FEA Analysis of Tyre Tread Under Loading and Unloading Condition

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Abstract: ***This project aims to realize the life cycle and best Tyre tread design. An important aspect is the development of robust Tyre friction model to include Tyre and road interaction. Gripping characteristic of Tyre tread plays a vital role in friction between Tyre and road when loading and unloading is done quickly. Tread should be such that it provides the most grip and have operating constancy on road. This component is for the safety concern of the vehicles. In this project, the Tyre model will be modeled using Creo software. Then, the prepared model is simulated for rubber material and different tread pattern. Tyre model is simulated using the Finite Element Method (FEM). FEA is used to simulate engineering problems. FEM software, ANSYS Static Structural is used for the calculating stress and strain in tread. Static structural determines the displacements, stress, strains and forces in Tyre caused by the loads that do not induce inertia and damping effects. Steady loading and structure's response are assumed to vary slowly with respect to time. On loading conditions, the load to be assumed is 31 ton and on unloading conditions, load is 10 ton approximately, In Static Position of Vehicle. The simulation result with lower stress and strain values is the point of interest.***

Keywords: FEA, FEM, ANSYS

1. Problem Formulation

Heavy trucks are made for goods transportation. They are meant to travel from very bad road conditions. Truck gripping is the most important factor for smooth travelling. Actually, there are several factors that affect the road grip. Some of which are critical.

1) Truck tread design.
2) The material of the contacting surfaces, i.e. rubber quality and road surface material.
3) The texture of these materials, i.e. the rougher texture the better road grip.
4) The force pressing the surfaces together, i.e. the weight of the vehicle.
5) Other materials between the contact surfaces, e.g. water, ice, gravel or oil spill.

In a typical driving situation, the first four factors are rather constant; our vehicle has a certain weight and certain tires, and we drive on a long road. Accordingly, we adapt our driving style to these given factors. But all of a sudden, there could be a heavy rain, and everything changes.

Therefore, Tread of a tyre is what we cam develop on our own for better gripping on any type of road. For different tread type we will find out stress via static structural analysis on one of the best Finite Element Analysis based software, ANSYS.

2. Background

Keeping heavy duty in mind, TATA Motor's new release TATA LPT 3118 is selected as our model. The TATA LPT 3118 is a heavy duty truck from the indigenous manufacturer. It is made to be a heavy-duty truck with a very high payload capacity of 23,250 kilograms. However, the gross vehicle weight is also on the higher side at 31,000 kilograms.

A) Tyre Tread

Tread is often used casually to refer to the pattern of grooves molded into the rubber, but those grooves are correctly called the tread pattern.

B) Tyre Tread Designs

Tyres generally fall into one of the following categories:

- Directional
- Non-directional
- Symmetric and Asymmetric.

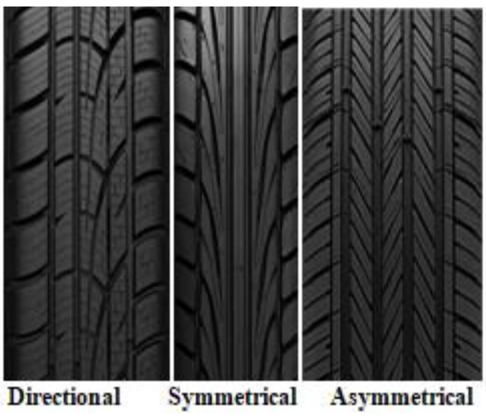


Figure a): Different types of Tyre Tread

C) Tyre Designations

There are 3 types of tyre designations, which are used:

Table a): Tyre designations [3]

Numeric	Metric	Alphanumeric
10.00-20 16 PR JET TRAK	185/65R14 VECTRA 82 T	F78- 15 8PR JETRIB
10.00R20 16PR JS JDH 146/142 K	215 R14 C 10PR STEELKING	
11R22.5 16 PR JW JUH	295/80R22.5 16PR JS JUH	

Figure b) Tyre designation

In this project, We are taking the standard dimensions of TATA LPT 3118i.e 10.00 R20 16PR or 185/65 R 14. In the above mentioned specification,

- 185: Nominal section width in mm
- 65: Aspect ratio. This means section height of Tyre is that many percent of its section width i.e. 65 % of 185 =120 mm(Approx.)
- R: Denotes the construction of tyre which is Radial in this case
- 14: Rim code or rim diameter in inches

D)Tyre code calculation

According to the selected set of tyre code 185/65 R 14, its dimensions are calculated

- **Rim Diameter : D:** 14 inches =355.6 mm
- **Thickness : t:** 65 % of 185 =120.25 mm
- **Outside diameter: D_o :**120.25 * 2 + 355.6 = 596.1 mm

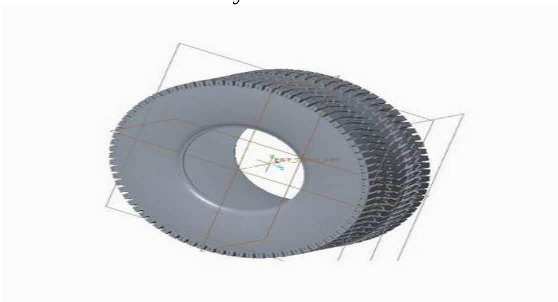
3. Methodology

The Model to be considered for our project is TATA LPT 3118. TATA LPT 3118 - India's most capable 4 Axle unbending that spearheaded the lift pivot innovation in India is the market pioneer in 31T GVW space and offers the most astounding resource turnover for clients. Clinically structured with a built up power train, drive-line and case it conveys the best in fragment stacking ability, fuel and Tyre mileage, torque at haggle durability. With choices of cowl and Tilt lodge and a scope of market-prepared completely constructed arrangements (HSD, FSD, Bulker, Reefer), 3118 is the best for substantial 31T unbending truck section

Figure 3.1: TATA LPT 3118

A) Model

Tyre for TATA LPT 3118 is modeled using Creo 5.0. Tyre Tread is Directional and Symmetric one.



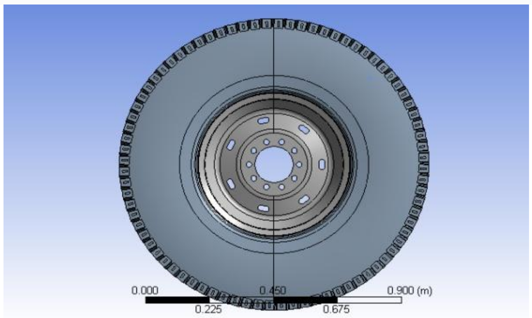


Figure c): Tyre Tread 1

Engineering Data

Open the ANSYS Workbench 18.0 .Select and drag Static Structural (Samccef) into the red dotted loop. You will see the steps to carry on. Select the Engineering data and set the materials for rim and tyre.TATA LPT 3118 tyre rim material is Structured steel. Tyre tread material is taken as rubber.

Rim Material: Structured Steel

Density	7850 kg m^-3
Coefficient of Thermal Expansion	1.2e-005 C^-1
Specific Heat	434 J kg^-1 C^-1
Thermal Conductivity	60.5 W m^-1 C^-1
Resistivity	1.7e-007 ohm m

Tyre Material: Rubber2

Density	1154 kg m^-3
Coefficient of Thermal Expansion	27 C^-1

Table 3.6: Material Data of Rubber2

Temperature C	Young's Modulus Pa	Poisson's Ratio	Bulk Modulus Pa	Shear Modulus Pa
22	50000	0.3	41667	19231

The geometry is then imported for further simulation process. The geometry will be in .igs format or change to .step format for easy importing. The first Tyre tread model is given in one directional.

D) Meshing

Meshing is the heart of Finite Element Analysis. It needs to be done before applying any boundary conditions. Meshed Tyre model is shown below in Figure 3.8.

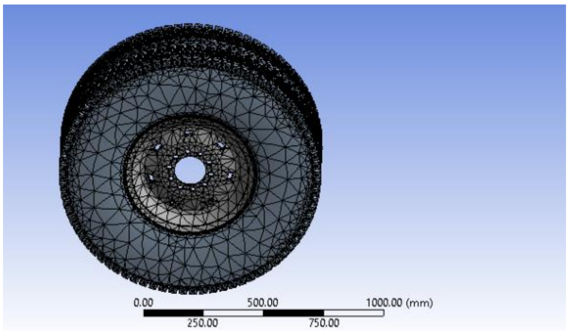


Figure d): Tyre Mesh

E) Boundary Conditions

The contact between the tyre and road is fixed on loading and unloading conditions, as the truck is considered to be at rest. Static Structural is preformed for the static objects.

The heavier trucks usually specify very high air pressure. A common air pressure for truck would be 55 front, 80 rear, or 75 front and rear. But a right tyre pressure recommended is 60 psi. An average of all 60psi to be taken.1 Psi = 6894.75 Pascals

60 Psi = 60* 6894.75 Pa ~ 4 e+005 Pa

Load is applied vertically downward as the whole weight of truck along with the load is acting on the 6 tyres. Load is equally distributed on each tyre. On loading conditions gross vehicle weight comes to be 31000 N.Load acting on each tyre will be:

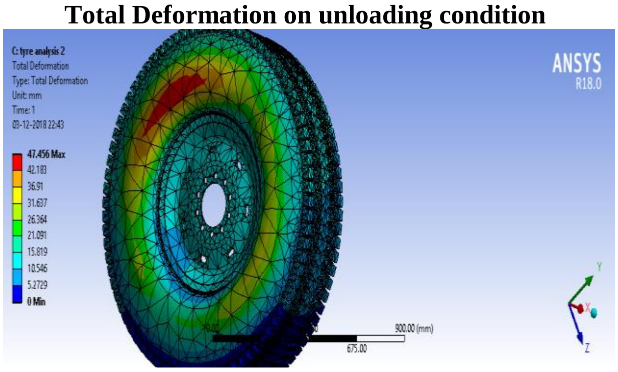
F = 31000/ 6 N ~ 5kN

On unloading conditions, the vehicle weight will be 19000N. So load on each tyre be: F = 19000/6 N ~3kN

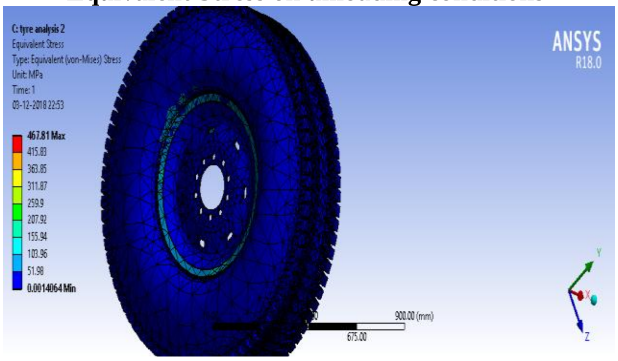
F) First Tread Pattern Simulation

On solving for the equivalent stress and total deformation, we get the following results for first tread design with loading and unloading conditions

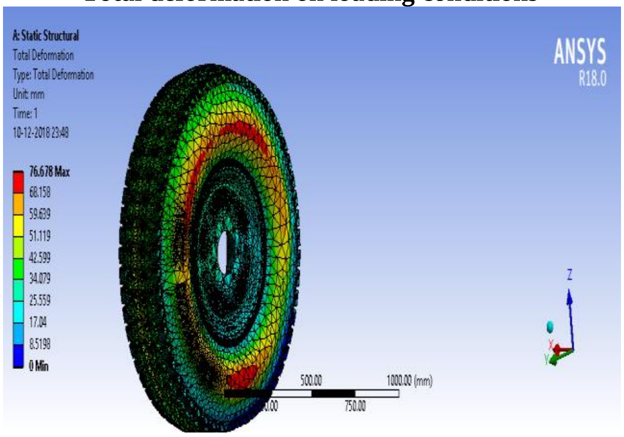
Total Deformation on unloading condition



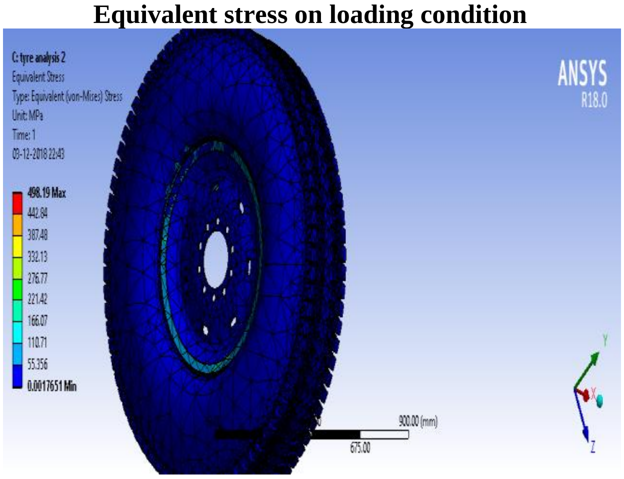
Equivalent Stress on unloading conditions



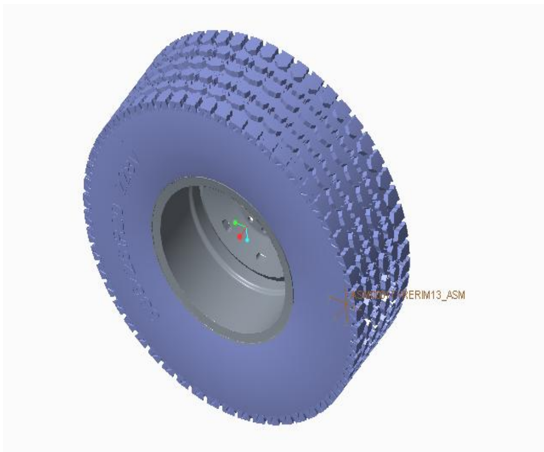
Total deformation on loading conditions



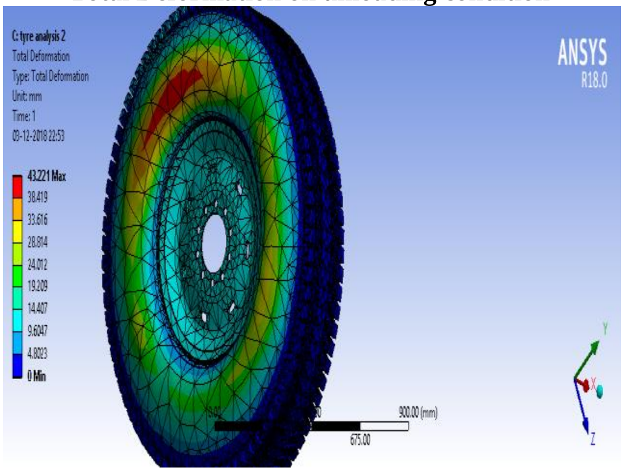
Equivalent stress on loading condition



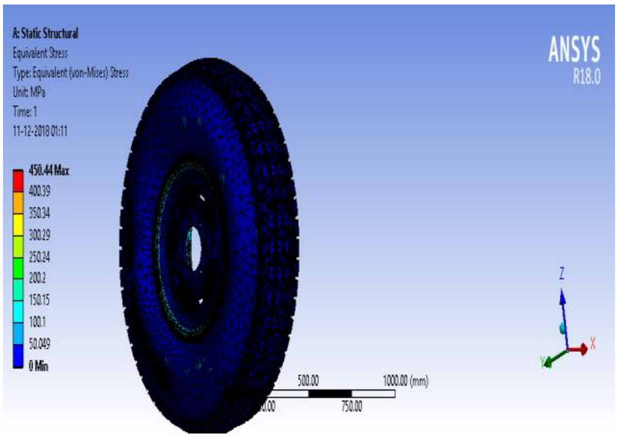
G) Second tread Pattern CAD Model



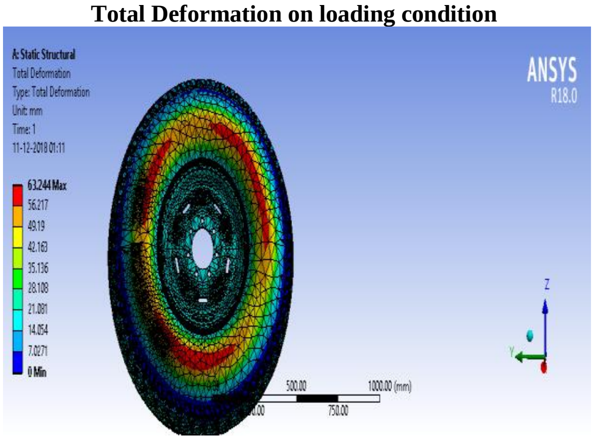
Total Deformation on unloading condition



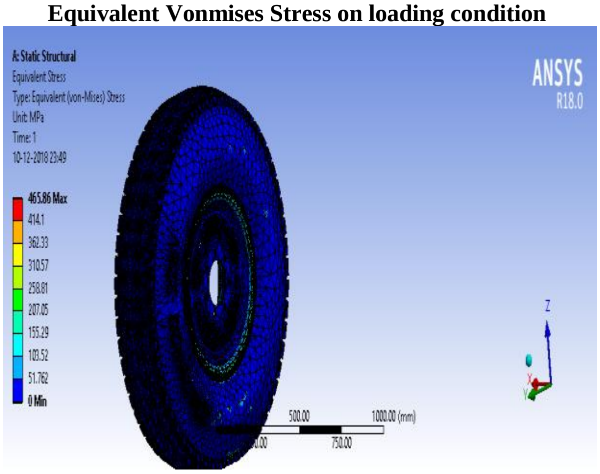
Equivalent Vonmises Stress on unloading condition



Total Deformation on loading condition



Equivalent Vonmises Stress on loading condition



4. Result

Each force passes through the tire and tends to compress the wheel in the radial direction. When the car is in motion, the radial load becomes cyclic in nature with a continuous rotation of the wheel. Hence, a careful evaluation of wheel fatigue strength, under radial load, is important purposes of structural integrity. According to the society of automotive engineers (SAE), a wheel should maintain structural integrity, without developing macroscopic cracks or undergoing excessive plastic deformation, for more than 4×10^6 rotations, under the influence of a radial load (Q).

The radial load is expressed by the equation, **Q = Sr · Fr** where Sr is acceleration test factor in conformance with SAE J328 specification (Sr = 2.2), and Fr is the maximum load on the tire.

On unloading, Q = 2.2 * 3000 = 6600 N ~ 6.6 kN
On loading, Q = 2.2 * 5000 = 11,000 N ~ 11kN

In this research study the radial load is considered to be the force exerted on the bead seats arising as a result of a vertical reaction of the weight of the automobile on the road surface. The radial load is considered to be equivalent to a static load imparted on both the rim and tire in a direction normal to the surface of the road. Summing horizontal components of the force vector due to the normal loads does not change the resultant state of stress in the rotating wheel. This enables significantly less computation time. For a radial load, the tensile strength of the rim exerts a profound influence on durability, or fatigue life, of the rotating wheel. This ensures a precise evaluation of the stresses to be centered on the rim.

Accordingly, the distributed pressure W_r is given by the expression:

$$W_r = W_0 \cdot \cos(\pi/2 \cdot \theta/\theta_0)$$

The total radial load *Wo* is calculated as follows:

$$F_r = 8 \cdot b \cdot r_b \cdot \theta_0 \cdot W_0/\pi$$

where *rb* is the radius, *b* is the width of the bead seat, and $\theta 0$ is the angle of loading. Production car tires typically develop this maximum lateral force, or cornering force, at a slip angle of 6-10 degrees, although this angle increases as the vertical load on the tire increases. We can calculate W_0 with given F_r and the distributed pressure, W_r, on bead seats can be decided. In this analysis, a radial load (F_r) of 5kN is applied on loading condition and 3kNon unloading condition to the model. This load magnitude is chosen to be the same as that experienced by an actual wheel in stress measurement experiments.

On loading condition, Fr = 8 * 0.035 * 0.596 * 10* π/180 * Wo/ π

$5000 = 0.00927 * W_o$

$W_o = 539.38$ kN

Stress = Total Radial Force / Area = 539.38 /0.785 = 687.12 MPa

On unloading condition,Fr = 8 * 0.035 * 0.596 * 10* π/180 * W_o/ π

$3000 = 0.00927 * W_o$

$W_o = 323.62$ kN

Stress = Total Radial Force / Area= 323.62 /0.785= 411.73 MPa

Hence, our Stress analysis is under consideration. Comparison is done for different tread pattern with the same material. Depending on loading and unloading conditions there are different stress values and deformation. On comparison, we will get the best Tyre tread. Best tyre tread will give us best gripping between truck Tyre and road.

5. Conclusion

On unloading Condition

Treads	Maximum Equivalent Vonmises Stress (MPa)
Tread 1	467.81
Tread 2	450.44

Treads	Maximum Equivalent Vonmises Stress (MPa)
Tread 1	**498.19**
Tread 2	**465.86**

On comparing for Equivalent Vonmises Stress, on unloading condition Tread 2 have lesser Stress value. On the other hand, for loading condition too Tread 2 have lesser Stress value. Hence Tread2 is the best choice for the tread pattern.

Treads	Total Deformation (mm)
Tread 1	**76.678**
Tread 2	**63.244**

Treads	Total Deformation (mm)
Tread 1	**47.456**
Tread 2	**43.221**

On comparing for total Deformation, unloading condition Tread 2 have lesser deformation value. On the other hand, for loading condition too Tread 2 have lesser deformation value. Hence Tread 2 is the best choice for the tread pattern.
This project focused on the tread pattern analysis. As one of the factor for heavy truck to maintain good grip over any type of surface is the Tread Pattern. With the two different tread patterns, we performed static structural analysis and came upon the following results.

As we can observe in all the above comparisions, we came to know that Tread 2 have the lowest Equivalent Vonmises Stress as well as Total Defomation. Hence, We consider Tread 2 as our best choice for tread pattern for best grip of our considered truck model TATA LPT 3118.

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