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Flexible cellular solid spokes of a Non-Pneumatic Tyre

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Abstract: **As the name suggests Non-Pneumatic Tyres are the tyres that don't use air to support the load. The Non-Pneumatic Tyres use compliant cellular solid spokes which takes the load. The spokes can be of different shapes and sizes depending upon load carrying capacity and stiffness. One of the most widely used spoke structure is honeycomb structure. Using the honeycomb mechanics two cases of honeycombs are designed: (i) The same wall thickness and (ii) The same load carrying capacity. We conducted static analysis on different tyres by varying cell wall thickness and keeping cell angle, length and height same, and studied the effect of increasing cell wall thickness of Non-Pneumatic Tyre.**

The hexagonal structures are analysed on parameters like mass, von misses stress, contact pressure and deformation. The Non-Pneumatic Tyres undergo compression and tension while rolling, thus the material should have stiffness as well as resilience.

Keywords **— Tyres, Non-Pneumatic Tyre, Honeycomb, Hexagonal, Catia, Ansys.**

I. LITERATURE SURVEY

Jaehyung Ju et al [1], studied the effect of three types of hexagonal spoke designs by sorting the analysis into two categories, first with constant cell thickness and second with constant load bearing capacity. He investigated cellular spoke geometries with regular and auxetic honeycomb spokes using the compliant cellular design concept and found out the ratio of inclined cell length i.e. l, to overall height, is the key factor to determine flexibility of honeycombs under uniaxial loading.

Aravind Mohan et al [2], conducted structural analysis of honeycomb structures with same cell thickness and found out the spoke with larger cell angle shows least stress concentration which was desired property fatigue resistant designs.

Umesh G C et al [4], conducted static analysis and verified if the equivalent stress value was under permissible limit of material properties and stated that honeycomb tyres are better than tweel tyre because of its capacity to provide uniform traction and uniform wear similar to conventional tyre.

II. INTRODUCTION

When the concept of NPTs wasn't discovered the Pneumatic tyres were dominant in the market for all the operations. Pneumatic tyres had several advantages over the Pneumatic tyres, but they have several disadvantages as well: (i) burst out while driving, (ii) complex manufacturing process, (iii) need to maintain sufficient internal pressure of air. From the early 1920s the concept of Non-Pneumatic Tyres came into existence.

When the NPTs are put to the road, the spokes absorb road impacts the same way air pressure does in pneumatic tyres [3]. The disadvantages of the Pneumatic tyres were overcome by the NPTs. The NPTs have flexible polygon spokes and an elastomer having inner and outer rings. Since the NPTs undergo compression and tension, it is necessary to minimize localized stress at the contact while driving. Now a days, Vehicle manufacturers are concerned about overall weight of the vehicle, hence the NPTs play a significant role in reducing the weight of the vehicle. NPT play a vital role when the vehicle has to travel a rough terrain with maximum grip.

NPTs increase the fuel efficiency of the vehicle due do minimum contact pressure. Because the NPTs are made up of composite materials, their life is longer and also their wear and tear rate is slow. The composite materials used can be recycled and reused. We are conducting 2D analysis on contact pressure, deformation and von misses stress. Airless tyres can be made with different spoke tensions, allowing for different handling characteristics. However recently, there have been efforts to use lower in-plane stiffness for designing flexible honeycomb structures to be used in applications that require high deformation under targeted loads [1].

Some applications where more deformation is required are MEMS (micro-electro-mechanical-system), aircraft morphing structures. The different cell types that can be designed are squares, mixed squares, triangles, diamonds and some other polygons. Amongst these cell types, squares and hexagonal structures are the most used. Hexagonal structures are flexible in axial and shear loadings [1]. It is necessary to design materials that have both high stiffness and resilience. Finite Element Analysis (FEA) is used commonly to analyze and solve complex structural combining its linear and non-linear behaviour. In this study, a commercial FE code, ABAQUS is used for numerical experiment with NPTs having hexagonal honeycomb spokes. The honeycomb spokes are usually made of Polyurethane which adequately replace air-filled pneumatic tyres. Better compliant spokes results in more comfortable ride with improved and easy handling. Resilient Technologies and Wisconsin-Madison's is a company specializing in Polymer Engineering and design are creating a Non-Pneumatic tyre which is a round polymeric honeycomb wrapped with thick, black tread and that will support heavy weight, survive IED attack and the tyres can run up to a speed of 75 mph for 60 miles with only 10% damage to the honeycomb structure.

III. PROBLEM DEFINITION

Considering the fact that NPTs undergo tension and compression, it is of prime importance to make the spokes fatigue resistant. In this project we designed NPT based on hexagonal honeycomb spokes. The hexagonal structure is an array of hollow cells formed between thin vertical walls. Triangular, Kagome, and diamond cell honeycombs are good for high modulus structural designs [3]. Square and hexagonal cell honeycombs are known to be good for flexible structural designs. Hexagonal cell structures are to be flexible in both axial and shear loading also, hexagonal honeycombs can easily be tailored to have targeted in-plane.

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 high modulus, it shows a low elastic strain limit, and vice versa.

The different types of NPT geometry are created using CATIA and AUTOCAD. The analysis is done by modelling the structure into thousands of small pieces. In this study, ANSYS Workbench is used for a numerical experiment with NPTs having hexagonal honeycomb spokes.

IV. CONSTITUENT MATERIALS OF NPT

The Non-Pneumatic tyre consists of following parts namely, A Hub, honeycomb spokes, outer ring and Thread. The Honeycomb spokes is the main part or component of NPT, which actually replaces the pneumatic tyres. The honeycomb spokes should have stiffness as well as resilience under cyclic compression and tension loading. The function of outer ring is to enforce the thread rubber to be deformed by shear. The thread is a component which serves necessary traction between the road surface and the vehicle tyres.

Fig -1: Hub

The Hub should provide Rigidity to the tyre. Aluminium Alloy, AL 7075-T6 is selected as the hub material. Zinc is the main alloying element used in Aluminium Alloy. It is strong and its fatigue strength is good enough to be compared with steels but its cost is high. The composition of aluminum alloy 7075 roughly includes 5.6-6% zinc, 2-2.5% magnesium, 1-1.5% copper, and some minor composition of silicon, iron, manganese, chromium and other metals. The T6 temper 7075 has following properties: density, ρ = 2800 kg/m³, Modulus, E = 72Gpa, and Poisson's ratio, ν= 0.33, Yield Strength = 500MPa. Thickness of hub is kept 1.5 mm.

Fig. 2- Honeycomb Spokes

Honeycomb Spokes are made up of Polyurethane material. Polyurethane offers elasticity as well as toughness. It has got desired properties like good stiffness and resilience. The properties of Polyurethane are: Density, ρ = 1200 kg/m³, Young's Modulus, E = 32 MPa, shear modulus, G = 10.81 MPa and poison's ratio ν = 0.49 and Yield Strength = 140 MPa.

Fig. 3: Outer Ring

The Outer Ring is made up of high strength steel, AISI 4340. This makes the Thread rubber to be deformed by shearing. It the outer ring wasn't there, the edges of spokes during contact with the ground would buckle and cause non-linear undesirable effects of the honeycomb. The Properties if high strength steel is: density, ρ = 7800 kg/m^3, Modulus, E = 210Gpa, and Poisson's ratio, ν= 0.29, Yield Strength = 470MPa. The thickness of outer ring is kept 1 mm.

Fig. 4: Thread

Thread is made of Synthetic rubber material. It helps to provide necessary traction between the road surface and the tyre. The thread should most importantly provide good grip on the road surface during all terrains. Synthetic polymer is a polymer, synthesized from petroleum by products. The properties of Synthetic rubber are: Density, ρ = 1043 kg/m^3, Young's Modulus, E = 11.9 MPa, shear modulus, G = 4 MPa and poison's ratio ν = 0.49 and Yield Strength = 16 MPa. The thickness of Thread is taken to be 15 mm.

Part	**Hub**	**Spokes**	**Outer Ring**	**Thread**
Material	AL 7075-T6	Polyurethane	AISI 4340	Rubber
Density (kg/m^3)	2800	1200	7800	1043
Young's Modulus (MPa)	72000	32	210000	11.9
Poisson's Ratio	0.33	0.49	0.29	0.49
Yield Strength (MPa)	500	140	470	16

Table 1: Properties of Constituents Parts of NPT

V. MODELING OF DIFFERENT TYPES OF NPT

The design of honeycomb spokes affect the stiffness and resilience of the NPT. The dimensions of the other components of the NPT were kept constant and all the dimensions of the honeycomb spokes were varied to create different designs. The models of NPT's are created in CATIA.

Fig. 5: Hexagonal Notations

The honeycomb cells are designed with the cell wall thickness, t, verticals cell length, h, the inclined cell length, l, and cell angle, θ. Here we are considering six different types of Hexagonal cells.

NPT Type	**l (mm)**	**h (mm)**	**Θ (degree)**	**t (mm)**
Type A	26.25	36.66	15.76	3.2
Type B	29.65	28.52	31.50	3.8
Type C	37.21	16.74	47.14	4.2
Type A1	26.25	36.66	15.76	5
Type B1	29.65	28.52	31.50	6.30
Type C1	37.21	16.74	47.14	7.55

Table 2: Dimensions of Hexagonal Spokes

The Table 2 shows the dimensions of all six types of hexagonal cells which are modeled. We have considered only regular honeycombs with positive poisons ratio. The ones with negative honeycombs are called as auxetic honeycombs. These have more stiffness in the lateral direction under loading as compared to regular honeycombs. The cell angle, θ is of great importance because as cell angle increases the flexibility of the honeycomb structure increases.

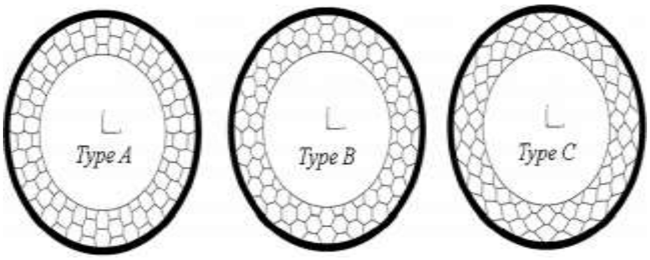

Fig. 6: Honeycomb Design in CATIA

Figure 6 shows the suggested types of designs in CATIA. The 3D modeling involves various steps like sketching, extruding, padding, etc.

VI. FINITE ELEMENT ANALYSIS

The models that are created in the CATIA are imported to ANSYS WORKBENCH. In order to perform static analysis, the material properties were assigned to each element of the NPT. Then the bonding operation is carried out, it is used to specify bonds between all the components of the NPT. The Thread and the outer ring, the outer ring and the spokes, the spokes and the aluminium hub all these components were assigned a bonded constraint. Also we assigned fixed bond between the road surface ant the tyre. The road surface is made up of concrete so as to provide maximum rigidity. The movement of NPT is arrested in all the direction except the vertical direction. All the parts of the NPT are properly meshed. Coarse type meshing is used for meshing since all the components are symmetrical. The number of nodes in NPT formed are around 38000. The load was applied at the hub centre. We applied a load of

4000N at the hub centre.

Type A

The mass of tyre A after assigning material properties is 53.924 KG. Due to coarse meshing type the nodes generated were 36240 and elements 9784. A load of 4000N was applied at centre of tyre. The maximum deformation for this load is 3.1401 mm and local stress on the tyre is 57.766 MPa also the contact pressure at the contact between road surface and tyre is 21.394 MPa. The maximum equivalent stress thus obtained permissible limits and hence the design was safe.

The cell angle in this case was minimum as compared to other tyres also the thickness was the least. We have designed tyres for constant bearing capacity.

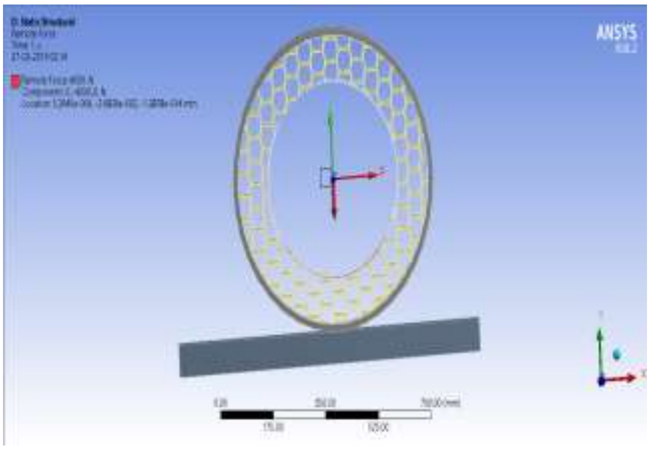

Fig 7: Force of 4000N applied at the centre

When the vehicle is at static condition the load gets distributed to all the tyres depending upon its Centre of Gravity. Thus considering ideal condition and load acting on each tyre to be 4000 N, the load will tend to act from centre of hub and will deform the tyre in vertical direction.

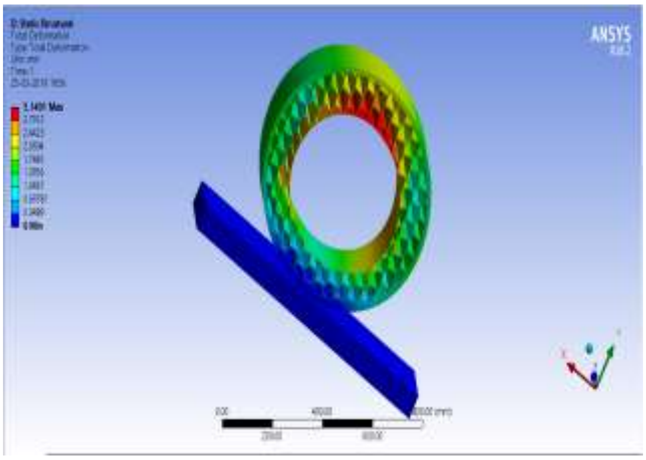

Fig 8: Deformation of an NPT with Type A honeycomb spokes

From Figure 8 it can be clearly seen that the deformation is more prominent in the upper part of the tyre and is shown with red colour. During deformation the lower part of the tyre will be under compression and the upper part will be under tension. Thus how the tyres behave under tension and compression can be seen here.

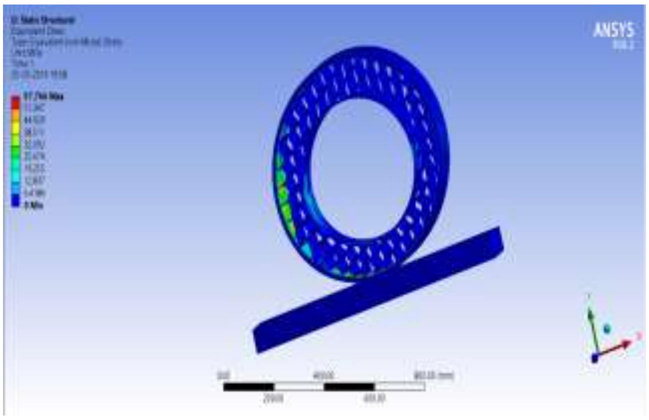

Fig 9: Distribution of Equivalent stress on Type A tyre

.We can see from Figure 9 that the stress is equally distributed throughout the tyre except for the inner part of outer ring, the stresses is comparatively more.

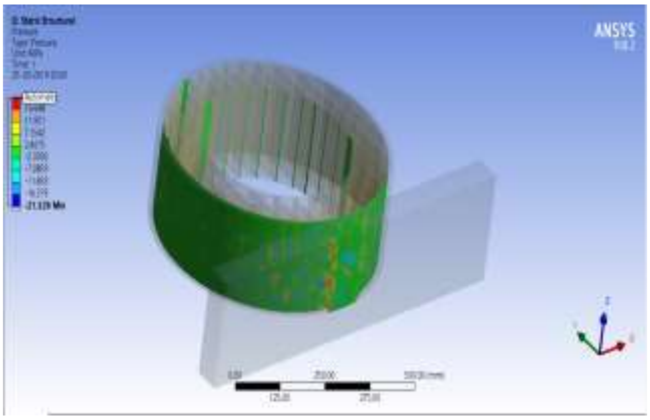

Fig 10: Contact Pressure analysis of Type A tyre

Tyre	Mass (kg)	Maximum Deformation (mm)	Von mises stress (Mpa)	Maximum Contact Pressure
Type A	53.924	3.1401	57.66	21.394
Type B	54.786	3.6349	63.403	23.233
Type C	55.571	3.9758	68.504	27.989
Type A1	56.686	2.5386	56.312	23.557
Type B1	58.498	2.6088	59.811	24.734
Type C1	60.514	2.5145	60.499	25.34

Table 3: Summarized Results

VII. RESULTS AND DISCUSSION

A static structural analysis of NPTs with hexagonal honeycomb structures having different cell angles and cell thickness has been performed. While the vertical displacement is applied at the centre of the hub, the horizontal displacement of bottom centre on thread is set as zero so that deformed geometry can be maintained. All the degrees of freedom of a line of contact at bottom of thread is set to zero. The desired properties of the Non-Pneumatic Tyres are: less deformation, sufficient traction, high fatigue resistance, low contact pressure and localized stresses should be minimum, also the tyre must be able to minimize the local stresses under cyclic compression and tension loading i.e. under working condition.

Table 3 shows the result of structural analysis carried out on six types of Non-Pneumatic Tyres (According to table 2).

When types A, B and C are compared the Von-Mises stress of Type A is less, so Type A tyre is more fatigue resistant. The Von-Mises stress in A is 57.66 Mpa and in C is 68.504 Mpa. Also deformation in A is less than that in B and C with a deformation of 3.1401 mm. The weight of Type A tyre is lesser than all other tyres which helps in reduction of total weight of the vehicle.

When all the types of tyres are compared Tyre C1 showed least deformation which is advantageous during working condition of the tyres. The deformation at 4000 N in type C is found to be 2.5145 mm. The Von-Mises stress in Type C is less than Type B and Type C and when compared to other tyres it is not very high. The lower stress in Type C1 is due to higher cell angle which results in increased flexibility. The Type C1 is found to have more weight than all other tyres.

When comparing the tyres A and A1, after increasing the cell wall thickness maximum deformation has reduced from 3.1401 mm to 2.5386 mm and the Von-Mises stresses are also reduced from 57.66 Mpa to 56.312 Mpa. Thus contributing to more stiffness and resilience with minimum local stresses.

Similarly in Type B and B1, the maximum deformation is decreased from 3.6349 mm to 2.6088 mm and the Von-Mises stresses are reduced from 63.403 Mpa to 59.811 Mpa. Hence with negligible increase in weight of the tyres we are getting better characteristics of the tyres.

And finally comparing Type C and C1, same as the above two results, the deformation is reduced from 3.9758 mm to 2.5145 mm which is least deformation obtained, and the Von-Mises stress is decreased from 68.504 Mpa to 60.499 MPa.

Thus we can say that with increase in cell wall thickness the deformation is decreasing and also minimizing local stresses acting on the tyre.

VIII. CONCLUSION

In this project different cellular hexagonal structure geometries were studied with regular honeycomb spokes. Non-Pneumatic tyres are the tyres that are not supported by air pressure and are prominent in overcoming the disadvantages of the Pneumatic tyres.

The desired properties of the NPTs were studied and according to the desired properties the constituent material were decided. Six different types of cellular structures (hexagonal honeycomb cells) were modeled and their static structural analysis was conducted. The Total mass of the models were found out from CATIA by assigning all the materials to respective part and it was found that Type C1 have 11.26 % higher mass than that of Type A. The increase in mass was basically due to increase in cell wall thickness of Type C1 model.

The main conclusion of the analysis is the hexagonal structure with increase in cell wall thickness the deformation and local stresses are reduced. .

Type C1 has lower local stresses than type C.

REFERENCES

[1] Jaehyung Ju, Doo Man Kim, Kwangwon Kim 2012 “Flexible cellular solid spokes of a non-pneumatic Tire.”

[2] Aravind Mohan, 2017, “Design and analysis of non-pneumatic tyre”.

[3] Vinay T V, Kuriakose J Marattukalam, Sachu Zachariah Varghese, Shibin Samuel, Sooraj Sreekumar, 2015, “Modeling and Analysis of Non-Pneumatic Tyres with Hexagonal Honeycomb spokes”.

[4] Umesh G C, Amith Kumar SN, 2016, “Design and Analysis of Non-Pneumatic Tyres(NPT) With Honeycomb Spokes Structure”.

[5] N.Korunović, M.Trajanović, M.Stojković, 2014, “FEA of tyres subjected to static loading”.

[6] Kwangwon Kim and Doo Man Kim, 2011, “Contact Pressure of Non-Pneumatic Tires with Hexagonal Lattice Spokes”.

[7] Yinghao Ning, Ruochen Niu, Shuai Wang, Bing Li, 2016, “A New Kind of Non-Pneumatic Tire for Attenuating Vibration”.