of Plate spokes structure

D. CURVED SPOKES STRUCTURE:

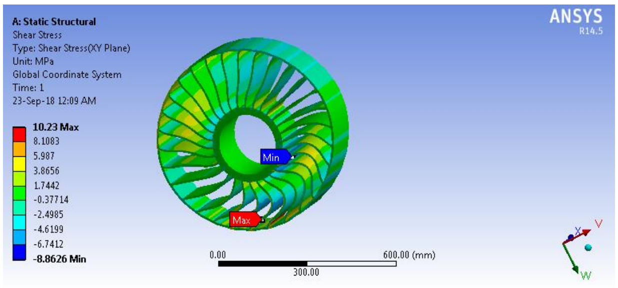
I.FOR THE LOAD ON TOP SURFACE 3000N



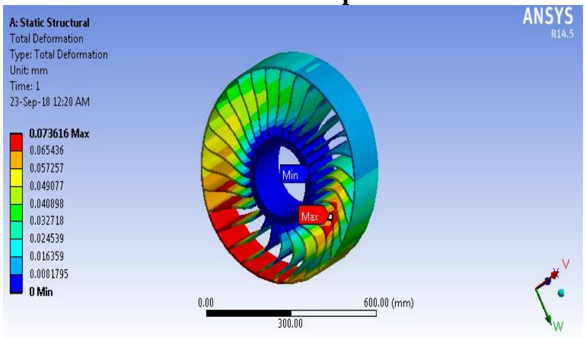
Von-misses stress of Curved spokes structure



Strain of Curved spokes structure

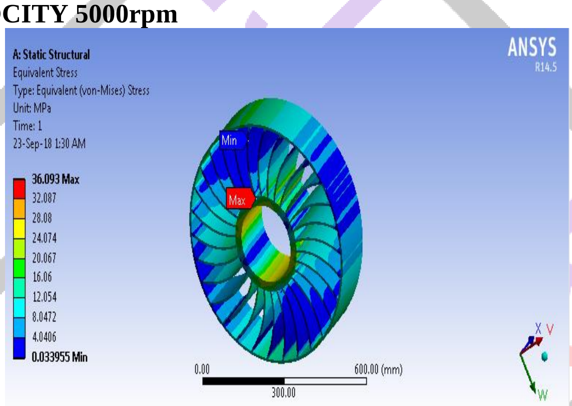


Shear stress of Curved spokes structure

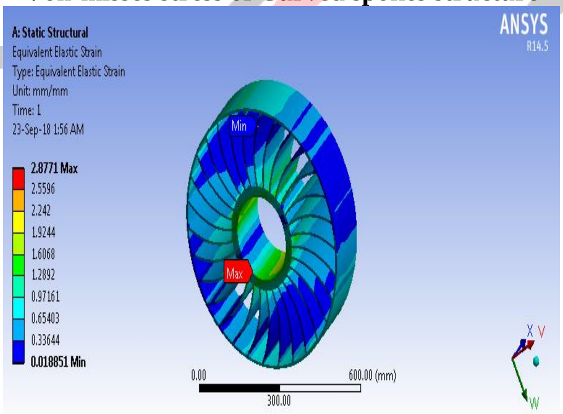


Total deformation of Curved spokes structure

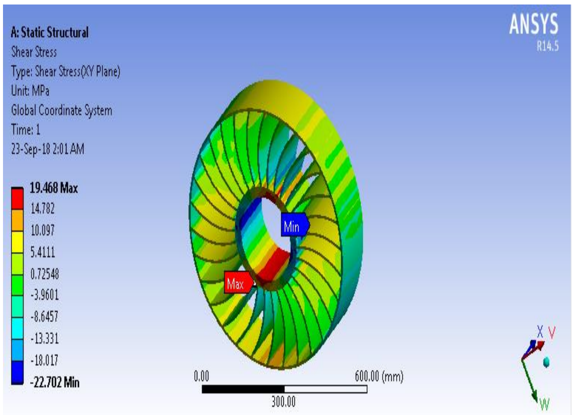
II.FORTHE ROTATIONAL VELOCITY 5000rpm



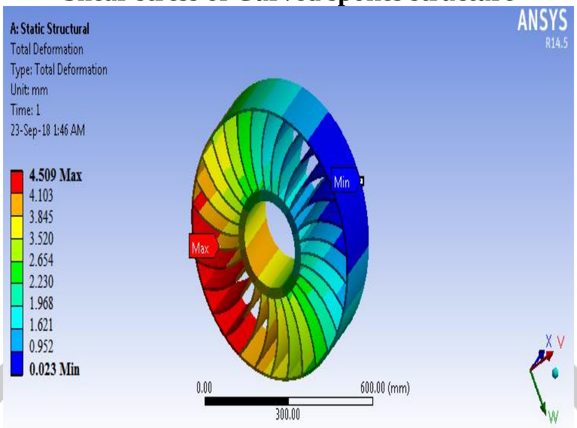
Von-misses stress of Curved spokes structure



Strain of Curved spokes structure



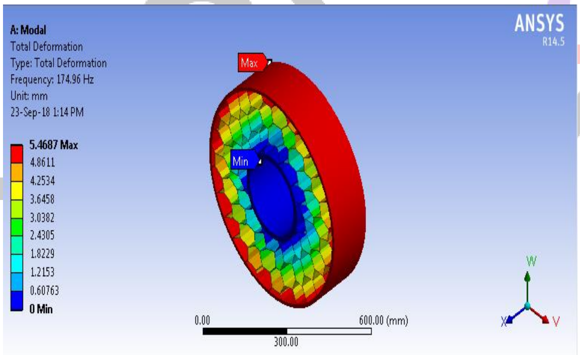
Shear stress of Curved spokes structure



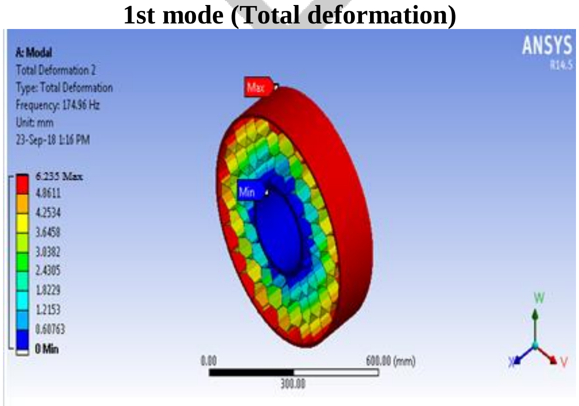
Total deformation of Curved spokes structure

E. MODAL ANALYSIS:

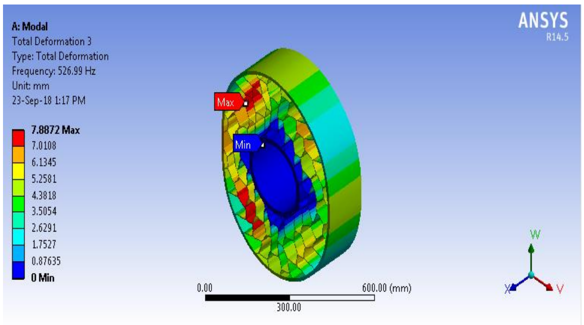
The modal analysis is carried out for honeycomb spokes structure at six different modes which led to the result of six different frequencies (total deformations) as shown below



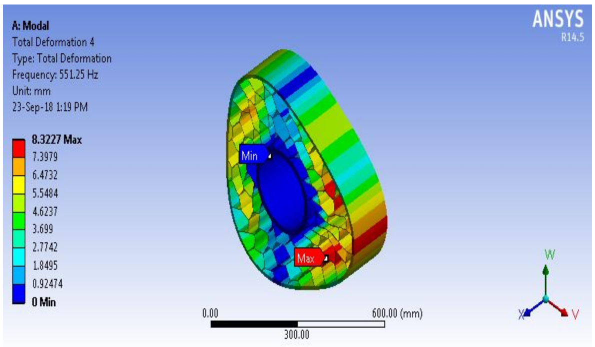
1st mode (Total deformation)



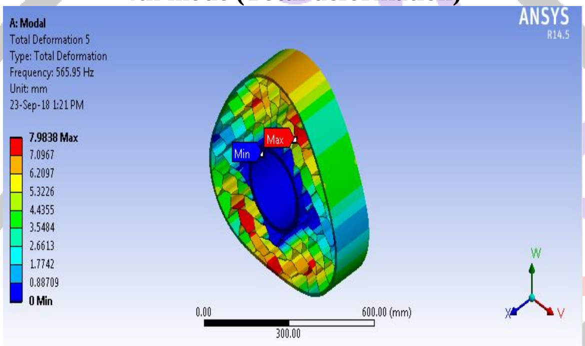
2nd mode (Total deformation)



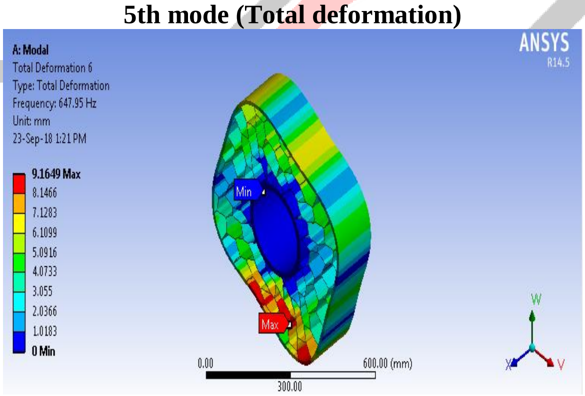
3rd mode (Total deformation)



4th mode (Total deformation)



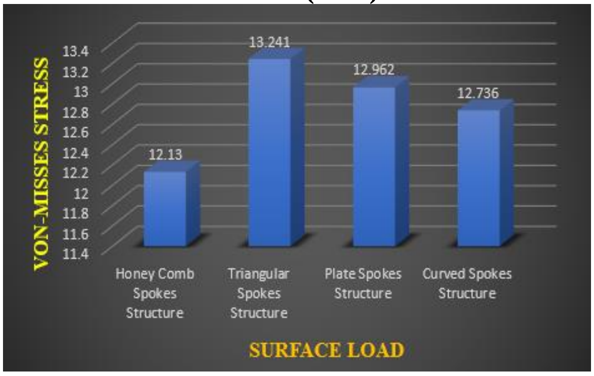
5th mode (Total deformation)



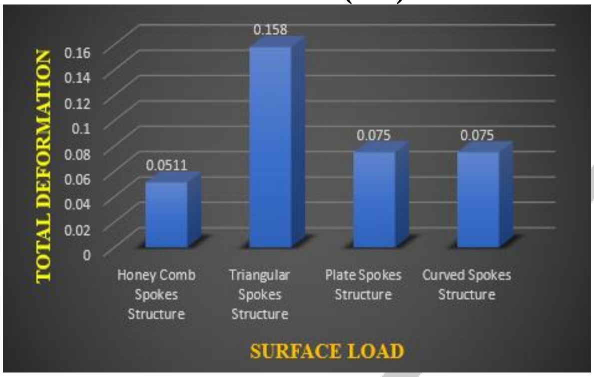
6th mode (Total deformation)

7. GRAPHS:

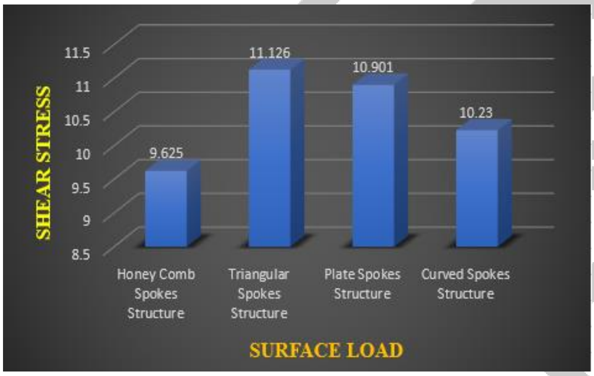
I. VON-MISSES STRESS (MPa) vs TOP SURFACE LOAD 3000N



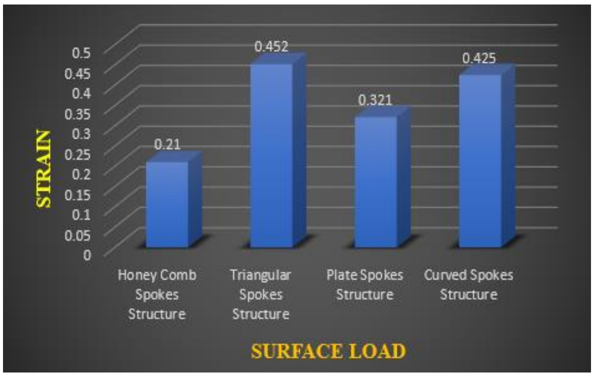
II.TOTAL DEFORMATION (mm) vs TOP SURFACE LOAD 3000N



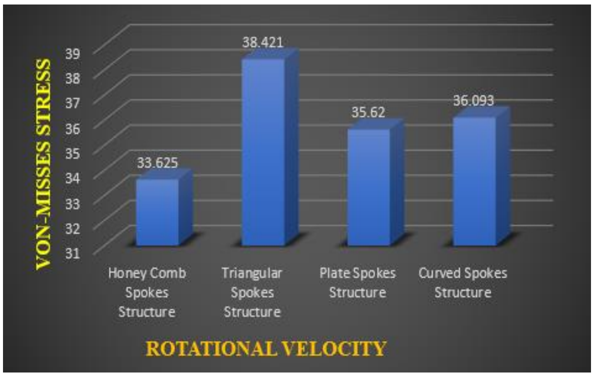
III.SHEAR STRESS vs TOP SURFACE LOAD 3000N



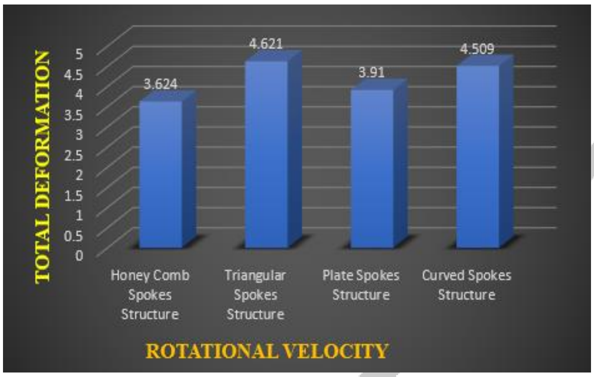
IV.STRAIN vs TOP SURFACE LOAD 3000N



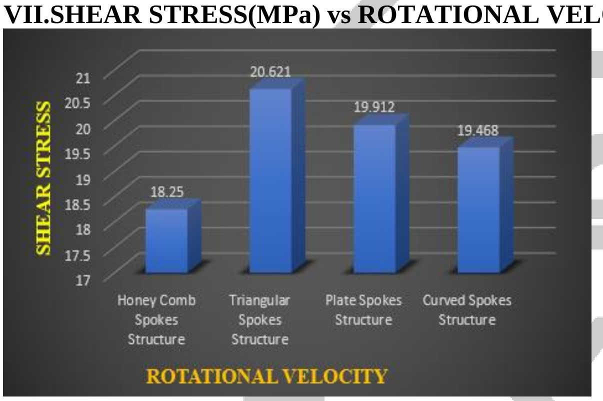
V. VON-MISSES STRESS (MPa) vs ROTATIONAL VELOCITY 5000rpm



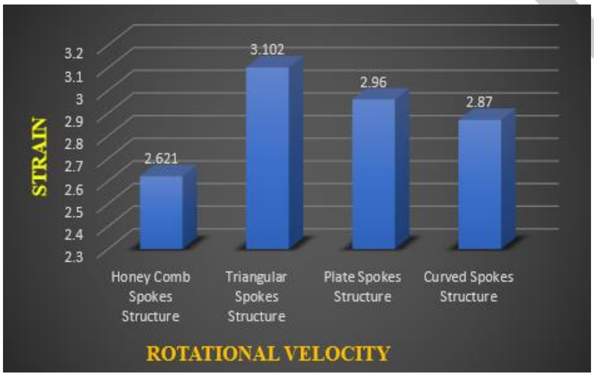
VI. TOTAL DEFORMATION (mm) vs ROTATIONAVELOCITY 5000rpm



VII.SHEAR STRESS(MPa) vs ROTATIONAL VELOCITY 5000rpm



VIII.STRAIN vs ROTATIONAL VELOCITY 5000rpm



IX. MODAL ANALYSIS TABLE:

MODE	FREQUENCY(Hz)
1	174.96
2	526.99
3	551.25
4	565.95
5	647.95
6	669.26

8. CONCLUSIONS:

1. From the design analysis, it was concluded that the Honeycomb spokes tyre structure was found out to be solid, and also bears more load comparative to the other structures.
2. Here honeycomb spokes design constitutes low stress values, strains and deformations than other designs because the honeycomb structure offers more space for the same material and closed cellular structural(hexagonal) which can sustain greater amount of force thereby exhibiting more compressive and shear strength.
3. Honeycomb spokes structure shows lower localized stresses and deformation values which is good for a fatigue resistant spoke design and thus the proposed work can bear a greater amount force and at the same time exhibits a comparatively small total deformation.
4. The NPT based on hexagonal honeycomb spokes can be used to replace a conventional pneumatic tyre since they provide uniform traction and wear as that of conventional tyre and also it offers good strength, fatigue life (endurance limit), reliability and reduces the overall weight and cost than the conventional pneumatic tyre.

REFERENCES

[1]. Mohammad Fazelpoue "A comparison of design approaches to meso-structure development". ASME journal paper DETC 2013-12295, 2013, doi: 10.115/ DETC 2013-12295.
[2]. A.M. Aboul-Yazid., "Effect of spokes structure on characteristics performance of non-Pneumatic tyres," ISSN: 2180-1606 Volume 11, pp. 2212-2223, January-June 2015.
[3]. Bert Bras., "Life-cycle environmental impact of Michelin tweel tyre for passenger vehicles" SAE International Journal 2011-01-0093, 2011, doi: 10.4271/2011-01-0093.
[4]. Pajtas, S., "Polyurethane non-pneumatic tyres technology-development and testing history," SAE Technical Paper 900763, 1990, doi: 10.4271/900763.
[5]. Jaehyung, Ju., "Optimization of Geometry and Material properties of a non-pneumatic tyre for reducing rolling resistance" Int. J. Vehicle Design, Vol. 66, No. 2, 2014.
[6]. Kim, K. and Kim, D., "Contact pressure of non-pneumatic tyres with hexagonal lattice spokes," SAE Technical Paper 2011-01-0099, 2011, doi: 10.4271/2011-01-0099.