

# Tire Wear Analysis using ABAQUS

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**ABSTRACT:** The tire tread pattern is the arrangement of blocks, grooves, voids, sipes and channels designed into the tread to enhance its grip on the road. Tread is the uppermost part of any tire which contact into the road. This research work aims at conducting Finite Element Analysis on tire tread wear for its performance in steady rolling condition to predict its behaviour and wear in on-road conditions. The tire wear is analysed on the basis of Archard wear theory. The Finite Element Analysis software ABAQUS 6.14 is used for the analysis and the tire is modelled using CREO 2.0. This work includes the tread wear analysis of different types of rubber used to make tire tread and also the influence of inflation pressure on tire wear will be studied. Thus the optimum tire tread material properties for various on road conditions and optimum inflation pressure can be obtained.

**KEYWORDS:** Tire tread, Archard wear theory, Tire tread wear, Inflation pressure.

## I. INTRODUCTION

The tire is an important component in the vehicle. It is the source of contact between the vehicle and the road. Proper contact between tire and road is necessary for proper steering of vehicle. Tire wear is a complex phenomenon and can be a result of variety of factors like improper inflation pressure, overloading of vehicle, improper alignment of tire and worn out struts. Tire wear is a major source of noise in vehicles travelling at speeds above 50 km/h. Tire wear has an impact on the vehicle mileage. As tire wear increases, fuel economy decreases. When the vehicle passes through a wet road; tread depth, water depth, speed, inflation pressure, load on tire, and tread design are the main factors which determines the ability of tire to remove water. As tire wear increases, tread depth decreases which can lead to hydroplaning. It occurs when a layer of water is formed between wheels and road that leads to loss of traction and stability.

## II. RELATED WORK

Olivier Le Maître et al. [1] proposed a method to characterize tire wear in customer use. 25 to 100 vehicles were sampled and their severity of usage was determined. Their method takes into account various factors like surface of road, different styles of driving, weather conditions, driving routes and other factors which affects wear. Statistical distribution was used to represent wear performance of tire. Kaiming Xia **Error! Reference source not found.** used finite element method to study interaction between tire and terrain. ABAQUS software was used for modelling tire and terrain. Hyper elasticitic model was used for modelling tire. Simulations are used to show how soil compaction and mobility of tires can be predicted from tire-terrain model. ShahyarTaheri et al. [3] investigated dynamic behaviour of tire involving transient characteristics. Dynamic finite element simulation was done in two stages. First, an implicit method was used for inflating and loading tire using refined mesh in contact patch. For further simulations final state vectors were used as initial conditions. Validation was done using comparing modal shapes and frequencies with experimental data. Jin Chang et al. [4] modelled tire with complicated tread pattern instead of the conventional smooth tread tires. Rebar layer model was used for composite materials. Simulations were done using ABAQUS code and the conditions used were straight driving, straight braking and straight free rolling. Wear quantity was assessed using wear mass and wear depth. J.R. Cho et al. **Error! Reference source not found.** proposed a numerical technique for finding tire wear. Wear model was derived from the tests conducted in laboratory. Frictional energy dissipation and wear rate of tire were correlated using this model. Virtual simulations done in ADAMS were used for obtaining driving and loading conditions. Dynamic rolling analysis of the 3D model is done and the frictional energy dissipation rate was obtained. William Blythe et al. [6] conducted laboratory testing of tire to study tire performance during cornering. Tests

were also done to estimate tire wear and its effect on the performance of tire in wet road conditions. The effect of tire wear in hydroplaning was studied.

The objective of this work is to conduct a steady state rolling analysis of the tire and to determine the wear rate with the aid of Archard wear theory. The material properties of the tread material are as per the standard type of rubbers used for the manufacture of treads and the wear rates in all cases are determined. Also the influence of inflation pressure on wear rate is studied.

### III. METHODOLOGY

#### 1. Modelling of tire

The tire model chosen in this work is MRF ZVTV 175/65 R14 82T with dimensions as shown in Fig: 1, which is modeled using CREO 2.0.

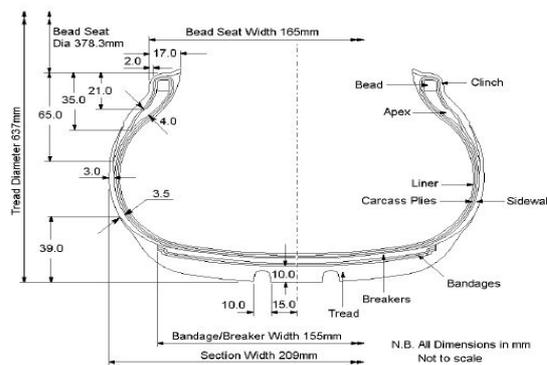


Fig: 1 Tire dimensions

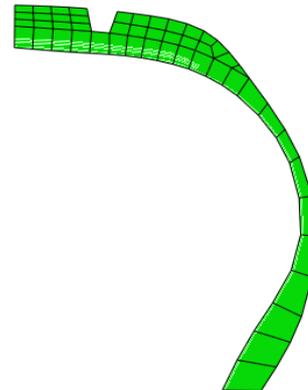


Fig: 2 Tire model

The tire modeled in CREO 2.0 is imported into ABAQUS 6.14 for analysis as shown in Fig: 2. In the axisymmetric half-model of the tire shown above, CGAX4 AND CGAX3 elements are used to model the rubber matrix, the reinforcement is modeled using SFMGAX1 elements that carry rebar layers. Reinforcement layers are embed in the rubber matrix using an embedded element constraint. The tread is modeled with a linear elastic material to avoid difficulties with the hyper elastic material state during the adaptive meshing procedure. The hyper elastic material model is used to model rest of the tire. The polynomial strain energy potential is used with coefficients  $C_{10}=10^6$ ,  $C_{01}=0.0$ , and  $D_1=2 \times 10^{-8}$ . The rebar layers used to model the carcass fibers are oriented at  $0^\circ$  to the radial direction and have an elastic modulus of 9.87 GPa. The modulus in compression is set to 1/100th of the modulus in tension. The Marlow hyperplastic model is used to specify the nominal stress-nominal strain data for such a material definition. The elastic modulus in tension of the material of the belt fibers is 172.2 GPa. This model consists of two numbers of belts with same elastic modulus. The modulus in compression is set to 1/100th of the modulus in tension. The fibers in the belts are oriented at  $+20^\circ$  and  $-20^\circ$  with respect to the hoop (circumferential) direction.

The three-dimensional model is created by first revolving the axisymmetric half-model, using symmetric model generation, by  $360^\circ$  to generate the partial three-dimensional model shown in Fig: 3.

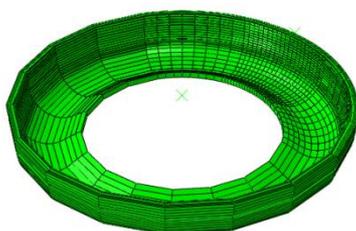


Fig: 3 Revolved model of tire

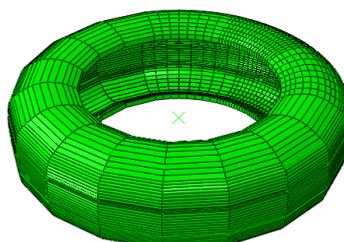


Fig: 4 Reflected model of tire

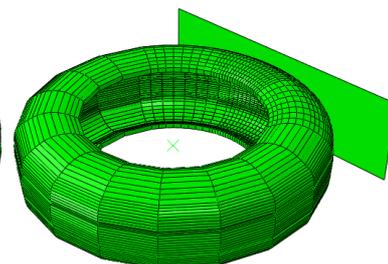


Fig: 5 Tire model with road

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The partial three-dimensional model is then reflected about a line to generate the full three-dimensional model. The results are then transferred from the end of the footprint simulation for the partial three-dimensional model as shown in Fig: 4. The final tire model along with the road surface is shown in Fig: 5.

## 2. Applying Input Parameters

The generated full model of the tire is then subjected to a steady-state transport analysis. The conditions applied in the analysis correspond to a state of braking. The steady-state transport analysis uses a moving reference frame in which rigid body rotation is described in an Eulerian manner and the deformation is described in a Lagrangian manner. This kinematic description converts the steady moving contact problem into a pure spatially dependent simulation. Thus, the mesh need to be refined only in the contact region-the steady motion transports the material through the mesh. Frictional effects, inertia effects, and history effects in the material can all be accounted for in a steady-state transport analysis. Adaptive meshing is used in the analysis which has the following assumptions.

- In this model cylindrical elements are not used as it is not supported in adaptive meshing.
- The tread is modeled with linear elastic material as adaptive meshing gives poor results with hyper elastic materials due to inaccurate advection of deformation gradient state variables.
- In the adaptive mesh domain no embedded elements including rebar layers are used.
- Adaptive mesh smoothing on free surfaces occurs in directions determined by features of the element geometry, which may not always be consistent with or easily enable description of wear directions. As a result, some additional work has to be done to explicitly describe the direction of wear.

The following boundary conditions are applied in the analysis

- Tire inflation pressure = 200 kPa
- Linear velocity of tire = 32 kmph
- Angular velocity of tire = 25 rad/s
- Load on tire = 3300 N
- Testing distance = 32000 km

The material properties of various types of rubber used in the analysis is listed in Table: 1 as shown below.

Types of rubber	Density (kg/m <sup>3</sup> )	Young's Modulus (MPa)	Poisson's Ratio
Natural Rubber	1100	6	.49
Styrene Butadiene Rubber (SBR)	950	10	.48
Acrylonitrile Rubber (ACN)	1300	6.89	.35
Poly Butadiene Rubber	940	2.2	.49

Table: 1 Mechanical properties of various types of rubber.

## 3. Archard Wear Theory

To illustrate the wear process, a simple wear model is employed based on the assumption that the wear rate is a linear function of the local contact pressure and slip rate. Although we can calculate these quantities locally, due to the Eulerian formulation used in steady-state transport they must be applied over tread streamlines to model the wear of the entire tire perimeter.

The wear constitutive model employed for this simulation is a form of the Archard model. The theory states that the volume of the removed debris due to wear is proportional to the work done by friction forces. According to Archard wear theory the wear rate is given by,

$$\dot{q} = \frac{k}{H} P A \dot{\gamma} \quad (1)$$

Where,

- $\dot{q}$  - wear rate
- k - non dimensional wear coefficient =  $1.11 \times 10^{-4}$
- H - material hardness = 2GPa
- P - contact pressure
- A - contact area =  $T\Delta S$
- $\gamma$  - slip rate

#### IV. RESULTS AND DISCUSSIONS

Steady state rolling analysis of tire was conducted for four different tread materials and its wear rates were obtained. Effect of inflation pressure on wear is also studied. The results obtained are as follows.

##### 1. Inflation pressure = 200 kPa

##### 1.1 Natural Rubber

Steady rolling analysis was conducted on tire with tread made of natural rubber. The results obtained for contact pressure, slip rate and nodal displacements were shown in Fig: 6.

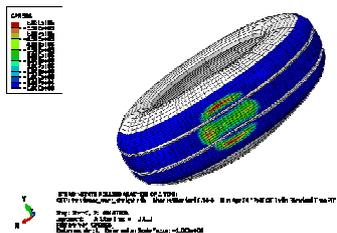


Fig: 6(a) Contact pressure

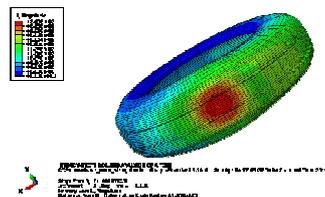


Fig: 6(b) Slip rate

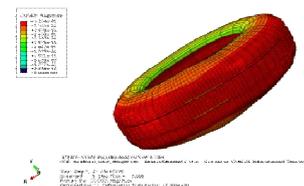


Fig: 6(c) Nodal displacement

Natural rubber is having second highest wear rate at 200kPa inflation pressure due to high density and elastic modulus. But their slip rate is low.

##### 1.2 Styrene Butadiene Rubber (SBR)

The results obtained for SBR under steady rolling analysis is shown in Fig: 7 below.

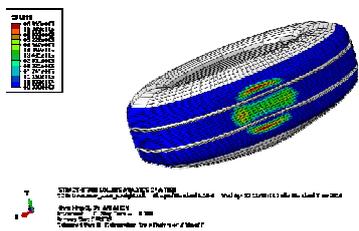


Fig: 7(a) Contact pressure

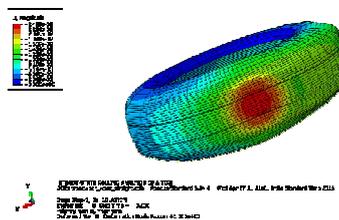


Fig: 7(b) Slip rate

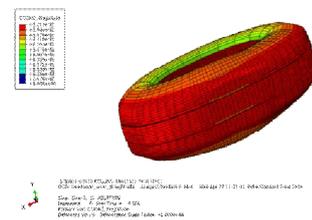


Fig: 7(c) Nodal displacement

SBR is having the highest wear rate among the four types of tread materials chosen due to high Young's modulus.

##### 1.3 Acrylonitrile Rubber (ACN)

Steady rolling analysis is carried out on tire with ACN tread and the contact pressure, slip rate and the nodal displacements obtained are shown in Fig: 8 below.

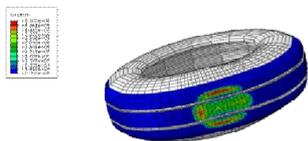


Fig: 8 (a) Contact pressure

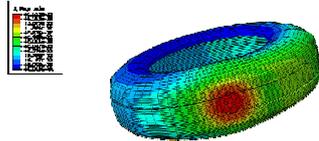


Fig: 8 (b) Slip rate

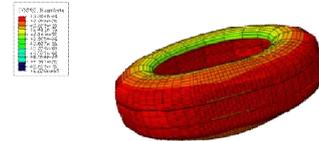


Fig: 8(c) Nodal displacement

Results show that ACN rubber is having the second least wear rate among other tread materials due to high density and low poisson's ratio.

#### 1.4 Poly Butadiene Rubber

The results obtained for contact pressure, slip rate and nodal displacement of poly butadiene rubber after conducting steady rolling analysis is as shown in Fig: 9 below.

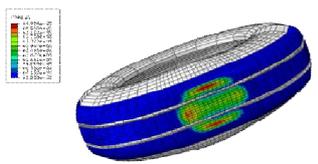


Fig: 9 (a) Contact pressure

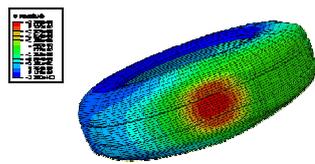


Fig: 9 (b) Slip rate

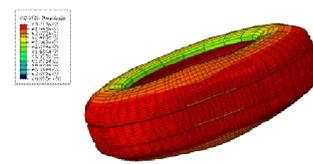


Fig: 9(c) Nodal displacement

Poly butadiene rubber is having the least wear rate due to low elastic constant and density than other types of tread material chosen for analysis.

### 2. Inflation Pressure = 250 kPa

#### 2.1 Natural Rubber

Tire with natural rubber tread is subjected to steady rolling analysis with increase in inflation pressure and the results obtained for contact pressure, slip rate and nodal displacements are shown in Fig: 10 below.

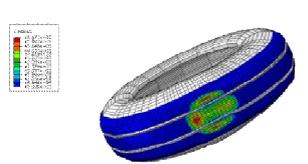


Fig: 10 (a) Contact pressure

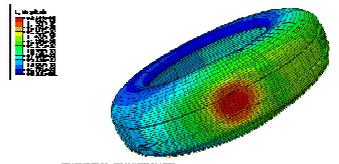


Fig: 10 (b) Slip rate

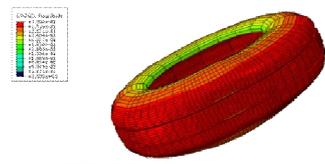
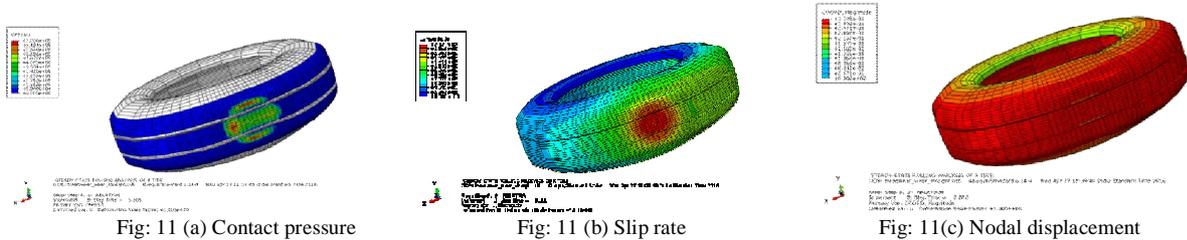


Fig: 10(c) Nodal displacement

It can be seen that with the increase of inflation pressure, the wear rate is decreasing. This is because as the inflation pressure increases the contact area between the tire and road surfaces decreases and hence wear rate also decreases. Natural rubber is having the second highest wear rate.

#### 2.2 Styrene Butadiene Rubber (SBR)

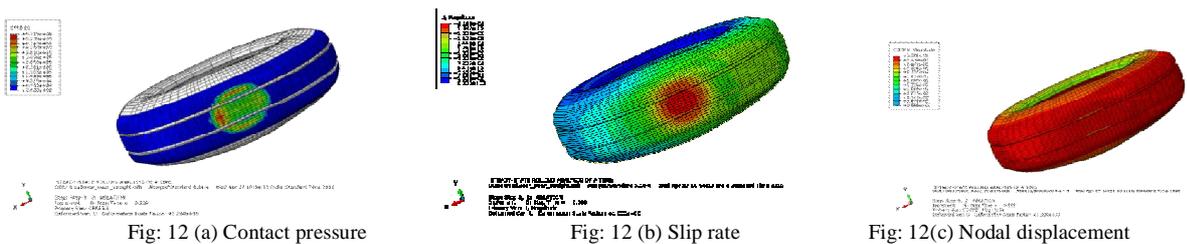
Steady rolling analysis is conducted on tire with treads made of SBR and following results were obtained for contact pressure, slip rate and nodal displacements as shown in Fig 11 below.



Results obtained shows that SBR has got the highest wear rate because of very high contact pressure between tire and road surface. The slip rate in this case is very low.

### 2.3 Acrylonitrile Rubber (ACN)

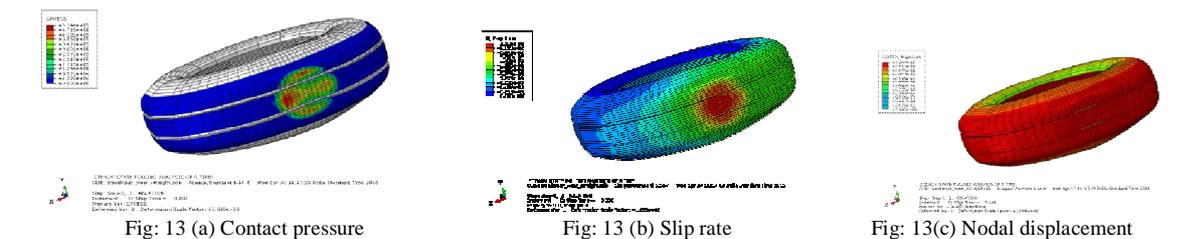
Tire with tread made of ACN rubber is subjected to steady rolling analysis and the results obtained for contact pressure, slip rate and nodal displacements are shown in Fig: 12 below.



ACN rubber is having the second least wear rate due to lower contact pressure between the tire and road surface.

### 2.4 Poly Butadiene Rubber

Results obtained for steady rolling analysis of tire tread made of poly butadiene rubber is shown in Fig: 13 below.

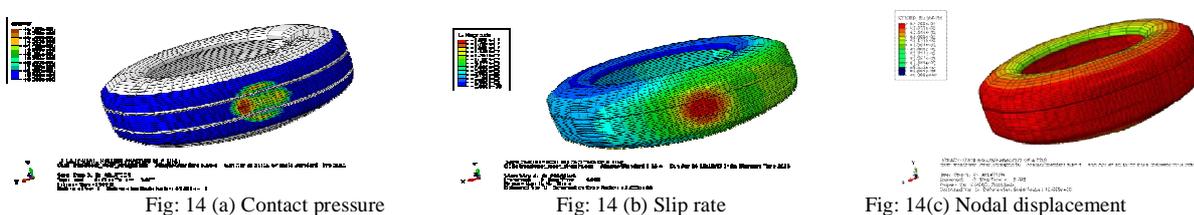


Poly butadiene rubber is having the least wear rate among the types of rubber chosen for analysis. As its elastic modulus is very low, it is having very less contact pressure.

## 3. Inflation Pressure = 300 kPa

### 3.1 Natural Rubber

Tire with tread made of natural rubber is subjected to steady rolling analysis at an inflation pressure of 300 kPa and following results were obtained for contact pressure, slip rate and nodal displacement as shown in Fig: 14 below.



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As the inflation pressure is further increased it can be seen that the wear rate decreases. This is because less contact pressure is generated between tire and road surfaces as the contact area is reduced. Slip rate also decreases with increase in inflation pressure.

### 3.2 Styrene Butadiene Rubber (SBR)

SBR tread tire is subjected to steady rolling analysis at an inflation pressure of 300 kPa and the results obtained as shown in Fig: 15 below.

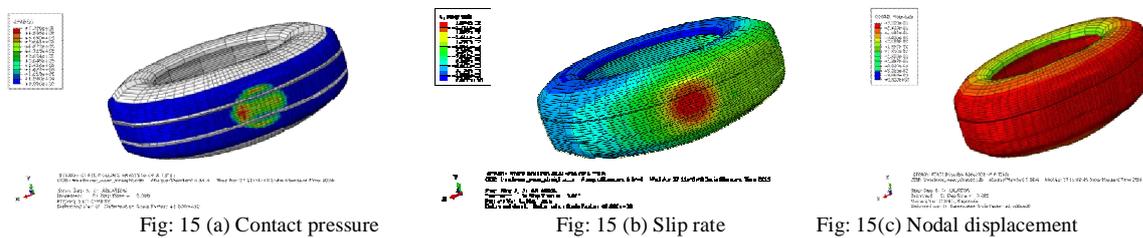


Fig: 15 (a) Contact pressure

Fig: 15 (b) Slip rate

Fig: 15(c) Nodal displacement

Results show that SBR has got the greatest wear rate due to high contact pressure between the tire and road surface. Same as for other types, for SBR also the wear rate decreases with increase in inflation pressure.

### 3.3 Acrylonitrile Rubber (ACN)

Inflation pressure of 300 kPa is applied to tire with ACN tread and steady state rolling analysis is carried out. The results obtained for contact pressure, slip rate and nodal deflections are shown in Fig: 16 below.

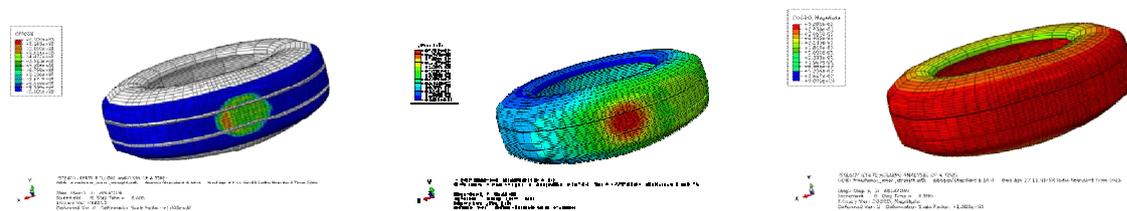


Fig: 16 (a) Contact pressure

Fig: 16 (b) Slip rate

Fig: 16(c) Nodal displacement

ACN is having the second least wear rate due to less contact pressure between tire and road surface. For ACN also the wear rate decreases with increase in inflation pressure.

### 3.4 Poly Butadiene Rubber

Steady rolling analysis is carried for tire with poly butadiene tread material. The results obtained for contact pressure, slip rate and nodal displacement is shown in Fig: 17 below.

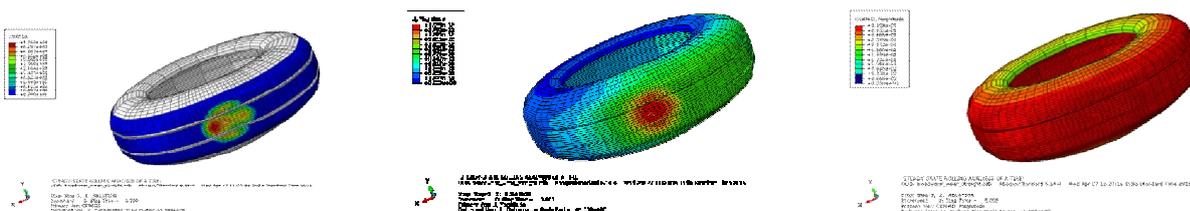


Fig: 17 (a) Contact pressure

Fig: 17 (b) Slip rate

Fig: 17(c) Nodal displacement

Poly butadiene is having the least wear rate among other types of rubber chosen for analysis. This is because they are having very less contact pressure between tire and road surfaces. Also its wear rate decreases with increase in contact pressure.

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## V. CONCLUSION

From the analysis it is seen that wear rate is a function of inflation pressure and material properties of the tread material. The obtained results through Finite Element Analysis is agreeing with those obtained through experimental methods in the literatures studied. Following conclusions are arrived from the analysis.

- Material with high elastic modulus is having high contact pressure, hence have high wear rate.
- Wear rate depends on the inflation pressure of the tire. As inflation pressure is increased, the wear rate decreases.

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