STATIC ANALYSIS OF AIRLESS TYRES

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***Abstract* -** Airless tyres or Non-pneumatic tyres is introduced with a replacement of poly- composite materials in place of air in a definite structure. The construction and material study of these tyres is done by comparing it with pneumatic tyres. A brief structural study on spokes of airless tyres is done and is related with rolling resistance and fuel efficiency.

I. INTRODUCTION

The first pneumatic tyres for bicycle by Dunlop have been dominant since 1888. Its market was stable due to the following four advantages over rigid wheel: (I) low energy loss on rough surfaces, (II) low vertical stiffness, (III) low contact pressure and (IV) low mass. But as study says they do have four compensating disadvantages: (I) the possibility of catastrophic damage – flat while driving, (II) the required maintenance for proper internal air pressure, (III) the complicated manufacturing process.**[1]** In the next stage of development wire spokes in the tyre material were added to increase the resilience property. Engineers, in the aspect of overcoming the disadvantages of pneumatic tyres, invented non-pneumatic tyres by replacing air column with elastomers or polygon flexible spokes.

Airless tyres are similar to pneumatic tyres in that they carry significant loads at large deformations but are quite different in that they carry these loads without the benefit of inflation pressure. Whereas all pneumatic tyres of a given size, inflated to a particular pressure, will have nearly identical vertical stiffness and ground contact pressure, an airless tyre has it's stiffness and contact pressure governed by a host of geometric and material parameters.

II. CONSTRUCTION AND MATERIAL PROPERTIES OF AIRLESS TYRES

An important significance in its construction is the combination of tire and wheel. It consists of a metal hub, polyurethane fins and an outer ring as shown in the *fig1*. The design allows the tire to deflect under pressure similar to pneumatic tires. For a terrain with rough surface and uneven lane demands such kinds of design with high traction. It's flexible spokes bends and performs as a cushion; its property of regaining the shape is mainly because of polyurethane material. **[2]** The airless tires promises 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 be punctured.

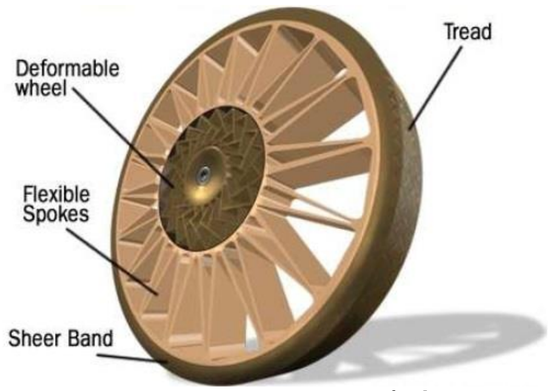

FIG.1 Part components of airless tyre

MATERIAL AND WEIGHT DISTRIBUTION

Raw	Shear band	Tread	Spokes	Hub	Total weight
Raw material	Wt %	Wt %	Wt %	Wt %	Wt %
Synthetic rubber	0	41	0	0	1.15
Natural rubber	0	4	0	0	.10
Carbon black	0	10	0	0	.26
Silica	0	28	0	0	.77
Sulfur	0	1	0	0	.02
Zno	0	1	0	0	.03
Oil	0	11	0	0	.29
Stearic acid	0	1	0	0	.04
Recycled rubber	0	0	0	0	0
Coated wires	10	0	0	0	.62
Textile	0	0	0	0	0
Polyeurathane	90	0	100	0	8.44
Steel	0	0	0	100	4.0
Total%	**100**	**100**	**100**	**100**	
Weight	**6.35**	**2.75**	**2.65**	**4**	**15.75**

TABLE.1:- Material weight distribution

III. POLYURETHANE

Several types of polyurethane exist today from solid elastomers to flexible foam for car seats. Only minimal data are available in Sima Pro's databases, but as the manufacturing processes can vary greatly between different types of polyurethane, it is important to analyze the specific production process used by manufacturers instead of finding data from other sources. Polyurethane makes up the spokes and the majority of the shear band in an airless tyre, and Michelin's process of molding this product is different from other major polyurethane producers. **[3]**

A. Cushioning

The cushioning ability of a tire is directly related to its durometer or hardness. The higher the durometer number, the harder the tire. Rubber tires will typically be in the range of 67-75 durometer
while polyurethane tires will fall between 83 and 95 durometer. Simply put, the softer the tire, the more impact it can absorb. Since polyurethane is typically harder, it is known for giving a rougher ride to the lift truck operator than rubber. Rubber is about 15 durometer points softer than the softest polyurethane compound. If a soft ride is important to a lift truck operator, then a rubber tire can be used efficiently and effectively. Polyurethane tires are not widely available in compounds softer than 83 durometer. Softer polyurethane quickly loose their overall toughness and load capacity. As loads have increased over the years polyurethane manufactures have developed compounds as hard as 95 durometer to increase performance. While these compounds can carry significantly more load, they offer little in the way of cushion to the operator. Many times the maintenance manager is faced with the difficult decision to sacrifice operator comfort for increased productivity that can be attained with the higher durometer polyurethane tire. Summarizing, 95 durometer polyurethane tire will offer about 15% additional load capacity than an 83 durometer. The additional load capacity may not sound like much, however it can mean getting the tonnage through a warehouse without the downtime from failing tires.

B. Traction

Another difference between rubber and polyurethane can be found in each material's ability to grip the surface on which it operates. Rubber tires will always have a softer tread surface, while polyurethane tires will be harder. Since rubber is softer, it will provide a broader foot print on the surface than polyurethane. As a result, rubber will always provide the customer with better traction than even the softest polyurethane. However, polyurethane manufacturers have developed a process called "siping" or "routing" where various tread styles are machined onto the surface of the tire. After this process, polyurethane tires have significantly better traction without sacrificing load capacity.

C. Load capacity

From a capacity standpoint, a polyurethane tire will carry twice the load of a rubber tire. For this reason alone, lift truck manufacturers have utilized polyurethane for load wheels and tires. Tires made of polyurethane will be much more resistant to splitting, tearing, or chunking out under load as rubber tires have a tendency to do. Since loads and speeds carried by all types of lift trucks seem to be constantly increasing in recent years, premature failure caused by continuous overloading seems to be the main cause of failure for both rubber and polyurethane.

D. Wear and Abrasion Resistance

While rubber will offer a softer ride, it will not wear as well as polyurethane. In fact, as a general rule polyurethane tires will outlast rubber tires by about four times. As the rubber tire is used, it looses fragments of its tread because of surface conditions and general abrasion. On the other hand,
Polyurethane does not experience similar wear due to its overall toughness. Polyurethanes tend to excel under sliding abrasion while rubber performs less effectively.

E. *Cutting and Tearing Resistance*

Due to its overall toughness, the polyurethane tire will withstand rough floor conditions and debris
much better than rubber. Rubber does not exhibit high cut / tear strengths. Once torn or cut, a rubber tire will see the cut or tear area propagate. Polyurethane is resistant to both cutting and tearing. In fact, the items that would normally cut and tear a rubber tire will become imbedded in the
Polyurethane tread without causing it to cut or tear. However, it should be noted that the cutting and
tearing of both rubber and polyurethane, ultimately reduces the life of each compound.

F. High Speed Operation

Polyurethane tires do not dissipate internal heat well. As the speed of the truck is increased, the polyurethane tire becomes less desirable. Internal
Combustion and propane lift trucks generally travel too fast for polyurethane tires and operate outside,
So a rubber tire is the preferred choice in this application. Most electric lift trucks travel at speeds of 6-8 miles per hour. Within this speed range, polyurethanes excel. Rubber dissipates heat well and will hold up in the higher speed applications.

G. Floor Marking

Polyurethane tires do not mark the floor of a warehouse. Even though polyurethane tires come
in a wide array of colors, the basic chemistry used will not allow any colorant to mark floors. A polyurethane tire can pick up dirt off the floor and lay it back down on the coated surface. This can leave one with the impression that the polyurethane tire is marking the floor. Dirt that has impregnated the coated surface does look like particles from the tire. Rubber on the other hand does mark floors if one is using a standard rubber compound. Carbon
Black used in rubber is the primary culprit. There are non-marking rubber products on the market that
generally do not mark the floor. These tires are typically grey in color as they lack the carbon black
Additive.

H. Chemical Resistance

Another comparison between rubber and polyurethane tires can be made in the area of chemical resistance. As an example, a rubber tire exposed to solvents may tend to loose its ability to have good tear strength and chunk resistance while the polyurethane is unaffected after long term exposure. However, it should be noted that harsh solvents like methyl ethyl ketone, methylene chloride or acids can destroy polyurethanes as well.

I. Price

From a pricing stand point it is difficult to precisely compare a polyurethane and rubber tire. One can
Always be sure of one thing; the polyurethane tire will be more expensive due to raw material costs.
Conversely, rubber raw materials are much less expensive. Depending on the compounds, a rubber
tyre can cost 25-50% less than a polyurethane tire. Since rubber tires can be used in a wider array of applications and will always cost less, rubber will always be the most prevalent product used in the material handling industry. However, if the lift truck is an electric and the load requirements are high, then a polyurethane tire is used in spite of the additional costs. But

remember, while a polyurethane tire can cost twice as much as a rubber tire, the polyurethane tire can last up to four times longer.

IV. STATIC STRUCTURAL ANALYSIS

The overall vertical stiffness of the airless tyre is controlled by the bending and extensional stiffness of the ring combined with the radial stiffness of the spokes.

The alteration of the geometry of the structure or the composition of the polyurethane composite used, offers a wide range of operation applicable for various load. Once an application has been identified for designing an airless tyre, the first step in the design process is to define the technical targets against which the design iterations can be measured. The following list is typical of the technical characteristics that might be specified for a new design:

- Overall tyre Geometry (Diameter, Width)
- Hub Geometry (Diameter, Width)
- Mass
- Stiffness (Vertical, Lateral, and Longitudinal)
- Ground Contact Pressure (Average and Peak)
- Rolling Resistance
- Durability
- Maximum Speed
- Impact Resistance

At a minimum, the designer must define the following parameters:

- Ring Shear Layer Material modulus
- Ring Shear Layer Thickness
- Spoke Modulus
- Spoke Thickness
- Spoke Count
- Spoke Curvature
- Spoke Length

The structural analysis of airless tyre for passenger vehicle application was done.

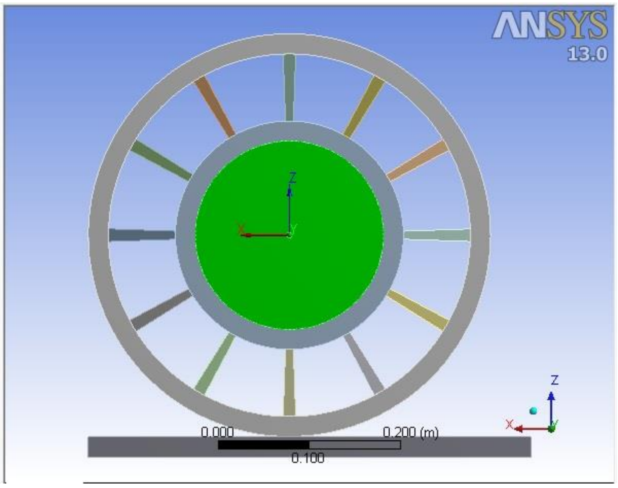

FIG.2 Ansys model of airless tyre.

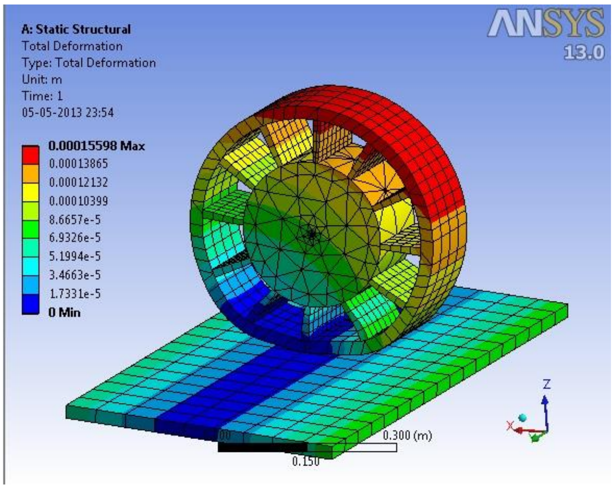

FIG.3 Total deformation on static loading.

The analysis is that of a passenger vehicle with an airless tyre in statically loaded condition. The deflection of the tyre for various loads was done and the results were compared with that of a pneumatic tyre of the same dimension. While the pneumatic tyre acts as a hardening spring, the airless tyre acts as a softening spring. Note that the two tires have the same load at a deflection of about 0.011 M. Looking at the 0.011 M point where the secant stiffness of both tires is the same, we can see that the tangent stiffness of the airless tyre is about half that of the pneumatic tire. We have the paradoxical situation of low deflection and low stiffness.

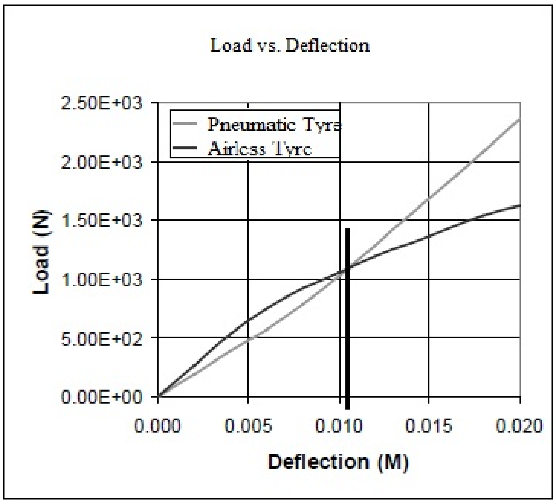

FIG.4 Comparison of load deflection.

The greater is the deflection of the airless tyre at higher loads offering greater cushioning to the vehicle and thereby reducing the rolling resistance by a considerable value when compared to the pneumatic tyre. Therefore it is more efficient at higher load applications. The dependence of rolling resistance on load is discussed in the following sections.

V. ROLLING RESISTANCE

In the graph, load Vs. Rolling resistance efficiency curve has been plotted. It conveys that it is a linear function which always have a positive slope which means they are proportional.[9]

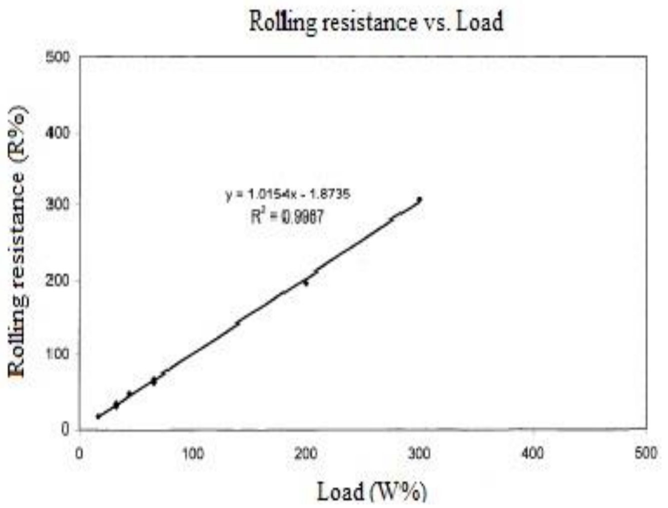

FIG5:- Load VS Rolling resistance.

The effect of increase in rolling resistance on the fuel consumed is analyzed. It can be assumed that the tyres are loaded 100% and the increase in the rolling resistance is also 100% at same inflation pressure p1. Applying schuring's rolling losses it could be concluded that the 100% weight increase leads to 25-30 % increase in the fuel efficiency. It is shown that the increase in pressure by 50% to 1.5 p1 leads to decrease in rolling resistance by 63%; the fuel consumption is decreased by 8-10%. Since this is the case of pneumatic tyres, when tried to relate with non-pneumatic tyre stiffness factor and the contact patch angle matters. Here the absence of air makes lot of changes. The polyurethane spokes are stronger and stiffer to maintain the tyre as a pneumatic tyre with regular size.**[10]** This could be achieved only by increasing the stiffness of the wheel and reducing the contact thread angle. The stiffness factor is of no doubt that the spokes will take care.

VI. CONCLUSIONS

Hence in this paper different parameters affecting the rolling resistance and also different cross-section of Tweel or airless tyre has been discussed. For the airless tyre to perform with low rolling resistance and give better fuel efficiency following conditions are decided :(i) since polyurethane composite has the capacity of both elasticity and stiffness at the same time , it becomes ideal to perform better than pneumatic tyre in case of rolling resistance. (ii) From the structural analysis, it can be concluded that polyurethane offers a wide range of operation applicable for various load applications. This is done by altering the geometry of the structure or by altering the properties of the polyurethane composite used. (iii) From the material study it can be inferred that the absence of rubber and the higher domination of polyurethane for the manufacturing of an airless tyre makes it more ecofriendly and increases the fuel efficiency in a greater extent. Therefore rolling resistance is brought less than 3% whereas in conventional tyres it is 4—5%.

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