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Non Pneumatic Tyre design with Honeycomb spoke structure

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Abstract

Every person now a day's use vehicles for transport like bicycle, cars, buses etc. the most important part of these vehicles are tyre. Many years ago people use the vehicle wheels made up of wood or stones for travelling. After improvement it was developed into tube and tube less tyre. These tyres are tested and applied on various vehicles but there were some problems in terms of puncture. Tyre with tube gets quickly puncher while tube less tyre takes some time for air leakage. To overcome the puncture issue, in recent years a number of companies are working on making airless tyre.

Non pneumatic tyre (NPT) is a type of tyre that does not support compressed air i.e. they are airless. The NPT composed of mainly three parts- a rigid hub, deformable spokes (made of polyurethane honeycomb structure) that supports load, reinforced shear band and treat made of rubber which comes in contact with surface. The most popular design in this field is a combination of wheel and tyre i.e. Michelin Tweel.

***Keywords**: Honeycomb structure, Michelin Tweel, Non Pneumatic Tyre, Pneumatic Tyre*

I. INTRODUCTION

A tyre is one of the essential parts of any vehicle. Tyre is made with rubber member who provides cushioning effect as well as provides clearance to vehicle. The rubber member is attached over the wheel rim. In tube tyre, tube is fitted inside the tyre while in tubeless tyre there is no tube inside. A tire is a circular shaped component which is mounted on a wheel's rim to transfer the vehicle's load from the axle. Tyre which is used in automobile, bicycle, motorcycle, car etc is pneumatically inflated structures which provide a good rolling, cushioning effect. Such tyres are in use from numbers of year and they are developing. Some companies are trying to develop airless tyre that means they are non pneumatic. Michelin and Bridgestone is the tyre making companies which design the non pneumatic tyre. Honeycomb structure tyres are also a type of non pneumatic tyre.

II. POLYURETHANE MANUFACTURING

The manufacturing process associate with the reaction of pre polymer with a curative. The pre polymer composed of two parts, Polyols and Diisocyanate. The Polyols are mainly Polyesters or Polyethers and the Diisocyanate are Toluene Diisocyanate or Methylene Diphenyl Diisocyanate. The Polyols and Diisocyanateis undergoes an exothermic reaction. In molten state the temperate of pre polymer will be about 60 degree Celsius.

The reaction of this pre polymer with a curative (butadiene) at 40 degree Celsius will form the polyurethane. The solidification of this polyurethane will occur at 100 degree Celsius in about 4 hours. A block diagram of polyurethane formation is shown below.

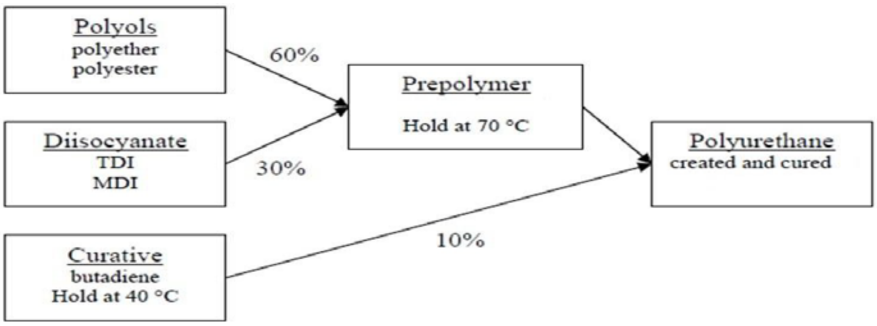

Fig.1 Polyurethane Manufacturing Block Diagram

III. FABRICATION OF NON PNEUMATIC TYRE

Non-Pneumatic tyres involve three steps: tread and shear band making, hub making, and assembling the parts with polyurethane spokes. In the first step, the tread is manufacture by a similar method as the tyre tread manufacturing process. The tread on a Non- Pneumatic tyre is similar as a pneumatic tyre and is manufactured in the same way. It is then mated to layers of belts in the same manner as conventional tyres. The process of rolling plies onto a drum to achieve the correct diameter currently is performed manually, but the same basic process that is performed on tyres will be mimicked when the non-pneumatic tyre production is fully automated. In this process, rectangular sheets of rubber and steel cord are rolled onto a steel drum, and the excess material from each sheet is detached. Once the desired base thickness is achieved, the extruded tread is rolled onto the top, and the entire assembly is vulcanized.

Second step involves the manufacturing of the 4 kg steel hub casting or the aluminum alloy casting similar to ordinary casting process where the molten metal is poured into the mold and solidified.

In the third step, the hub and the tread are arranged concentrically and polyurethane is filled into a spoke and shear band mold while the entire assembly rotate so that the polyurethane will sufficiently fill the mold in the radial direction. The energy needed to rorate the non-pneumatic tyre assembly and polyurethane mold for just 5 minutes while the polyurethane filled is considered irrelevant compared to the large amount of energy required to heat and pressurize the ovens needed to cure the shear band and then cure the entire assembly after the polyurethane is filled. Before the filling process occurs though, all the surfaces that contact the polyurethane are cleaned and covered with either an adhesive or a mold release for the shear band and spoke mold, respectively. The adhesives used are Ethyl acetate, Chemlok 7710, Stoner M-804 etc. The polyurethane pre-polymers and curative are stored separately until they are heated and combined at this point in the manufacturing process. The combination of the heated pre polymers and curative could be considered in this Tweel manufacturing section, but in order to organize the impacts of the raw materials it is treated as part of the raw material production of polyurethane.

After the polyurethane is filled and the assembly is allowed to stop rotating, the entire Tweel tire (shear band, spokes, and hub) is placed into another oven. This final curing occurs at 100°C degrees for 4 hours so that the desired polyurethane properties are obtained and to assure all the components are securely bonded together. To save some energy this curing process could take place at room temperature, but it would take much time to complete and during this time it would be susceptible to being bumped and permanently damaged. The properties of the materials used for making non-pneumatic tyres are given in table 1. For rubber curing presses the energy inputs have been recorded and analyzed by tire manufacturers, and the average tire curing process requires about 1.1 kWh of energy for a tire weighing 10 kg, which means roughly 0.11 kWh of energy is needed to vulcanize 1 kg of rubber. Michelin, at the early stages of Tweel manufacturing used the same type of press that is used to cure radial tires, so it is assumed in this analysis that the same energy will be required to cure 1 kg of rubber in a Tweel tire as 1 kg of pneumatic tire rubber. The thickness of rubber in these two products varies slightly, but the curing temperature and time is close enough to assume the same energy requirements per kg of rubber. So, the required energy to cure the shear band in the Tweel is roughly (6.35 kg)*(0.11 kWh/kg), which equals 0.7 kWh. The energy required to heat, mix, and cure the polyurethane is allocated to the raw material production of polyurethane, so this 0.7 kWh is all the energy that is needed in the Tweel manufacturing inventory.

Table 1: Material properties of non-pneumatic tyre

Part	Hub	Spokes	Outer Ring	Thread
Material	AL 7075-T6	Polyurethane	AISI 4340	Rubber
Density P,kg/m3	2800	1200	7800	1043
Youngs Modulus E (MPa)	72000	32	210000	11.9
Poisons Ratio,υ	0.33	0.49	0.29	0.49
Yield Strength (MPa)	500	140	470	16

Table 2: NPT material composition in weight percentage

Raw material	Carcass wt %	Tread wt %	Spokes wt %	Hub wt%	Total kg
Synthetic rubber	0	41	0	0	1.15
Natural rubber	0	4	0	0	0.10
Carbon Black	0	10	0	0	0.26
Silica	0	28	0	0	0.77
Sulphur	0	1	0	0	0.02
ZnO	0	1	0	0	0.03
Oil	0	11	0	0	0.29
Stearic Acid	0	1	0	0	0.04
Recycled rubber	0	0	0	0	0
Coated wires	10	0	0	0	0.62
Textile	0	0	0	0	0
Polyurethane	90	0	100	0	8.44
Steel	0	0	0	100	4.00
Totals %	**100.0**	**100**	**100**	**100**	
Weight (kg)	**6.35**	**2.75**	**2.65**	**4**	**15.75**

IV. DESIGN ANALYSIS OF HONEYCOMB SPOKES

SUGGESTED HONEYCOMB DESIGNS

Using the beam theory earlier honeycomb engineers developed an Effective in-plane modulus of hexagonal honeycombs and these developments are collectively called cellular materials theory. The suggested honeycomb designs of the non-pneumatic tires are given below.

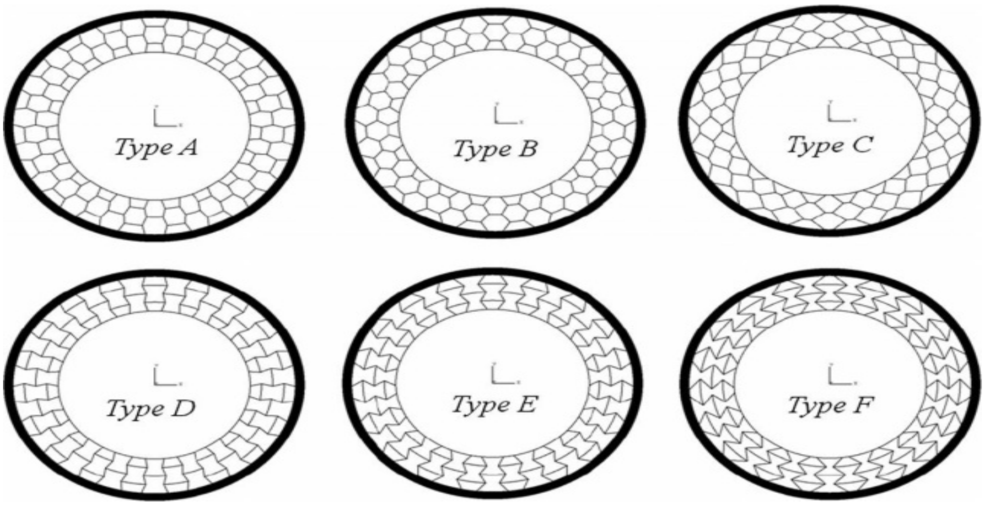

Fig. 2 suggested Honeycomb Designs

Here six types of honeycomb spokes are considered for NPTs as shown in above fig. Both regular honeycombs as well as auxetic honeycombs having a negative effective Poisson's ratio are used for the cellular spoke design. The type A B C are the regular honeycomb structures and type D E F are the auxetic honeycomb structures. These six cellular spoke designs are applied for a magnitude of vertical displacement of 20mm for each type of tyre and from this the force displacement graphs are analyzed.

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V. FORCE DISPLACEMENT CURVES AND DEFORMED SHAPES OF DESIGNS

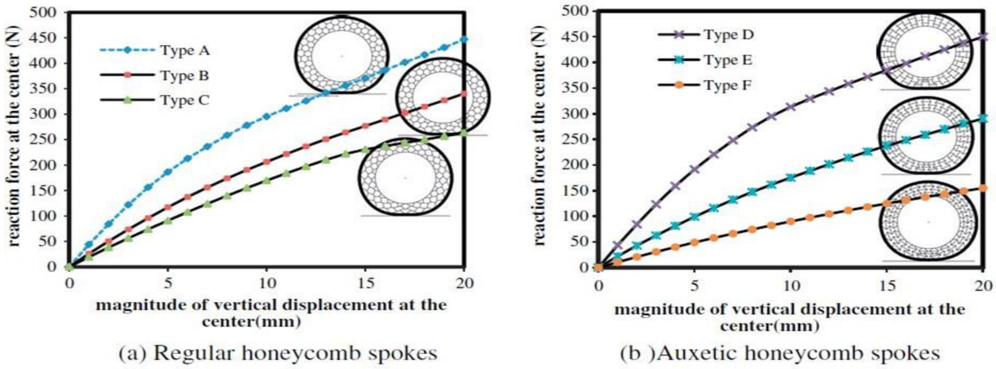

Fig. 3 Force-displacement curves with cell wall thickness is 5mm and tire width of 100mm

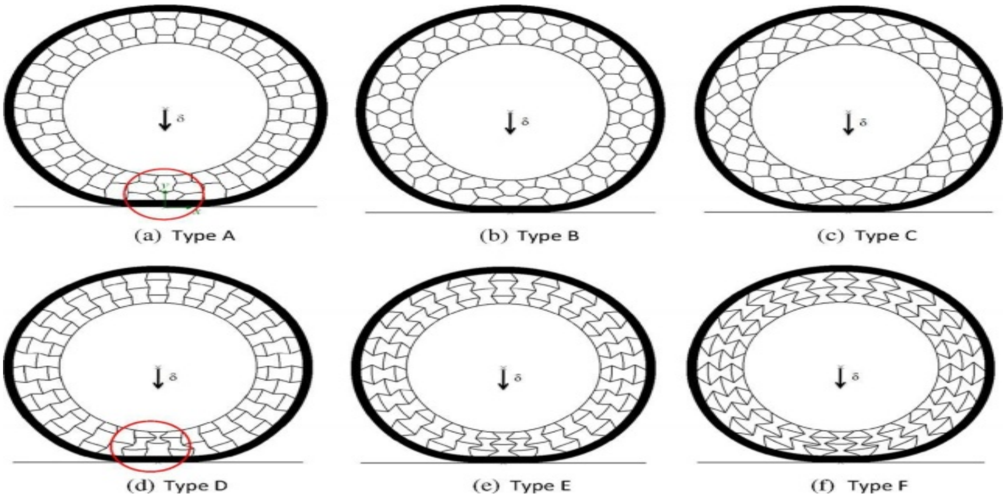

Fig. 4 Deformed shapes of NPTs under a vertical displacement, 10mm at the center.

The honeycomb spokes with a high cell angle magnitude experience low local stresses, which is satisfactory for the fatigue resistant spoke design. The types C and F honeycomb spokes are good for fatigue resistance. In terms of lower mass design, the Type C spokes are thought to be good among the honeycomb spokes investigated.

Fig. shows the total mass of NPTs with the honeycomb spokes when the lateral width is set to be 100 mm.

The local stresses in the honeycomb spokes are checked when the NPTs are designed to have the same load carrying capability. Due to the nonlinear load carrying behavior as a function of vertical displacement, loading at a certain vertical displacement can be used as a reference value. The effective force–deflection curve shows the nonlinear behavior associated with combined nonlinear effects of materials and geometries; primarily

(i) hyper elastic material behavior, and (ii) large deflection and buckling of cell walls of honeycomb spokes, respectively.

Force–deflection curves of NPTs with the honeycomb spokes having negative cell angles and their deformation are checked. The force–deflection curve of an NPT with the Type D honeycomb spokes whose cell wall thickness is 4.85 mm associated with the reference load carrying capability design. A similar macroscopic force–deflection behavior as an NPT with the Type A spokes is noticed due to the similar effective modulus between the Type A and the Type D spokes in the radial and the circumferential directions. The maximum local stress levels of the Type D spokes and Type A spokes are almost same. Large cell deformation of the Type D honeycomb spokes is also observed as it was in the Type A spokes which might be caused by the low cell wall thickness design which leads to easy deformation of cell walls including buckling.

A lower geometric nonlinear effect is observed with the Type E spokes having a cell wall thickness of 6.74 mm. The corresponding maximum von Misses stresses are 2.3 MPa and 4.7 MPa at the global central displacements of 10 and 20 mm respectively which are lower than those with the Type D spokes. The auxetic honeycomb spokes require more mass to meet the reference load carrying capacity, for example the Type D and the Type E spokes have about 15% and 80% increased mass. Total mass of NPTs with the honeycomb spokes for a lateral width of 100 mm.

The Type F spokes have a higher thickness, resulting in an increase in mass to meet the reference load carrying capacity; about 23.5% mass increase compared to the Type A spokes. The global force– deflection curve of an NPT with the Type F spokes having a thickness of 10.2mm. A geometric nonlinear effect is rarely observed compared to the former honeycomb spokes. This leads the spokes to have the lower local stress values, which is good for fatigue resistant honeycomb spokes.

VI. RESULT

In result, NPT with the Type F spokes has the highest mass, which is not acceptable for light weight design. The mass of NPT with the Type C spokes is 18% higher than that of Type A. To design a tire for both low mass and high fatigue resistant honeycomb spokes, high modulus elastomer as a base material with the Type C spokes is preferable when designed to acquire the same load carrying capacity.

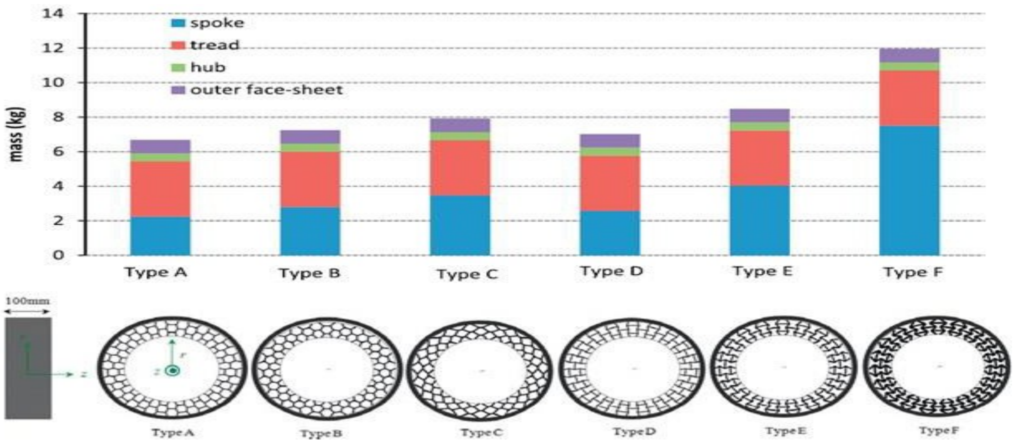

Fig. 5 Total mass of NPT with honeycomb spokes with lateral width of 100mm

VII. COMPARISION BETWEEN PNEUMATIC AND NON PNEUMATIC TYRE

Sr. No	Parameter	Pneumatic Tyre	Non Pneumatic Tyre
1	Life	Life of tyre is less	Life of tyre is long as it was made of polymer
2	Efficiency	More efficiency about 80%	Less efficiency about 40%
3	Cost	cheaper	High costlier
4	Air used	Air is essential factor	No use of air
5	Air Valve attachment	Valve is attached	No need of attached
6	Puncture	Occurred	No puncture occurred

VIII. DISCUSSION

A structural application of the flexible in-plane properties of hexagonal honeycombs was suggested – the honeycomb spokes of an NPT to replace the air of a pneumatic tire. Cellular spoke geometries for an NPT were checked with regular and auxetic honeycomb spokes using the compliant cellular design concept.

IX. CONCLUSION

Tyres are most essential part of any automotive vehicle. Tyre may seem to be a unchanged part of automobile that cannot be improved, but research into airless tyre can gives more efficiency as well as more rolling effect. This new technology will increase the safety of automobile as well as have a positive impact environmentally. The cost of this tyre is high because this tyre is made up of high quality polymer, so it cannot be affordable to lower income people. But research into it can make it cheaper than pneumatic tyre. This innovative project is guided by engineering codes of ethics which will ensure that the development is conducted in a responsible and fair way. This type of innovation will become more valuable in the future because of its advantages and this tyre has a wide range of applications in which it can be used. So non pneumatic tyre is more valuable and has more scope in future. Thus it concludes that non pneumatic tyre is more useful and profitable in future than pneumatic.

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