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Effect of Tyre Overload and Inflation Pressure On Rolling Loss with Fuel Consumption of Automobile Cars

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ABSTRACT

The effect of tyre overload and inflation pressure on rolling loss with fuel consumption in Automobile cars. Fuel consumption and tyre rolling losses in all types of automobiles have become increasingly important, because of adverse environmental effects (air pollution and global warming) and economical cost (high petroleum price), due to improving of fuel efficiency for automobiles. The automobile industry implementing many programs to accomplish this goal. Improving the efficiency of I.C engines, hybrid engine, lighter automobiles for reducing aerodynamic drag, reformulated gasoline and solar powered cars are some of the methods implemented by the automobile industry. Tyre industry for it's part has developed fuel efficient tyre's by reducing tyre rolling losses. The tyre rolling losses mainly load, pressure, vehicle speed, stop and go driving and vehicle styling (aerodynamic shape verses box type) are some of the influencing parameters of rolling loss.

The rolling resistance has historically been treated as a force opposing the direction of travel like a frictional force, rolling resistance divided into two types first one steady-state resistance occurs due to constant speed and second is dynamic resistance occurs due to vehicle acceleration (vehicle inertia).

The rolling losses is calculated using the experimental procedure according to (IJEMS Journal Volume 11, Oct 2004 & SAE J1269 experimental results in Published journal) standard measurements. The equations of Rolling resistances are ($R = C_1W$ and $R = C_1*1/p^{0.5}$). The rolling losses influences Fuel consumption that depends according to schruing's rolling resistance verses fuel consumption results, it can be concluded that 100% increase in rolling resistance of tyre would cause about 25-30% increase in fuel consumption.

In this project, a possible method of optimizing fuel use by adjusting the tyre load/pressure conditions in Skoda rapid and Ford classic car tyre's in which car tyre's using tubeless tyre's and the 3D model of car tyre is prepared using Pro-E software. The prepared 3D model will export into the Ansys software going to calculate displacement, Stress and Strain values at different pressures.

1. INTRODUCTION

The pneumatic tyre plays an increasingly important role in the performance of vehicle on road. However, this state achieved because of more than 100 years' tyre evolution. Since the initial invention of the pneumatic tyre by John Boyd Dunlop around 1888. Tyre's are required to produce the forces necessary to control the vehicle. As we know that the tyre is the only means of contact between the road and the vehicle but they are at the heart of vehicle handling and performance. The inflated rubber structure provides comfortable ride for transportation. With the growing demand for the pneumatic tyre, many improvements have been made based on the initial conception, such as the re-inforcement cords, the beads, the vulcanization, the materials and the introduction of the tubeless tyre. The relationship between human, tyre and environmental surrounding play an important role for developing of tyre technology. These concerns include traffic accidents caused by tyre failure, the waste of energy due to bad tyre conditions, the pollution through the emission of harmful compounds by tyre's, and the degradation of road surfaces related to tyre performance, etc.

Tyre is one of the most important components of vehicle, requires to fulfill a fundamental set of functions are to provide load-carrying capacity, to provide cushioning and dampening against the road surface, to transmit driving and braking torque, to provide cornering force, to provide dimensional stability, to resist abrasion. Tyre's have ability to resist the longitudinal, lateral, and vertical reaction forces from the road surface without severe deformation or failure. Tyre performance is depends on the tyre rolling resistance, cornering properties, tyre traction, tyre wear, tyre temperature, tyre noise, tyre handling and characteristics, etc. There are various losses associated with the vehicle that affect its fuel economy as it is being operated. These losses include engine, driveline, aerodynamic and rolling losses, while the rolling loss is associated with the vehicle tyre's.

1.1 TYRE AXIS TERMINOLOGY

It need to understand some of the basic terminology for tyre, especially regarding the systems of coordinates, orientations, velocities, forces, moments. Nomenclature and definitions based on the SAE standard as shown in (Figure 1) X-axis is the intersection of the wheel plane and the road plane with positive direction forward. The Z-axis perpendicular to the road plane with positive direction downward. The Y-axis in the road plane, its direction being chosen to make the axis system orthogonal and right hand. There are several forces, moments and angles that prove to be very important in tyre behavior. All these forces can be seen as the forces and moments acting on the tyre from the road. First, there are two main angles to consider, the camber angle and the slip angle. The camber angle is the inclination angle from its vertical position while the slip angle is the difference in wheel heading and direction.

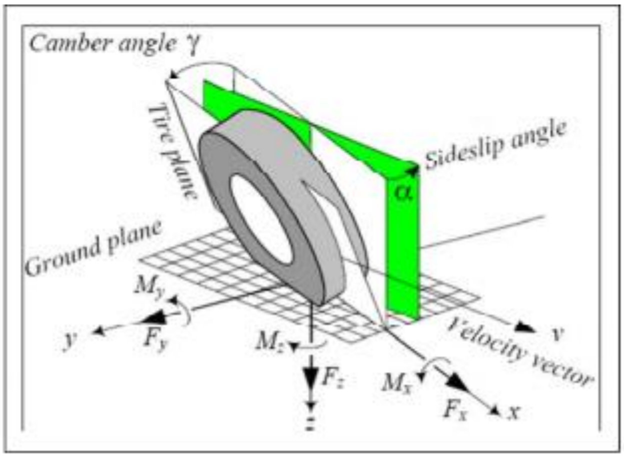

Fig.1 Tyre Axis Terminology

These two angles are associated with the lateral force. Forces include the longitudinal force in the X direction, the lateral force in the Y direction and the normal force in the Z direction. Longitudinal force (Fx) is the result of the tyre exerting force on the road and becomes negative during braking. The lateral force (Fy) is the resultant of the forces produced by a non – zero camber angle and by a non – zero slip angle during cornering. Normal force (F_z) can also be viewed as the negative of the upward vertical force. Moments include the overturning moment, the rolling resistance moment, the wheel torque and the aligning moment.

The overturning moment (Mx) is caused by a lateral shift of the vertical load during cornering. Rolling resistance (My) is created by various factors that lead to a loss of energy. The aligning moment (Mz), also known as the self-aligning torque, produces a restoring moment on the tyre to realign the direction of travel with the direction of heading when the slip angle is non-zero. It should also be noted that there is also a moment produced by the axle on the wheel.

1.2 PERFORMANCE PARAMETERS OF TYRE

Tyre performance is affected by the rolling resistance, tyre wear, tyre noise, tyre temperature, cornering properties.

1.2.1Rolling Resistance

When a tyre rolls on the road, mechanical energy is converted to heat as a result of the phenomenon referred to as rolling resistance. Effectively, the tyre consumes a portion of the power transmitted to the wheels, thus leaving less energy available for moving the vehicle forward. Rolling resistance therefore plays an important part in increasing vehicle fuel consumption. The rolling resistance of tyre's on hard surfaces is primarily caused by the hysteresis in tyre materials due to the deflection of the carcass while rolling. Friction between the tyre and the road caused by sliding, the resistance due to air circulating inside the tyre and the fan effect of the rotating tyre on the surrounding air also contribute to the rolling resistance of the tyre, but they are of secondary importance. Available experimental results give a data of tyre losses in the speed range 128-152 km/h (80-95 mph)as 90-95% due to internal hysteresis losses in the tyre, 2-10% due to friction between the tyre and the ground, and 1.5-3.5% due to air resistance. Fuel consumption is the most important topic of discussion in the automotive industry today. Tyre energy losses are responsible for about 25% of the total fuel consumption of a typical passenger car. The coefficient of rolling resistance of the first tyre's in 1900 was approximately 0.025. This value was reduced by 50% to 0.013 with the introduction of radial tyre's in 1946. The introduction of silica fillers in 1992 further reduced resistance to 0.008. Rolling resistance is the effort required to keep a given tyre rolling. Its magnitude depends on the tyre used, the nature of the surface on which it rolls, and the operating conditions inflation pressure, load and speed. Rolling resistance has historically been treated as a force opposing the direction of travel, like a frictional force. Amore general concept is in terms of the energy consumed by a rolling tyre. Driving resistance scan be divided into two categories one is steady-state resistances and second is dynamic resistances. Steady-state resistances occur when a vehicle is running at a constant speed, rolling resistance, aerodynamic drag and climbing resistance fall in to this categories. Dynamic resistance occurs when vehicle is accelerating, this type of resistance occurs due to the vehicle inertia. The rolling resistance of a wheel (FR) is made up of four components. The sum of these components is equal to the total rolling resistance Components such as Tyre rolling resistance (FR, T),Road rolling

FR = FR, T + FR, Tr+ FR, $\alpha\cdot$+ FR, fr

Resistance (FR, Tr) Resistance due to tyre slip angle (FR, $\alpha\cdot$) Resistance due to bearing friction and residual braking (FR, fr). Tyre rolling resistance is depends up on the following parameters.

1.2.2 Tyre Temperature

The temperature of the tyre has significant effect on rolling resistance of tyre. Increasing of rolling resistance of tyre is due to the deflection and energy loss in the material.

1.2.3 Tyre Inflation Pressure and Load

Tyre's are specified by the vehicle manufacturer with a recommended inflation pressure, which permits safe operation within the specified load rating and vehicle loading. Most tyre's are stamped with a maximum pressure rating. For passenger vehicles and light trucks, the tyre's should be inflated to what the vehicle manufacturer recommends, which is usually located on a decal just inside the driver's door or in the vehicle owners handbook. Tyre's should not generally be inflated to the pressure on the sidewall; this is the maximum pressure, rather than the recommended pressure. Many pressure gauges available at fuel stations have been de-calibrated by manhandling and the effect of time, and it is for this reason that vehicle owners should keep a personal pressure gauge with them to validate the correct tyre pressure.

Inflated tyre's naturally lose pressure over time. Not all tyre-to-rim seals, valve-stem-to-rim seals, and valve seals themselves are perfect. Furthermore, tyre's are not completely impermeable to air, and so lose pressure over time naturally due to diffusion of molecules *through* the rubber. Some drivers and stores inflate tyre's with nitrogen (typically at 95% purity), instead of atmospheric air, which is already 78% nitrogen, in an attempt to keep the tyre's at the proper inflation pressure longer. The effectiveness of the use of nitrogen vs. air as a means to reduce the rate of pressure loss is baseless, and has been shown to be a bogus marketing gimmick. One study noted a 1.3 psi (9.0 kPa; 0.090 bar) difference (from an initial pressure of 30 psi (210 kPa; 2.1 bar)) for air-filled vs. nitrogen-filled tyre's. However, the statistical significance of the purported 1.3 psi (9.0 kPa; 0.090 bar) difference in the latter study is questionable, since no *t*-test nor *p* values were reported. Furthermore, and more importantly, the experimental design of the latter study was flawed, since the experiment was not repeated for the air-filled tyre's switched with the nitrogen-filled tyre's. Such an experimental design would have controlled for the possibility that the putative faster-leaking air-filled tyre's was not due to leaking issues associated with the quality of the various seals (tyre-to-rim, valve-stem-to-rim, and the valve itself), rather than being due to differences in through-rubber diffusion rates, as implied.

The tyre contact patch is readily reduced by both over & under inflation. Over-inflation may increase the wear on the center contact patch, and under-inflation will cause a concave tread, resulting in less center contact. Most modern tyre's will wear evenly at very high tyre pressures, but will degrade prematurely due to low (or even standard) pressures. An increased tyre pressure has many benefits, including decreased rolling resistance. It has been found, that an increased tyre pressure almost exclusively results in shorter stopping distances, except in some circumstances that may be attributed to the low sample size. If tyre pressure is too low, the tyre contact patch is changed more than if it were over-inflated. This increases rolling resistance, tyre flexing, and friction between the road and tyre. Under-inflation can lead to tyre overheating, premature tread wear, and tread separation in severe cases.

High Pressure: High performance and dynamic drivers often increase the tire pressure to near the maximum pressure as printed on the sidewall. This is done to sacrifice comfort for performance and safety. A tire at higher pressure is more inclined to keep its shape during any encounter, and will thus transmit the forces of the road to the suspension, rather than being damaged itself. This allows for an increased reaction speed, and "feel" the driver perceives of the road. Modern tire designs allow for minimal tire contact surface deformity during high pressures, and as a result the traditional wear on the center of the tire due to reasonably high pressures is only known to very old or poorly designed tires.

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Low Pressure : It is dangerous to allow tire pressure to drop below the specification recommended on the vehicle placard. Low pressure increases the amount of tire wall movement resulting from cornering forces. Should a low-pressure tire be forced to perform an evasive maneuver, the tire wall will be more pliable than it would have been at normal pressure and thus it will "roll" under the wheel. This increases the entire roll movement of the car, and diminishes tire contact area on the negative side of the vector. Thus only half the tire is in contact with the road, and the tire may deform to such an extent that the side wall on the positive vector side becomes in contact with the road. The probability of failing in the emergency maneuver is thus increased.

When driving on sand or in deep snow, tire pressure is sometimes lowered to reduce the chance of bogging down. Furthermore, the tire will absorb more of the irregular forces of normal driving. With this constant bending of the side wall as it absorbs the contours of the road, it heats up the tire wall to possibly dangerous temperatures. Additionally, this flexing degrades the steel wire reinforcement; this often leads to side wall blow-outs.

Tyre inflation pressure determines the tyre elasticity and combination with load, determines the deflection in the side walls and contact region. The overall effect of rolling resistance is depends on the elasticity of the ground. On the soft surfaces like sand, high inflation pressure results in increased ground penetration work and therefore higher coefficients while the lower inflation pressure decreasing ground penetration. Thus the optimum pressure depends on the surface deformation characteristics.

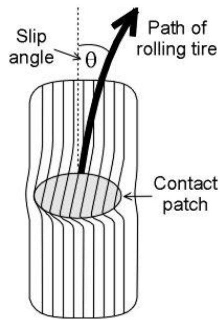
1.2.4 Speed of Vehicle

The rolling resistance is directly proportional to speed of vehicle because of increasing of flexing work and vibration in the tyre body. Influence of speed becomes more important when combines with lower inflation pressure.

1.2.5 Tyre Material Design

The material and thickness of both the tyre sidewalls and the tread determines the stiffness and energy losses in the rolling tyre. The cord material in the sidewall has only as mall effect, but the cord angle and tyre belt properties have significant influence on rolling resistance of tyre.

1.2.6 Tyre Slip Angle



Wheels Tractive and braking forces showshigher effects on rolling resistance due to thewheel slip angle. At a few degree of slip therolling resistance coefficient may nearly doublein the magnitude .

1.2.7 Tyre Wear

The wear performance of a tyre is its ability to reach high mileages. One way of evaluating this wear performance is consider the duration of tyre service life, which is the mileage after which a point on the tread has reached the legal limit of the wear indicator. The duration of a tyre's Service life depends on the mass loss from the tread, which is usually expressed in g/100 km, and by the transverse worn profile which enables the wear shape of the tread to be qualified. The duration of a tyre's service life depends on the condition in which the tyre is used, that is the type of driver and the geographical area. Wear is depend upon many parameters, which gives designer to modification tyre force applied on tyre or changes in rubber or ground surface.

1.2.8 Road Surface and Styles of Driving

Depending upon the route and the style of driving, the acceleration levels reached by the vehicle may vary. These acceleration levels modify the forces applied to the tyre. The system of loads causing wear in the contact patch (sliding, stresses) is directly proportional to these forces. The effect of the style of driving can be quantified by measuring the tyre wear on the same vehicle driven by different drivers over the same course .

1.2.9 Tyre selection

When selecting a tyre, look for the one most suitable for the job. Tyre size and PR should be determined after weighing the loads on each wheel according to accepted procedures or calculating the loads. Generally it is recommended to choose the tyre that carries the load with lowest the inflation pressure. After selecting the tyre's and mounting them do not overload the vehicle, for example, by adding sideboards.

1.2.10 Load capacity

When determining the minimum tyre size necessary for any particular wheel position of a vehicle, the approved load and the maximum design speed of the vehicle must always be used as a basis.All tyre pressures refer to the "cold" tyre which has been standing outdoors or several hours, not exposed to intense sunlight

1.3 INFLATION PRESSURE

Fig:1.3 Tyre variations based on Inflation Pressure

Proper inflation pressure is the single most important feature of a **good tyre maintenance** programme. 'Published'- Inflation pressures are for Standard Loads.
Inflation pressures should be checked daily. Recommended inflation pressures based on total load on tyre's should be used. Always use valve caps to prevent loss of air.

1.3.1 Over Inflation – Over inflated tyre's do not flex as designed, do not absorb shocks, makes too much tension on both rubber & fabric making tyre more vulnerable to cuts, snags, impact breaks, concussion & rapid tread wear.

- Reduces the amount of tread contact with ground.
- In soft soil – digs deeper into the ground.
- Provides less flotation & traction.
- Tends to spin & skid due to less contact patch.
- Center of tread wear faster.
- Vehicle rides harder & vibrates more ……..
- Causes ore spillage & excess wear & tear of vehicle components / parts.

1.3.2 Under Inflation – Under inflation results in excessive flexing of tyre's, excessive heat generation, rapid shoulder wear or uneven wear.

Underinflated tyre's flex too much on sidewall, causing excessive internal temperature. This can cause permanent tyre damage, such as: –

- Flex breaks / Casing break up.
- Radial Cracks
- Tread OR Ply Separation
- Loose cords in band ply.
- Excessive bead rocking in the flange area.

It is very important to maintain the Tyre inflation Pressure. Tyre life varies depending on the inflation pressure.

Over inflation decreases Tyre life, however – under inflation tends to cause various premature failures which result in much greater decrease in tyre life.

1.3.3 Proper Inflation – tyre's are designed to carry loads up to the maximum specified at the inflation pressure for desired deflections, road contact, tread wear. Any neglect of inflation pressure will result in one or more of serious tyre failures or loss of tyre life potential.

Overloading Kills tyre's:-

- To ensure maximum tyre life, never load off-the- highway tyres above the recommended maximum limit.
- Before increasing the vehicle load capacity, be sure that tyre with adequate load capacity to be applied (Larger size and (or) higher ply rating.)
- Load is closely related to Inflation, Speed and Length of Haul.

1.3.4 Speed:-

Tyre's should not exceed the maximum speed classification in relation with the load. Excessive speed results in higher heat generation, due to increase in the rate of flexing that takes place. This can result in tyre's failing due to heat separations, casing fracture due to impact & increased rate of tread wear.

1.4 Few common premature Tyre failure & its causes:-

1.4.1 Impact Break / Tread Concussion:-

CAUSE – TYRE BURST OR CASING FRACTURE

REASONS:-

- Mainly due to over inflation – excessive air pressure in tyre, in relation to load. Carcass or ply cords are over stretched and any slight impact or cut result in tyre blow out.
- Badly maintained road with potholes & spillage also can lead to tread concussion or casing fracture.

1.4.2 Deflation Damage / Run Flat:-

CAUSE - LOSS OF AIR FROM TYRE.

REASONS:-AIR LEAK IS DUE TO,

- O' Ring

- Valve core / Valve assembly
- Defective Rims – Bent rim / Pitted rims
- Damage on the tyre bead seat area incase of Tubeless tyre.
- Through cut on tyre.

Bleeding of tyre / slow loss of air from the tyre – result in excessive compression of cords or plies on sidewall and the cords are pulled out or broken.

1.5 HOW TO AVOID SUCH FAILURES:-

1. O' RING

- Always use new O-ring on every fitment.
- Lubricate O-ring with mild vegetable oil soap solution.
- Never use grease / petroleum based oils to lubricate rubber components.
- Never use a used or damaged / deformed O-ring.
- Always use a standard company O-ring as replacement.

2. VALVE CORE / VALVE ASSEMBLY

- Always use valve cap. It avoids mud / dust & small stone particles entering valve core pin.
- Metallic valve cap also arrest minor air leak if any through valve core.
- Check valve core & valve assembly joints with soap solution, if any leak found rectify immediately.

3. RIMS

- Old or poorly maintained rims will lead to corrosion / rusting due to humidity / water content in the air, inside tyre. Over a period of time, small pits / holes are formed on the inner surface of the rim.
- Periodically all rims should be cleaned & give anti-corrosive treatment (primer& painting) by which the life of the rims also can be increased.

4. IMPROPER BEAD SEATING

- Bent rim / severely run out rims, can have less contact with the bead seat – makes provision for air loss.
- Bead seat not properly seated on rim.
- To check the proper seating of the bead with rim centering lines.

5. DAMAGED BEAD SEAT IN TUBELESS TYRE

- Happens due to improper handling of tubeless tyres.
- Improper fitment.
- Defective rim.

6. TYRE PUNCTURE & THROUGH CUTS

- Mainly due to poor / bad road surface conditions. Potential for tyre cuts & through cuts.

1.6 Tread Looseness (or) Heat failure:-

MAJOR CAUSE - EXESSIVE HEAT BUILD UP IN TYRE.

REASONS:-

- Under inflation or overloading.

- Mismatch of tyre’s
- Speed

Uneven Tread wear:-

MAJOR CAUSE - MAINLY DUE TO VEHICLE MISALIGNEMENT.

REASONS:-

- Defective steering geometry.
- Defective / worn out wheel bearing.
- Worn out bushes / pins.

1.7 Road Traffic safety effect on tyre life:

Road traffic safety regulation require vehicle to be able to stop within visibility distance. The reaction pathway depends on the driver´s speed of reaction, concentration, experience and immediate mental and physical condition. The driver does not change direction or speed of a vehicle during the phase from noticing obstacle to the stopping of the vehicle. The stopping distance of a vehicle is determined by several factors which affect tyre grip such as weather conditions (e.g. rain, fog, lighting conditions), geography (e.g. slope traverse plane), speed, quality and type of tyre. The driver scope is influenced by density of transport flux, the driver's view of traffic flow (e.g. saddle, peak), topography and environment.

The driver is required to drive only at a speed to be able stop before an obstacle is suddenly revealed ahead. The distance travelled by the vehicle from the moment of the obstacle appearing to the vehicle standstill is called trajectory required to stop a vehicle. It is influenced by the driver's ability to respond to the technical and structural status of the braking system, driver´s speed and tyre design. This distance can be calculated using the following formula:

$$s_z = (t_r + t_o)v + v.t_n - \frac{b_N.t_N^2}{2} + \frac{v_N^2}{2.b}$$,[3] where

t_r - driver response time[s] – the period between the driver noticing and touching on the service brake pedal,

t_o - delay time of brakes[s] – for vehicles with hydraulic brakes application takes the value of 0.05 s,

t_N - increased time of braking deceleration[s] – for vehicles with hydraulic brakes application takes the value of 0.15s,

v - initial speed of the vehicle[m.s^{-1}],

v_N - vehicle speed is reduced due to the onset of braking deceleration[m.s^{-1}],

b_N - braking deceleration of the vehicle during braking increasing. Because of increases from 0 to full value can be determined as a half of the full average braking deceleration[m.s^{-2}],

b - full average braking deceleration[m.s^{-2}].

This equation describes the stopping distance, consisting of sections since the point of driver reaction time (appears obstacle) to the time to stop the vehicle. Stopping distance consists of the following phases.

1. phase - reactions driver t_R,

2. phase - delay braking performance t_O,

3. phase - attack braking, half braking deceleration,4. phase - full braking effect, fully developed deceleration.

1.8 Distance required to stop vehicles is influenced by:

Driver - physical and mental condition, age, level of training and experience affect the length of the reaction time of the driver and as well distance covered by vehicle without direction and speed of movement correction. This practice in turn affects response suitability. A quick but incorrect response is worse than the slow but correct response,

Vehicle - technical condition (condition of brake fluid, brake lining and pads etc.), design of the suspension and brake system (drum bakes or disc brakes, ABS, Brake Assistant, technical condition of suspension, shock absorbers, etc..) Specifications, Technical Condition and used Tyre's design.

Road – the kind of surface (asphalt, concrete panels, natural terrain) road surface condition (dry, wet, icy or snowy surface, flat bumpy or wavy surface) etc.

Tyre's basic conditions affecting the braking of the vehicle. These are in fact the only part that connect the vehicle with the ground. The ability to transmit force to the tyre base determines how big the vehicle deceleration is achieved. Size of load depends not only on the tyre and construction of the tyre and the wear speed, but also varies according to the inflation pressure. Each of the previously listed properties significantly affect the distance of track to stop the vehicle and thus drive safety. Tyre pressure is a parameter that 2/3 of drivers do not reach. Therefore, the aim of this paper is to show the influence of tyre pressure on the stopping distance of the vehicle. This will directly affect whether the driver stopped in front of an obstacle or it encounters a residual rate. Exclude the influence of the human factor, the measurement of the stopping distance consisting of Phase 2, 3 and 4 is performed on the same surface in order to ensure measurements comparability.

1.8.1 Tyre Pressure

Optimal value for a specific inflation pressure prescribed by the vehicle manufacturer to achieve the best performance of the vehicle, limiting the transmission of road surface irregularities on the vehicle, and of course to achieve the shortest stopping distance.

It has been perform comparative measurements at an initial speed of 50 km.h^{-1} to demonstrate the influence of pressure inflation on a braking distance of the vehicle. This speed has been determined based on the fact that most countries have set the speed limit in urban areas at 50 km.h^{-1}. The reason is high traffic volume and always increasing number of mobility vulnerable road users (e.g. pedestrians, cyclists, drivers) in the village. Increased probability of collision is also caused by building-up areas as driver´s view is restricted.

1.9 Tyre types

1.9.1 Classification According to the structure

Fig:1.4 Schematic representation of Tyre Structure

(1) Bias Tyre

Layers of one ply cord material are placed on the tyre carcass diagonally from one tyre bead to the other at angles of about 40° to the centerline of the tread. The lengthy research and development period have given this tyre an overall steady performance and stiff sidewall. With the advent of the radial tyre however, the bias tyre is now used much less frequently.

(2) Radial Tyre

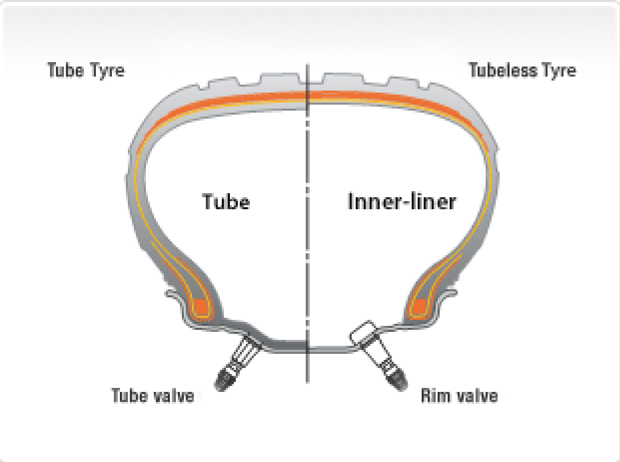
A radial tyre uses a cord angle of 90 degrees. That is, the cord material runs in a radial or direct line from one bead to the other across the tread. In addition, a radial tyre has a belt overwrap under the tread surface to provide greater structural stability. The belt overwrap of a radial tyre distortion while the radial structure enables high speed driving.

(3) Tubeless Tyre

As cars became faster, the tubeless tyre was developed to protect drivers and cars from the dangers of flat tyre accidents while driving at high speeds. Instead of using a tube, a lining (inner liner) of special rubber with low air permeability inside the tyre prevents air leaks from the tyre and rim. This means that even if a nail punctures the tyre while on the move, air pressure will not be lost very rapidly. However, careful tyre maintenance is still necessary as there is no tyre that does not go flat. In addition, there are tubeless tyre’s that use airtight, highly binding cement on the inside of the inner liner to decrease air leakage even further.

Advantages of a Tubeless Tyre
- Maintains air pressure
- Sudden air leakage does not occur even with puncture
- Improved heat emission while driving because air inside the tyre is in direct contact with rim
- Less maintenance or mishaps with tube
- Increased operation efficiency with no tube assembly

Disadvantages of a Tubeless Tyre
- Separation occurs if crack appears inside tyre bead
- Air leakage in the case of imperfect tyre-rim assembly or disfiguration in the rim flange. In particular, caution is needed when driving on unpaved roads as rocks and other debris may damage the rim flange and cause air leakage.



Structural comparison of tube/tubeless tyre

1.9.2 Classification According to season

(1) Summer Tyre

As a tyre for use in seasons without snow (spring, summer, fall), the summer or general tyre is optimized for reduced noise, smooth driving and safe handling at high speeds.

(2) All Season Tyre

Developed to relieve the difficulty of changing from summer tyres to winter ones in regions with short snow seasons, the all season has more tread kerfs than the summer tyre.

1.9.3 Classification According to application

(1) Regular Tyre

It is also called a ground tyre that is not for emergency use.

(2) All Season Tyre

When a regular tyre has been damaged by a flat or other reason and cannot be used, the emergency tyre may be used temporarily. Emergency tyre’s can save trunk space and reduce the weight of the car. There are two types of emergency tyre’s:

(a) Foldable emergency tyre’s

(b) T-type emergency tyre’s

Emergency tyre’s are manufactured only for use in emergencies and cannot be used at speeds of over 80km/h. The pneumatic pressure has to be maintained at 60psi and the air pressure should be checked at least once a month.

(3) Run Flat Tyre

Even when the air pressure within the tyre reaches zero due to damage such as a flat, this tyre can be used to drive 80km at 80km/h speed to a location where a tyre change can be made.

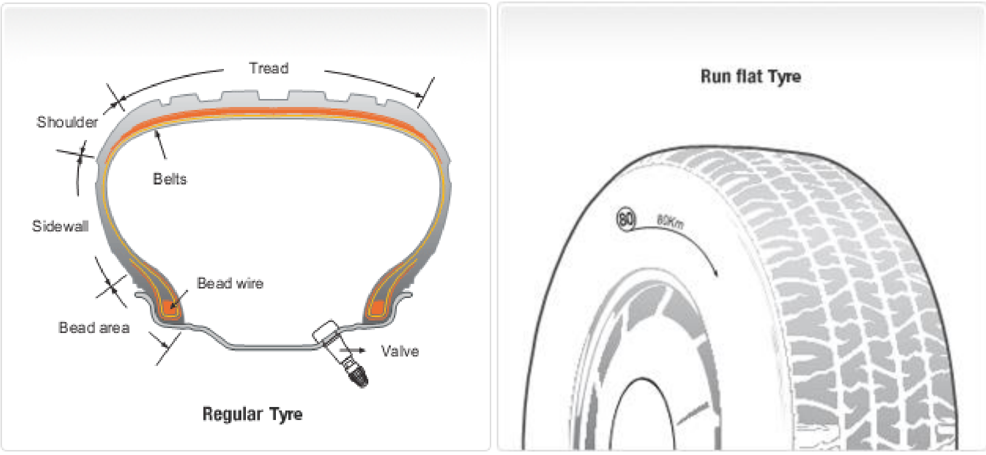
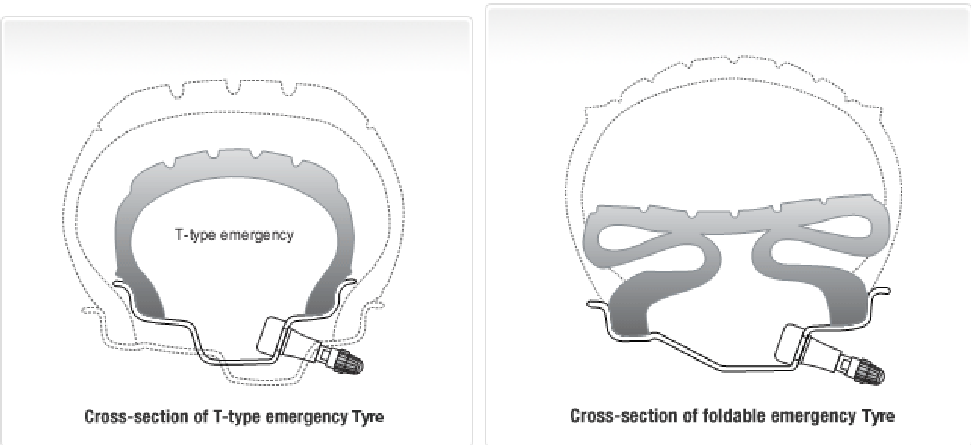


Fig:1.6 Types of car tyre’s according to applications



1.10 Life of a car tyre

The life of a car tyre varies with the size and kind of vehicle. Small hatchbacks tyre’s have an average life of about 40,000 km, but some even touch 50,000 km. SUV tyre’s can go about 60,000 km. Some expensive sedans with low-profile tyre’s only manage about 30,000 km from their tyre’s. The life of the tyre also depends on the compound used – softer tyre's have better grip, but last less. Harder tyre's have longer life, but may not be good at grip.

But all these figures can vary drastically depending on the driving conditions and maintenance of the vehicle. If you drive on bad roads, or drive fast and brake hard, you can reduce tyre life by nearly 50%. Or if your car has an alignment or suspension problem, this too will badly affect your tyre's. And then there's tyre pressure – always maintain the recommended pressure, checking it every fortnight.

LITERATURE SURVEY

REVIEW ON TYRE PERFORMANCE PARAMETERS AND ITS SETUP by Virkar D

The purpose of this review paper is to study of effect of the different tyre operating parameters on tyre performance and review of testing setup to test these tyre performance parameters. The testing of tyre performance parameters by experimentally is help to designer to correlate the relationships of parameters and to design the tyre, hence it is need to testing of tyre. Knowledge about dynamic properties of tyre's is an essential for any kind of research and development activities on vehicle dynamics. The main purpose of laboratory testing is to separate the properties of the tyre from the vehicle, achieve high rate of reproducibility and to optimize the cost. This review paper gives the information regarding of different researcher's works on inter laboratory tyre testing setup for measuring tyre performance parameters and also this review paper helps to understand the factors on which tyre performance parameters is depends.

TYRE INFLATION PRESSURE INFLUENCE ON VEHICLE STOPPING DISTANCES by VladimírRievaj, JánVrábel, Anton Hudák

Health and ensure the safety of the road is now a priority in Europe. The authors deal with the adhesion problems of tyre's – ground contact under process of vehicle braking. The proper tyre pressure is just part of many factors inflicting stopping distances of vehicle. The article describes the stopping distance dependence on tyre pressure. It has been tested three probable options (e.g. overcrowding, under-inflation and adherence to the values specified by the manufacturer).

DESIGN OF AUTOMATIC TYRE INFLATION SYSTEM

by HemantSoni, Pratik Golar, AshwinKherde

Driven by studies that show that a drop in tyre pressure by just a few PSI can result in the reduction of gas mileage, tyre life, safety, and vehicle performance, we have developed an automatic, self-inflating tyre system that ensures that tyre's are properly inflated at all times. Our design showing and successfully implements the use of a centralized compressor that will supply air to all four tyre's via hoses and a rotary joint fixed between the wheel spindle and wheel hub at each wheel. The rotary joints effectively allow air to be channeled to the tyre's without the tangling of hoses. With the recent oil price hikes and growing concern of environmental issues, this system addresses a potential improvement in gas mileage; tyre wear reduction; and an increase in handling and tyre performance in diverse conditions. In this paper we have taken into consideration design aspects of the ATIS.

2. CALCULATIONS

2.1 CALCULATION OF INFLATION PRESSURE IN TYRES

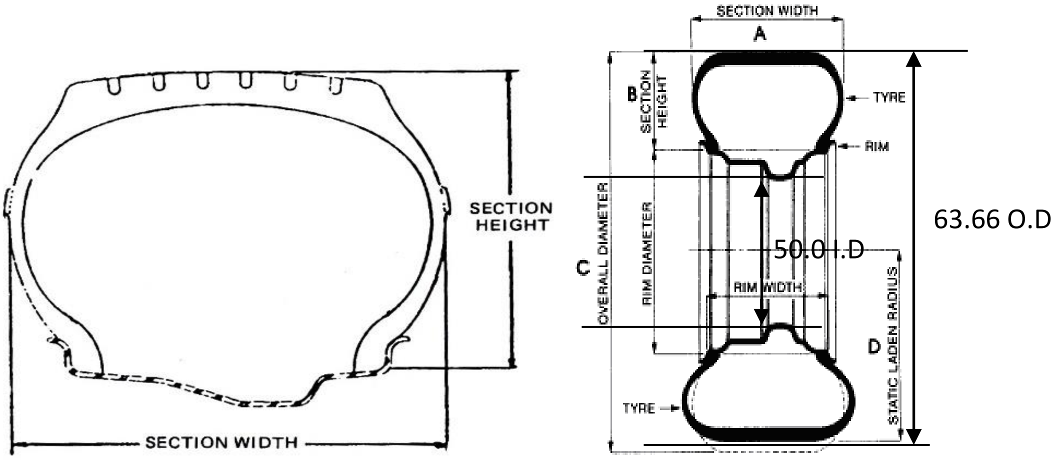


Fig:2.1 Schematic representation of Tyre section height and section width

Aspect ratio(a) $= \frac{\text{section Width}}{\text{section height}} \times 100$

Section width(w) $= \frac{OD-ID}{2}$

$= \frac{63.6620-50}{2} = 6.831\text{mm}$

Section height (h) = OD-ID

= 63.6620-50 =13.6620mm

Inflation pressure :

P = Inflation pressure (N/mm^2) w = load on tyre (250N)

r = Radius of Outer Dia (31.83mm) a = Aspect Ratio (50)

$$P = \frac{3w}{2\pi a^2}\sqrt{1-\left(\frac{r}{a}\right)^2} = \frac{3\times 250}{2\times 3.14\,(50*50)}\sqrt{1-\left(\frac{31.83}{50}\right)^2}$$

=0.04777070064×0.7711941649

=0.0368404N/mm^2

2.2 CALCULATION FOR ROLLING LOSS WITH RESPECT TO INFLATION RESSURE

R= Rolling resistance (N)

W= Tyre load (N)

P = Inflation pressure (N/mm^2)

$$R = \frac{energy\ input\ into\ a\ tyre - energy\ output\ by\ tire}{speed}$$

$$R = \frac{Energy\ lost\ in\ tyre}{speed}$$

General equation for Rolling resistance in terms of tire load (W) at constant inflation pressure is

$R = \frac{hwd}{A}(W) = C_1W$ (Using Journal SAE J1269 & IJEMS VOL. 11 Oct 2004)

Where h = Hysteresis ratio

w = footprint width

d = deflection

A = Area

W= weight (N)

Here C_1 is the constant. The mean slope C_1 was found to be 0.010 and 0.0078 for truck and passenger respectively.

2.2.1 Rolling resistance for considered loads

	Skoda Rapid (Kerb wt – 1500Kg)	Ford classic (Kerb wt - 1150Kg)
1.	1850kg	1500kg
2.	1920kg	1570kg
3.	1990kg	1640kg

Skoda Rapid

R = WC₁

R=1850*0.0078*9.81 =141.55N

R=1920*0.0078*9.81 =146.91N

R=1990*0.0078*9.81 =152.27N

Ford Classic

$R = WC_1$

R=1500*0.0078*9.81 =114.77N

R=1570*0.0078*9.81 =120.13N

R=1640*0.0078*9.81 =125.48N

A general relation between R and P can be express as

$$\boldsymbol{R} = \boldsymbol{C_1}\frac{\mathbf{1}}{\boldsymbol{P}^{0.5}} \text{ (Using Journal SAE J1269 \& } IJEMS\ VOL.\ 11\ Oct\ 2004)$$

Where

P= inflation pressure

C_1= constant $\left[\frac{\boldsymbol{hwd}}{\boldsymbol{A}}(\boldsymbol{W})\right]$

$$\boldsymbol{R} = \boldsymbol{C_1}\frac{\mathbf{1}}{\boldsymbol{P}^{0.5}}$$

On substituting the values in above equation

$$\boldsymbol{R} = (\mathbf{0.0078}) * \frac{\mathbf{1}}{(\mathbf{0.036})^{0.5}}$$

R=0.0411N

2.2 CALCULATION FOR FUEL CONSUMPTION WITH RESPECT TO ROLLING LOSS

By observing the above calculations, with the increase of weight, the rolling resistance increases, the fuel consumption also increases. Applying Schuring's rolling resistance versus fuel consumption results, it can be concluded that a 100% increase in rolling resistance of a tire would cause about 25-30% increase in fuel consumption.

Skoda Rapid

R=1850*0.0078*9.81 =141.55N
R=1920*0.0078*9.81 =146.91N
Rolling Resistance Change Percentage = 146.91-141.55/146.91 = 3.64%
Fuel Consumption change Percentage
100% - 3.64%
30% -?
3.64*30/100
= 1.094%
By increase of rolling resistance from 141.55N to 146.91N, the fuel consumption increase by 1.09%
R=1850*0.0078*9.81 =141.55N
R=1990*0.0078*9.81 =152.27N
Rolling Resistance Change Percentage = 152.27-141.55/152.27 = 7.04%
Fuel Consumption change Percentage
100% - 7.04%
30% - ?
7.04*30/100 = 2.11%

By increase of rolling resistance from 141.55N to 152.27N, the fuel consumption increase by 2.11%.

Ford Classic

R=1500*0.0078*9.81 =114.77N

R=1570*0.0078*9.81 =120.13N

Rolling Resistance Change Percentage = 120.13-114.77/120.13 = 4.46%

Fuel Consumption change Percentage

100% - 4.46%

30% - ?

4.46*30/100 = 1.33%

By increasing Rolling resistance from 114.77N to 120.13N,The fuel consumption increase by 1.33%

R=1500*0.0078*9.81 =114.77N

R=1640*0.0078*9.81 =125.48N

Rolling Resistance Change Percentage = 125.48-114.77/125.13 = 8.55%

Fuel Consumption change Percentage

100% - 8.55%

30% - ?

8.55*30/100 = 2.56%

By increase of rolling resistance from 114.77N to 125.48N, the fuel consumption increase by 2.56%

2.3 THE WEIGHTS CONSIDERED FOR ANALYSIS

According to the SAE Standard Procedure J1269, the relationship of load applied on tyre and road contact ellipse area is

Fig:2.2 Tyre road contact area in ellipse shape

Road contact ellipse Area (a) = 9.9*(load)$^{0.68}$

Tyre inside Pressure (P) = $\frac{\text{Applied load on tyre}}{\text{Contact area of tyre}}$

Skoda Rapid (Kerb wt – 1500Kg)

1. 5 persons weight each 70Kgs (350) + Kerb Weight (w) = 1850kg
Road contact ellipse Area (a) =1649.3 mm^2
Tyre inside Pressure(P) = $\frac{w}{a}$ = 1.12N/mm^2
2. 6 persons weight each 70Kgs (420) + Kerb Weight (w) =1920kg
Road contact ellipse Area (a) =1691.53 mm^2
Tyre inside Pressure(P) = $\frac{w}{a}$ = 1.13N/mm^2
3. 7 persons weight each 70Kgs (490) + Kerb Weight (w) =1990kg
Road contact ellipse Area (a) =1733.32 mm^2
Tyre inside Pressure(P) = $\frac{w}{a}$ = 1.14N/mm^2

Ford classic (Kerb wt - 1150Kg)

1. 5 persons weight each 70Kgs (350) + Kerb Weight (w) = 1500kg

Road contact ellipse Area (a) =1430.13 mm^2
Tyre inside Pressure(P) = $\frac{w}{a}$ = 1.04 N/mm^2

2. 6 persons weight each 70Kgs (420) + Kerb Weight (w) = 1570kg

Road contact ellipse Area (a) =1475.18 mm^2

Tyre inside Pressure(P) = $\frac{w}{a}$ = 1.06 N/mm^2

3. 7 persons weight each 70Kgs (490) + Kerb Weight (w) = 1640kg

Road contact ellipse Area (a) = 1519.59 mm^2

Tyre inside Pressure(P) = $\frac{w}{a}$ = 1.07 N/mm^2

Table 2.1: Values of Rolling loss change & Fuel consumption Change in Percentage of Skoda Rapid car

Load(W) in Kg (Car + Person's wt)	**Rolling loss(R) in N** ($R=C_1W$)	**Rolling loss change in percentage (%)** (Max-Min)/Max	**Fuel consumption change in percentage (%)**

1500+350 (5 members) 1500+420 (6 members) 1500+490 (7 members)	R_1= 141.55 N R_2 =146.91N R_3 = 152.27N	3.64% (R_2-R_1/ R_2) (From 5 to 6 members) 7.04% (R_3-R_1/ R_3) (From 5 to 7 members)	1.094% (using Schuring's eq) 2.11% (using Schuring's eq)

(The Schruing's equation is taken as reference in IJEMS VOL.11 Oct 2004)

Ford Classic car :

Table 2.2: Values of Rolling loss change & Fuel consumption Change in Percentage of Ford Classic car

Load(W) in Kg (car + Person's wt)	**Rolling loss(R) in N** ($R=C_1W$)	**Rolling loss change in percentage (%)** **(Max-Min)/Max**	**Fuel consumption change in percentage (%)**
1100+350 (5 members) 1100+420 (6 members) 1100+490 (7 members)	R_1= 114.77 N R_2 =120.13 N R_3 = 125.13N	4.46% (R_2-R_1/ R_2) (From 5 to 6 members) 8.55% (R_3-R_1/ R_3) (From 5 to 7 members)	1.33% (using Schuring's eq) 2.56% (using Schuring's eq)

(The Schruing's equation is taken as reference in IJEMS VOL.11 Oct 2004)

3. COMPUTER AIDED DESIGN

Introduction:

Computer-aided design (**CAD**), also known as **computer-aided design and drafting** (**CADD**), is the use of computer technology for the process of design and design-documentation. Computer Aided Drafting describes the process of drafting with a computer. CADD software, or environments, provide the user with input-tools for the purpose of streamlining design processes; drafting, documentation, and manufacturing processes. CADD output is often in the form of electronic files for print or machining operations. The development of CADD-based software is in direct correlation with the processes it seeks to economize; industry-based software (construction, manufacturing, etc.) typically uses vector-based (linear) environments whereas graphic-based software utilizes raster-based (pixelated) environments.

CAD may be used to design curves and figures in two-dimensional (2D) space; or curves, surfaces, and solids in three-dimensional (3D) objects.

CAD is an important industrial art extensively used in many applications, including automotive, shipbuilding, and aerospace industries, industrial and architectural design, prosthetics, and many more. CAD is also widely used to produce computer animation for special effects in movies, advertising and technical manuals. The modern ubiquity and power of computers means that even perfume bottles and shampoo dispensers are designed using techniques unheard of by engineers of the 1960s. Because of its enormous economic importance, CAD has been a major driving force for research in computational geometry, computer graphics (both hardware and software), and discrete differential geometry.

The design of geometric models for object shapes, in particular, is often called *computer-aided geometric design* (*CAGD*).

Current computer-aided design software packages range from 2D vector-based drafting systems to 3D solid and surfacemodelers. Modern CAD packages can also frequently allow rotations in three dimensions, allowing viewing of a designed object from any desired angle, even from the inside looking out. Some CAD software is capable of dynamic mathematic modeling, in which case it may be marketed as **CADD** — *computer-aided design and drafting*.

CAD is used in the design of tools and machinery and in the drafting and design of all types of buildings, from small residential types (houses) to the largest commercial and industrial structures (hospitals and factories).

CAD is mainly used for detailed engineering of 3D models and/or 2D drawings of physical components, but it is also used throughout the engineering process from conceptual design and layout of products, through strength and dynamic analysis of assemblies to definition of manufacturing methods of components. It can also be used to design objects.

CAD has become an especially important technology within the scope of computer-aided technologies, with benefits such as lower product development costs and a greatly shortened design cycle. CAD enables designers to lay out and develop work on screen, print it out and save it for future editing, saving time on their drawings.

3.1 Types of CAD Software

3.1.1 *2D CAD*

Two-dimensional, or 2D, CAD is used to create flat drawings of products and structures. Objects created in 2D CAD are made up of lines, circles, ovals, slots and curves. 2D CAD programs usually include a library of geometric images; the ability to create Bezier curves, splines and polylines; the ability to define hatching patterns; and the ability to provide a bill of materials generation. Among the most popular 2D CAD programs are AutoCAD, CADkey, CADDS 5, and Medusa.

3.1.2 *3D CAD*

Three-dimensional (3D) CAD programs come in a wide variety of types, intended for different applications and levels of detail. Overall, 3D CAD programs create a realistic model of what the design object will look like, allowing designers to solve potential problems earlier and with lower production costs. Some 3D CAD programs include Autodesk Inventor, CoCreate Solid Designer, Pro/Engineer SolidEdge, SolidWorks, Unigraphics NX and VX CAD, CATIA V5.

3.1.3 *3D Wireframe and Surface Modeling*

CAD programs that feature 3D wireframe and surface modeling create a skeleton-like inner structure of the object being modeled. A surface is added on later. These types of CAD models are difficult to translate into other software and are therefore rarely used anymore.

3.1.4 *Solid Modeling*

Solid modeling in general is useful because the program is often able to calculate the dimensionsof the object it is creating. Many sub-types of this exist. Constructive Solid Geometry (CSG) CAD uses the same basic logic as 2D CAD, that is, it uses prepared solid geometric objects to create an object.

3.2 INTRODUCTION TO PRO/ENGINEER

Pro/E- Wildfire is the standard in 3D product design, featuring industry-leading productivity tools that promote best practices in design while ensuring compliance with your industry and company standards. Integrated Pro/ENGINEER CAD/CAM/CAE solutions allow you to design faster than ever, while maximizing innovation and quality to ultimately create exceptional products.

Customer requirements may change and time pressures may continue to mount, but your product design needs remain the same - regardless of your project's scope, you need the powerful, easy-to-use, affordable solution that Pro/ENGINEER provides.

3.2.1 PRO/ENGINEER WILDFIRE BENEFITS

•Unsurpassed geometry creation capabilities allow superior product differentiation and manufacturability

•Fully integrated applications allow you to develop everything from concept to manufacturing within one application

•Automatic propagation of design changes to all downstream deliverables allows you to design with confidence

•Complete virtual simulation capabilities enable you to improve product performance and exceed product quality goals

•Automated generation of associative tooling design, assembly instructions, and machine code allow for maximum production efficiency

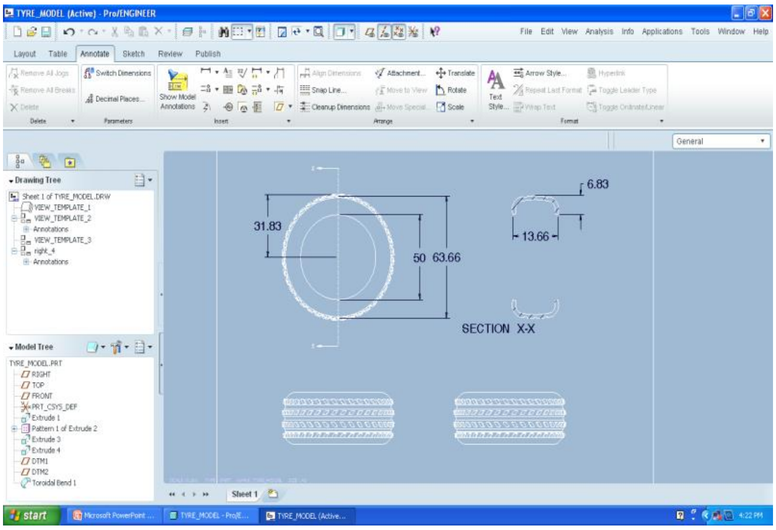
Pro ENGINEER can be packaged in different versions to suit your needs, from Pro/ENGINEER Foundation XE, to Advanced XE Package and Enterprise XE Package, Pro/ENGINEER Foundation XE Package brings together a broad base of functionality. From robust part modeling to advanced surfacing, powerful assembly modeling and simulation, your needs will be met with this scaleable solution. Flex3C and Flex Advantage Build on this base offering extended functionality of your choosing.

3.3 DIFFERENT MODULES IN PRO/ENGINEER

- PART DESIGN
- ASSEMBLY
- DRAWING
- SHEETMETAL

3.4 *3D MODELS OF TYRE AND RIM ASSEMBLY*

SKODA CAR TYRE MODELS



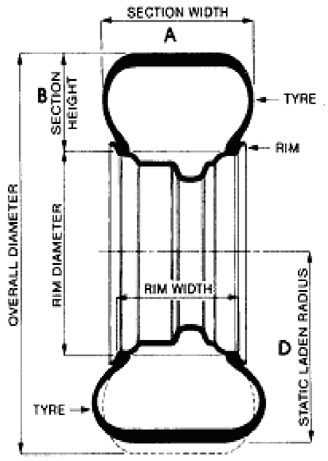


Fig 3.1 2D Design of Car Tyre Part with three views **Fig 3.1.1** Sectional 2d-representation

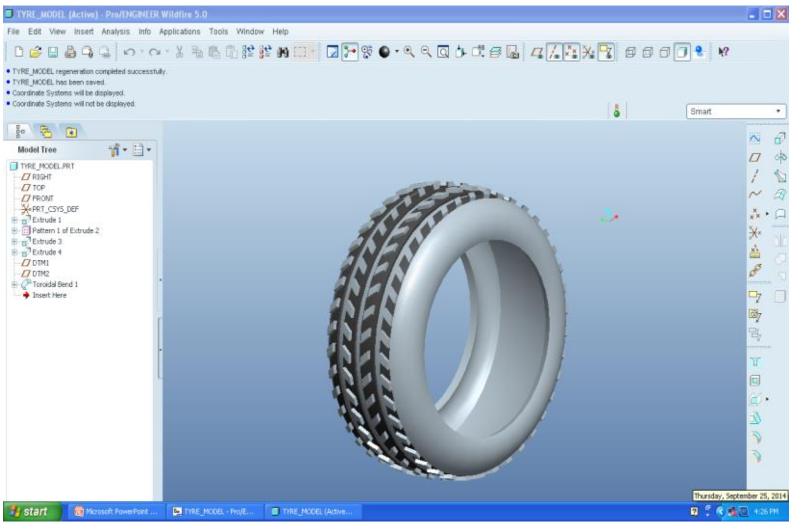


Fig 3.2 Pro-E Model of Skoda Car Tyre Part

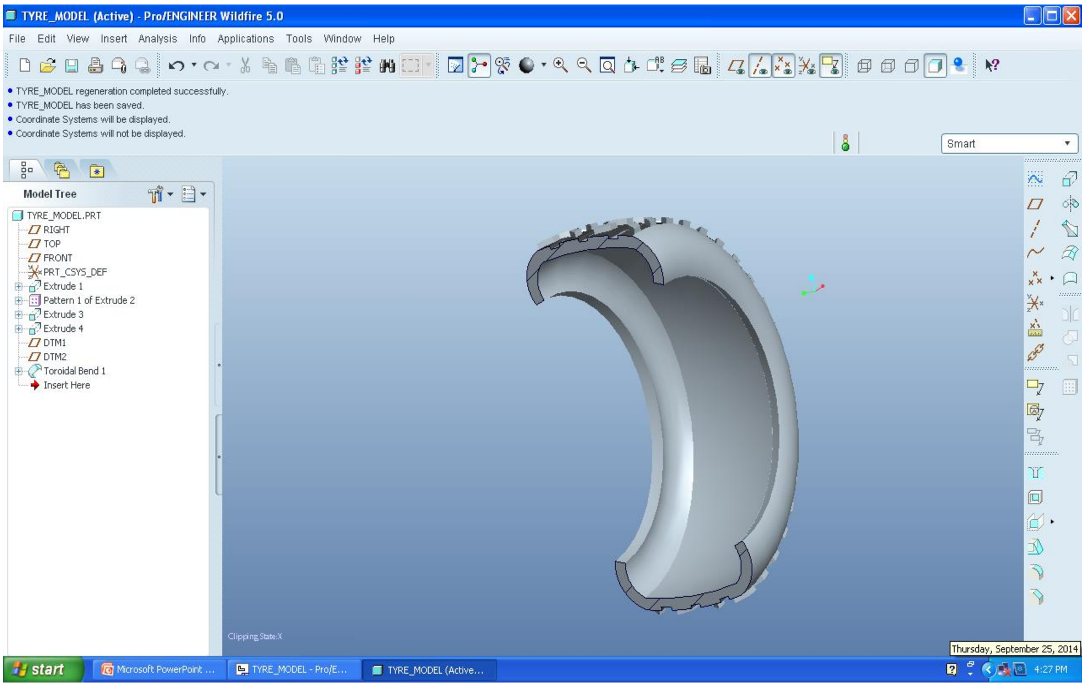


Fig 3.2.1 Sectional representation of Car Tyre Part in Part module environment

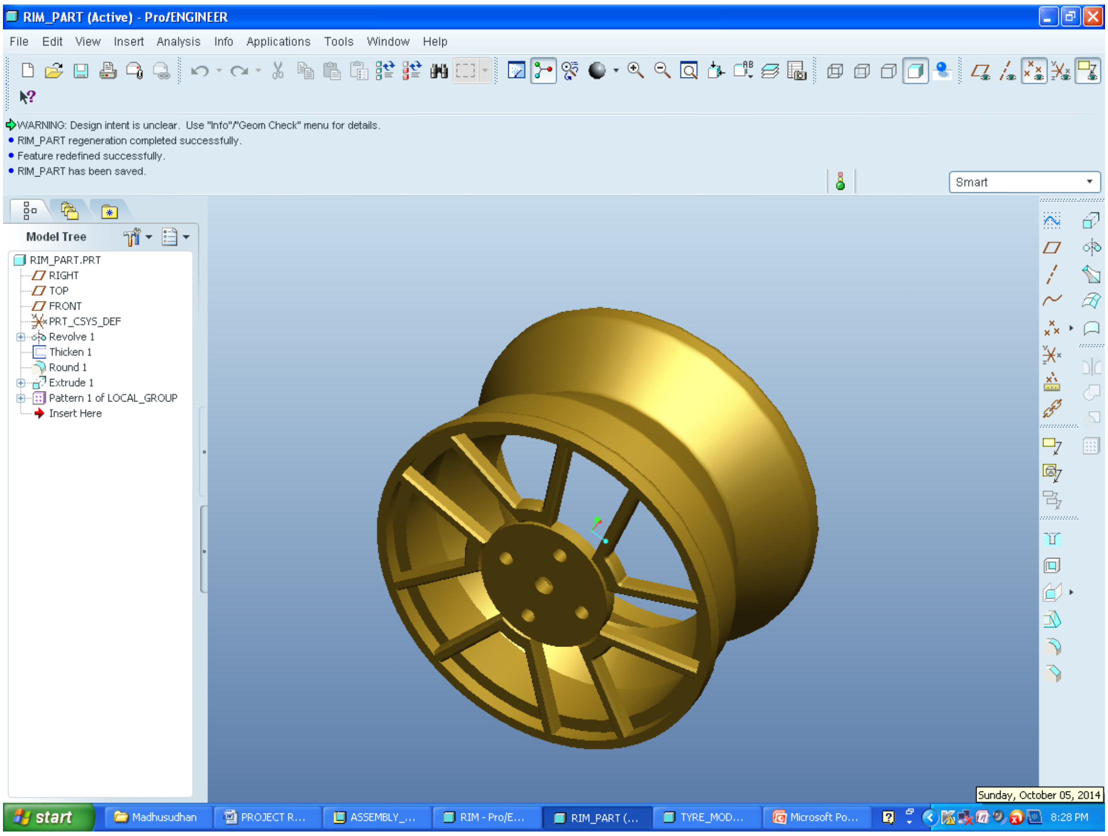


Fig 3.3 Pro-E Model of Skoda Car Rim Part

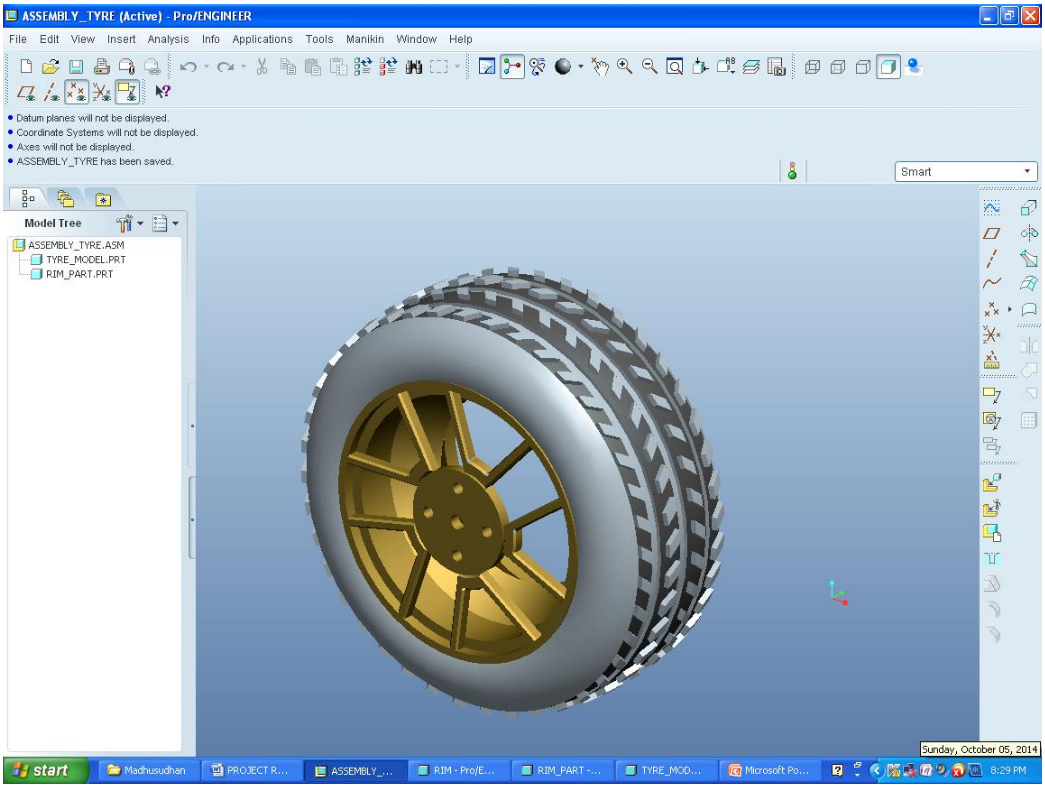
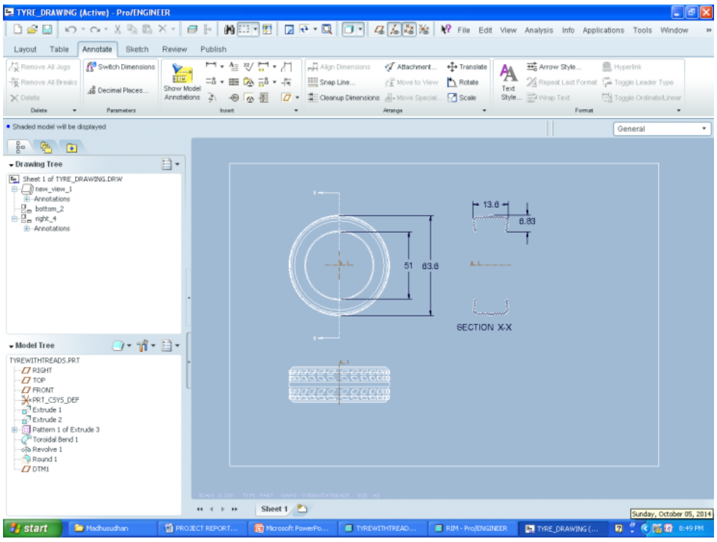


Fig 3.4 Pro-E Model of Skoda Car Tyre Assembly

FORD CAR TYRE MODELS



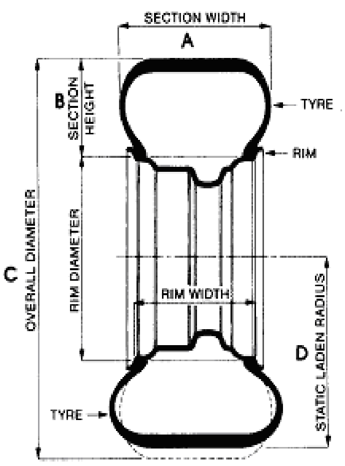


Fig 3.5 2D Design of Car Tyre Part with three views **Fig 3.5.1** Sectional 2d-representation

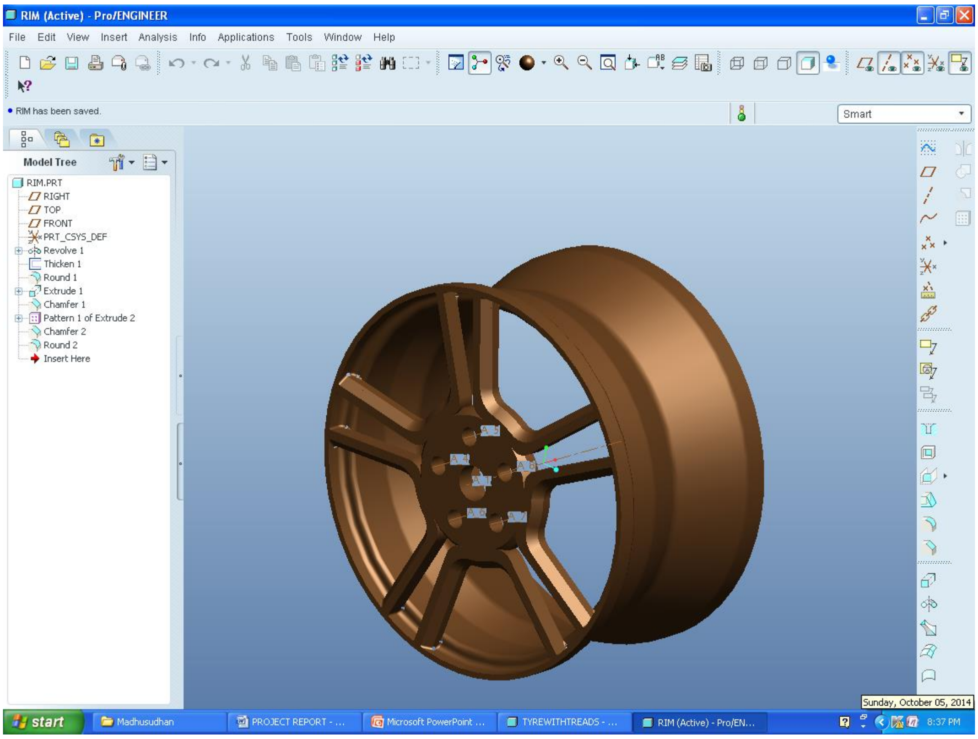


Fig 3.6 Pro-E Model of Ford Car Rim Part

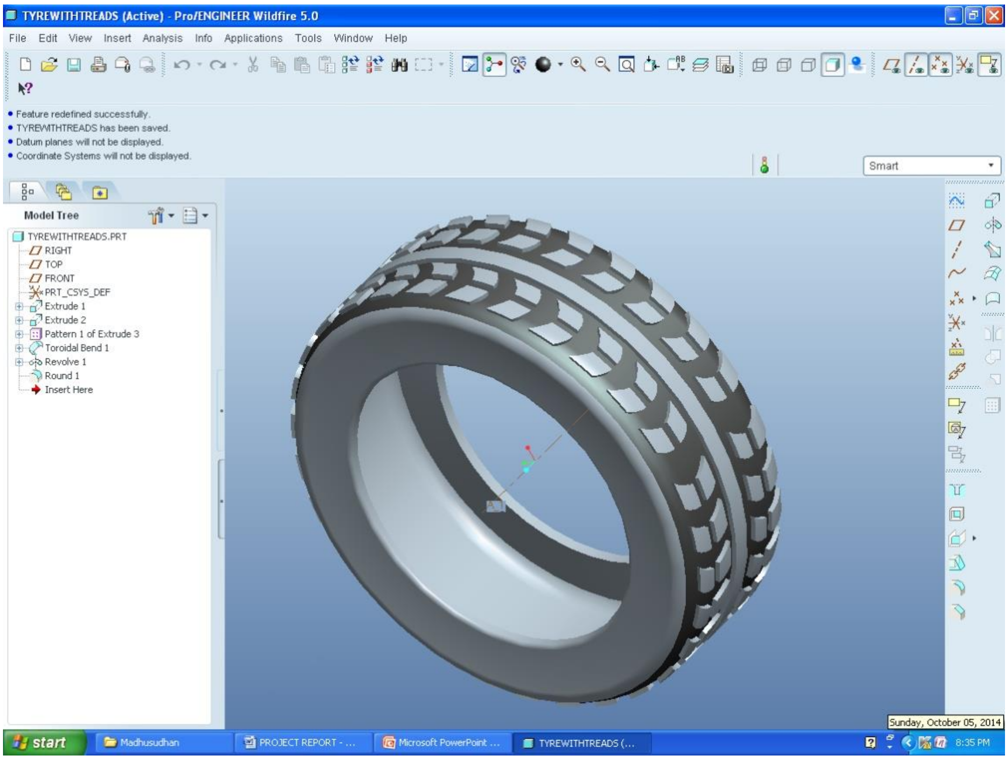


Fig 3.7 Pro-E Model of Ford Car Tyre Part

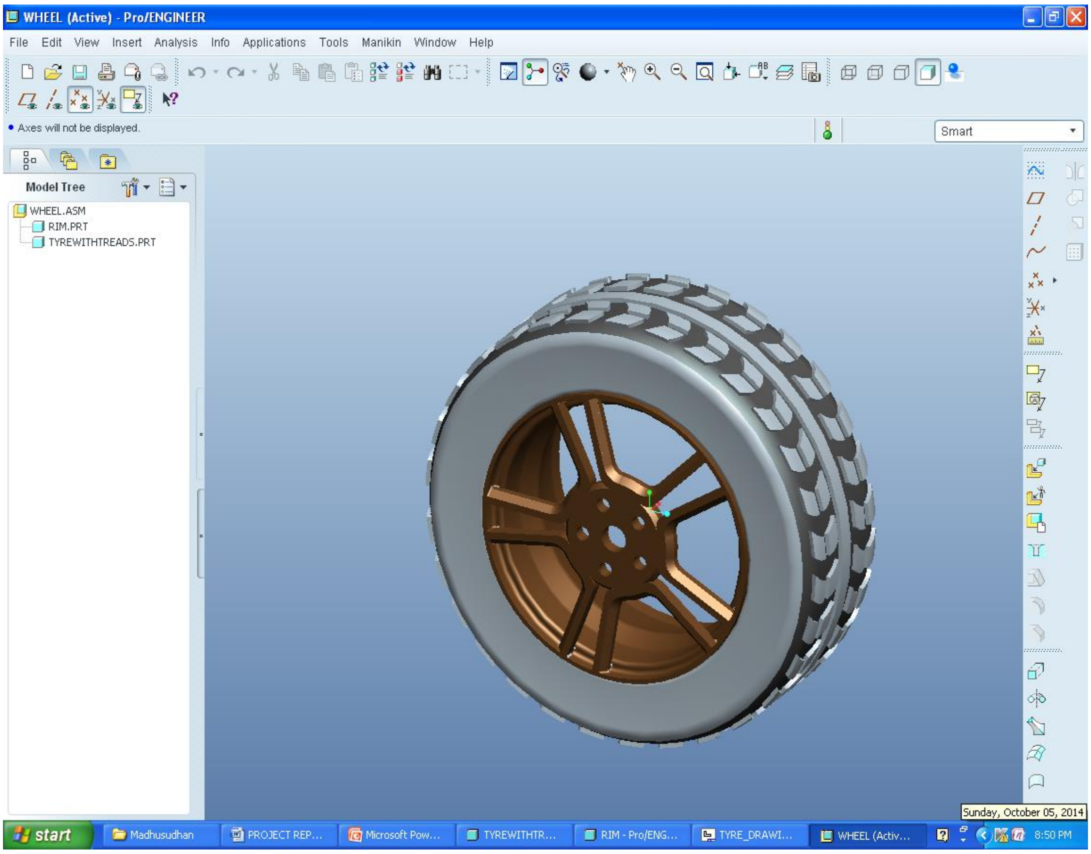


Fig 3.7 Pro-E Model of Skoda Car Tyre Assembly

4. FINITE ELEMENT METHOD

4.1 Introduction:

The FEM is numerical analysis technique for obtaining approximate solutions to a wide variety of engineering problems. Because of its diversity and flexibility as an analysis tool, it is receiving much attention in engineering schools and industries. In more and more engineering situations today, we find that it is necessary to obtain approximate solutions to problems rather than exact closed form solution.

It is not possible to obtain analytical mathematical solutions for many engineering problems. An analytical solutions is a mathematical expression that gives the values of the desired unknown quantity at any location in the body, as consequence it is valid for infinite number of location in the body. For problems involving complex material properties and boundary conditions, the engineer resorts to numerical methods that provide approximate, but acceptable solutions.

The FEM has become a powerful tool for the numerical problems and a wide range of engineering problems. It has developed simultaneously with the increasing use of the high-speed electronic digital computers and with the growing emphasis on numerical methods for engineering analysis. This method started as a generalization of the structural idea to some problems of elastic continuum problem, started in terms of different equations or as an extrinum problem.

The fundamental areas that have to be learned for working capability of finite element method include:

- **Matrix algebra.**
- **Solid mechanics.**
- **Variational methods.**
- **Computer skills.**

Matrix techniques are definitely most efficient and systematic way to handle algebra of finite element method. Basically matrix algebra provides a scheme by which a large number of equations can be stored and manipulated. Since vast majority of literature on the finite element method treats problems in structural and continuum mechanics, including soil and rock mechanics, the knowledge of these fields became necessary. It is useful to consider the finite element procedure basically as a Variational approach. This conception has contributed significantly to the convenience of formulating the method and to its generality.

The term "finite element" distinguishes the technique from the use of infinitesimal "differential elements" used in calculus, differential equations. The method is also distinguished from finite difference equations, for which although the steps in to which space is divided into finite elements are finite in size; there is a little freedom in the shapes that the discrete steps can take. F.E.A is a way to deal with structures that are more complex than dealt with analytically using the partial differential equations. F.E.A deals with complex boundaries better than finite difference equations and gives answers to the 'real world' structural problems. It has been substantially extended scope during the roughly forty years of its use.

F.E.A makes it possible it evaluate a detail and complex structure, in a computer during the planning of the structure. The demonstration in the computer about the adequate strength of the structure and possibility of improving design during planning can justify the cost of this analysis work. F.E.A has also been known to increase the rating of the structures that were significantly over design and build many decades ago.

Terms commonly used in finite element method:

- **Descritization:** The process of selecting only a certain number of discrete points in the body can be termed as Descritization.
- **Continuum:** The continuum is the physical body, structure or solid being analyzed.
- **Node:** The finite elements, which are interconnected at joints, are called nodes or nodal points.
- **Element:** Small geometrical regular figures are called elements.
- **Displace Models:** The nodal displacements, rotations and strains necessary to specify completely deformation of finite element.
- **Degree of freedom:** The nodal displacements, rotations and strains necessary to specify completely deformation of finite element.
- **Local coordinate system:** Local coordinate system is one that is defined for a particular element and not necessary for the entire body or structure.
- **Global system:** The coordinate system for the entire body is called the Global coordinate system.

- **Natural coordinate system:** Natural coordinate system is a local system, which permits the specification of point with in the element by a set of dimensionless numbers, whose magnitudes never exceeds unity.
- **Interpolation function:** It is a function, which has unit value at one nodal point and a zero value at all other nodal points.
- **Aspect ratio:** The aspect ratio describes the shapes of the element in the assemblage for two dimensional elements; this parameter is defined as the ratio of largest dimension of the element to the smallest dimension.
- **Field variables:** The principal unknowns of a problem are called the field variables.

4.2 General Description of FEM:

In the finite element method, the actual continuum of body of matter like solid, liquid or gas is represented as an assemblage of sub divisions called Finite elements. These elements are considered to be inter connected at specified points known as nodes or nodal points. These nodes usually lie on the element boundaries where an adjacent element is considered to be connected. Since the actual variation of the field variables (like Displacement, stress, temperature, pressure and velocity) inside the continuum are is not know, we assume that the variation of the field variable inside a finite element can be approximated by a simple function. These approximating functions (also called interpolation models) are defined in terms of the values at the nodes. When the field equations (like equilibrium equations) for the whole continuum are written, the new unknown will be the nodal values of the field variable. By solving the field equations, which are generally in the form of the matrix equations, the nodal values of the field variables will be known. Once these are known, the approximating function defines the field variable throughout the assemblage of elements.

The solution of a general continuum by the finite element method always follows as orderly step-by-step process. The step-by-step procedure for static structural problem can be stated as follows:

Step 1:- Description of Structure (Domain).

The first step in the finite element method is to divide the structure of solution region in to sub divisions or elements.

Step 2:- Selection of proper interpolation model.

Since the displacement (field variable) solution of a complex structure under any specified load conditions cannot be predicted exactly, we assume some suitable solution, within an element to approximate the unknown solution. The assumed solution must be simple and it should satisfy certain convergence requirements.

Step 3:- Derivation of element stiffness matrices (characteristic matrices) and load vectors.

From the assumed displacement model the stiffness matrix [K(e)] and the load vector P(e) of element 'e' are to be derived by using either equilibrium conditions or a suitable Variation principle.

Step 4:- Assemblage of element equations to obtain the equilibrium equations.

Since the structure is composed of several finite elements, the individual element stiffness matrices and load vectors are to be assembled in a suitable manner and the overall equilibrium equation has to be formulated as

[K]φ = P

Where [K] is called assembled stiffness matrix,

Φ is called the vector of nodal displacement and

P is the vector or nodal force for the complete structure.

Step 5:- Solution of system equation to find nodal values of displacement (field variable)

The overall equilibrium equations have to be modified to account for the boundary conditions of the problem. After the incorporation of the boundary conditions, the equilibrium equations can be expressed as,

[K]φ = P

For linear problems, the vector 'φ' can be solved very easily. But for non-linear problems, the solution has to be obtained in a sequence of steps, each step involving the modification of the stiffness matrix [K] and 'φ' or the load vector P.

Step 6:- Computation of element strains and stresses.

From the known nodal displacements, if required, the element strains and stresses can be computed by using the necessary equations of solid or structural mechanics.

In the above steps, the words indicated in brackets implement the general FEM step-by-step procedure.

4.3 Advantages of FEM:

The FEM is based on the concept of discretization. Nevertheless as either a variational or residual approach, the technique recognizes the multi dimensional continuity of the body not only does the idealizations portray the body as continuous but it also requires no separate interpolation process to extend the approximate solution to every point with in the continuum. Despite the fact that the solution is obtained at a finite number of discrete node points, the formation of field variable models inherently provides a solution at all other locations in the body. In contrast to other variational and residual approaches, the FEM does not require trail solutions, which must all, apply to the entire multi dimensional continuum. The use of separate sub-regions or the finite elements for the separate trial solutions thus permits a greater flexibility in considering continua of the shape.

Some of the most important advantages of the FEM derive from the techniques of introducing boundary conditions. This is another area in which the method differs from other variational or residual approaches. Rather than requiring every trial solution to satisfy the boundary conditions, one prescribes the conditions after obtaining the algebraic equations for assemblage.

No special techniques or artificial devices are necessary, such as the non-cantered difference equations or factious external points often employed in the finite difference method.

The FEM not only accommodates complex geometry and boundary conditions, but it also has proved successful in representing various types of complicated material properties that are difficult to incorporate in to other numerical methods. For example, formulations in solid mechanics have been devised for anisotropic, nonlinear, hysteretic, time dependant or temperature dependant material behaviour.

One of the most difficult problems encountered in applying numerical procedures of engineering analysis is the representation of non-homogeneous continua. Nevertheless the FEM readily accounts for non-homogeneity by the simple tactic of assigning different properties with in an element according to the pre selected polynomial pattern. For instance it is possible to accommodate continuous or discontinuous variations of the constitutive parameters or of the thickness of a two-dimensional body.

The systematic generality of the finite element procedure makes it a powerful and versatile tool for a wide range of problems. As a result, flexible general-purpose computer programs can be constructed. Primary examples of these programs are several structural analysis packages which include a variety of element configurations and which can be applied to several categories of structural problems. Among these packages are ASKA, STRUDL, SAP and NASTRAN & SAFE. Another indicator of the generality of the method is that programs developed for one field of engineering have been applied successfully to problems in different field with a little or no modification.

Finally an engineer may develop a concept of the FEM at different levels. IT is possible to interpret the method in physical terms. On the other hand the method may be explained entirely in mathematical terms. The physical or intuitive nature of the procedure is particularly useful to the engineering student and practicing engineer.

4.4 Limitation of FEM:

One limitation of finite element method is that a few complex phenomenon’s are not accommodated adequately by the method as its current state of development. Some examples of such phenomenon form the realm of solid mechanics are cracking and fracture behavior, contact problems, bond failures of composite materials, and non-linear material behavior with work softening. Another example is transient, unconfined seepage problems. The numerical solution of propagation or transient problem is not satisfactory in all respects. Many of these phenomenon’s are presently under research and refinements of the methods to accommodate these problems better can be expected.

The finite element method has reached a high level of development as a solution technique. However the method yields realistic results only if the coefficients or material parameters, which describe the basic phenomenon, are available. Material non-linearity in solid mechanics is a notable example of a field in which our understanding of material behavior has lagged behind the development of the analytical tool. In order to exploit fully the power of the finite element method, significant effort must be direct towards the development of constitutive laws and the evaluation of realistic coefficients and material parameters.

Even the most efficient finite element computer code requires a relatively large amount of computer memory and time. Hence use of this method is limited to those who have access to relatively large, high-speed computers. The advent of time-sharing, remote batch processing and computer service bureaus or utilities ahs alleviated this restriction to some degree. In addition the method can be applied indirectly to common engineering problems by utilizing tables, graphs and other analysis aids that have been generated by finite element codes.

The most tedious aspects of the use of finite element methods are the basic processes of sub-dividing the continuum and of generating error free input data for the computer. Although these processes may be automated to a degree they have been totally accomplished by computer because some engineer judgement may be employed in the descritization. Error in the input data may go undetected and erroneous result obtained there form may appear acceptable. Consequently it is essential that the engineer/programmer provide checks to detect such errors. In addition to check internal code, an auxiliary routine that reads the input data and generates a computer plot of the discritized continuum is desirable. This plot permits a rapid visual check of the input data.

Finally as for any approximate numerical method the results of the finite element analysis must be interpreted with care. We must be aware of the assumptions employed in the formulation, the possibility of the numerical difficulties and the limitations in the material characterizations used. A large volume of solution information is generated by a finite element routine but this data is worthwhile only when its generation and interpretation are tempered by proper engineering judgement.

4.5 Basic Approach to FEA

Basic approach for any finite element analysis (FEA) can be divided in to three parts

- Pre – processors
- Solver
- Post – Processor

Pre – Processor:

Pre – processor mainly contains building of model, meshing, assigning material properties etc.

Building of Model:

Geometry is usually difficult to describe, as it has to be as close to as real. Since it has to take real world loads and boundary conditions, it is equal to prototype simulated in computer.

Creation of finite element model for Meshing:

After assigning material properties and structural properties to the model, meshing is done. Meshing means dividing the model into finite number of finite sized elements.

FEA uses complex system of points called nodes, which make grid called MESH. This mesh is programmed to contain material and structural properties, which define how the structure will react to certain loading conditions. Nodes are assigned at a certain density throughout the material depending on the anticipated stress levels of a particular area. Regions that will receive large amounts of stress usually have a higher node density than those, which experience little or no stress.

Points of interest may consist or fracture point of previously tested material, fillets, corners, complex details and high stress areas.

The mesh acts like a spider web in that form each node, there extends a mesh element to each of the adjacent nodes. The web of vectors is what carries the material properties to the object, creating many elements.

Each FEA programs may came with an element library or one is constructed over time. Elements are thought to fill the whole experiment; hence choice of elements very critical.

While meshing it has to be decided whether we have to go for finer mesh or coarser one. The finer the mesh, the better is the result; but longer is the analysis time. Therefore a compromise between accuracy and solution speed is usually made.

The mesh may be created manually or automatically. In the manually created mesh, we will notice that the elements are similar at joints. This is known as mesh refinement and it enables the stress to be captured at the geometric discontinuities (the junction).

Manual meshing is a tedious process for models with any degree of complications but inbuilt mesh engine creates mesh automatically thus reducing the time. These automatic meshing has imitations as to regards mesh quality and solution accuracy.

Solver:

Solvers are geometric task oriented. These are developed for specific applications. Solvers are designed based on continuum approach where in construction of mass, momentum and energy equation of state, thermodynamic equations as and when required for each of the elements and the solution is obtained by interpreting these solutions. The solution to these equations essentially depends on two methods

1. Implicit
2. Explicit

Choice of the method is based on the nature of problems.

The main goal of a finite element analysis is to examine a structure or a component response to certain loading conditions. Therefore specifying the proper loading conditions is a key step in the analysis. These loading conditions may be static, dynamic or transient whose nature may be linear or non-linear.

The word loads in FEA includes the applied forcing functions externally or internally. For example loads in structural are displacements, forces, pressures, temperatures and gravity. In thermal analysis the applied loads are temperatures, heat flow rates convections and heat generation.

Solver reads the model created by the pre-processor and formulates the mathematical representation of the model. All the parameters defined in the pre-processing stage are used to do this. If the model is correct the solver proceeds to form the element stiffness matrix for the problem. After calculating the element stiffness matrix it calculates the results like displacements, pressure, stresses, strains etc at each node within the component or continuum. All these results are sent to a results file, which may be read by the Post-Processor.

Post – Processor:

Here the results of the analysis are read and interpreted. They can be presented in the form of a table, a colour plot, deformed shape of the component to the mode shapes and natural frequencies if frequencies are involved. Other results are available for fluids, thermal and electrical analysis types.

Contour plots are usually more effective way of viewing for structural type problems. Slices can be made through 3-D models to facilitate the viewing of internal stress patterns.

Post – Processor includes the calculations of stresses and strains I any of the x, y or z directions or induced in a direction at an angle to the coordinate axis. The principal stresses and strains may also be plotted or if required the yield stress and strains according to the main theories if failure (von mises, st-venani, treseaetc) can be plotted. Other information such as the strain energy, plastic strain and creep strain may be obtained for certain types of analysis.

5. **FEA SOFTWARE – ANSYS**

5.1 Introduction of ANSYS Program:

ANSYS Stands for Analysis System Product.

Dr. John Swanson founded ANSYS. Inc in 1970 with a vision to commercialize the concept of computer simulated engineering, establishing himself as one of the pioneers of Finite Element Analysis (FEA). ANSYS inc. supports the ongoing development of innovative technology and delivers flexible, enterprise wide engineering systems that enable companies to solve the full range of analysis problem, maximizing their existing investments in software and hardware. ANSYS Inc. continues its role as a technical innovator. It also supports a process-centric approach to design and manufacturing, allowing the users to avoid expensive and time-consuming “built and break” cycles. ANSYS analysis and simulation tools give customers ease-of-use, data compatibility, multi platform support and coupled field multi-physics capabilities.

5.2 Evolution of ANSYS Program

ANSYS has evolved into multipurpose design analysis software program, recognized around the world for its many capabilities. Today the program is extremely powerful and easy to use. Each release hosts new and enhanced capabilities that make the program more flexible, more usable and faster In this way ANSYS helps engineers meet the pressures and demands modern product development environment.

5.3 Overview of the program

The ANSYS program is flexible, robust design analysis and optimization package. The software operates on major computers and operating systems, from PCs to workstations and to super computers. ANSYS features file compatibility throughout the family of products and across all platforms. ANSYS design data access enables user to import computer aided design models in to ANSYS, eliminating repeated work. This ensures enterprise wide, flexible engineering solution for all ANSYS user.

User Interface:

Although the ANSYS program has extensive and complex capabilities, its organization and user-friendly graphical user interface makes it easy to learn and use.

There are four graphical methods to instruct the ANSYS program:

1. Menus.
2. Dialog Boxes
3. Tool bar.
4. Direct input of commands.

Menus:

Menus are groupings of related functions or operating the analysis program located in individual windows. These include:

- Utility menu
- Main menu
- Input window
- Graphics window
- Tool bar
- Dialog boxes

Dialog boxes:

Windows that presents the user with choices for completing operations or specifying settings. These boxes prompt the user to input data or make decisions for a particular function.

Tool bar:

The tool bar represents a very efficient means for executing commands for the ANSYS program because of its wide range of configurability. Regardless of how they are specified, commands are ultimately used to supply all the data and control all program functions.

Output window:

Records the ANSYS response to commands and functions.

Graphics window:

Represents the area for graphic displays such as model or graphically represented results of an analysis. The user can adjust the size of the graphics window, reducing or enlarging it to fit to personal preferences.

Input window:

Provides an input area for typing ANSYS commands and displays program prompt messages.

Main menu:

Comprise the primary ANSYS functions, which are organized in pop-up side menus, based on the progression of the program.

Processors:

ANSYS functions are organized into two groups called processors. The ANSYS program has one pre-processor, one solution processor; two post processors and several auxiliary processors such as the design optimizer. The ANSYS pre-processor allows the user to create a finite element model to specify options needed for a subsequent solution. The solution processor is used to apply the loads and the boundary conditions and then determine the response of the model to them. With the ANSYS post processors, the user retrieves and examines the solutions results to evaluate how the model responded and to perform additional calculations of interest.

Database:

The ANSYS program uses a single, centralized database for all model data and solution results. Model data (including solid model and finite element model geometry, materials etc) are written to the database using the processor. Loads and solution results data are written using the solutions processor. Post processing results data are written using the post processors. Data written to the database while using one processor are therefore available as necessary in the other processors.

File format:

Files are used, when necessary, to pass the data from part of the program to another, to store the program to the database, and to store the program output. These files include database files, the results file, and the graphics file and so on.

5.4 Reducing the design and manufacturing costs using ANSYS (FEA):

The ANSYS program allows engineers to construct computer models or transfer CAD models of structures, products, components, or systems, apply loads or other design performance conditions and study physical responses such as stress levels, temperature distribution or the impact of lector magnetic fields.

In some environments, prototype testing is undesirable or impossible. The ANSYS program has been used in several cases of this type including biomechanical applications such as hi replacement intraocular lenses. Other representative applications range from heavy equipment components, to an integrated circuit chip, to the bit-holding system of a continuous coal-mining machine.

ANSYS design optimization enables the engineers to reduce the number of costly prototypes, tailor rigidity and flexibility to meet objectives and find the proper balancing geometric modifications.

Competitive companies loom for ways to produce the highest quality product at the lowest cost. ANSYS (FEA) can help significantly by reducing the design and manufacturing costs and by giving engineers added confidence in the products they design. FEA is most effective when used at the conceptual design stage. It is also useful when used later in manufacturing process to verify the final design before prototyping.

Program availability:

The ANSYS program operates on 486 and Pentium based PCs running on Wndows95 or WindowsNT and workstations and super computers primarily running on UNIX operating system. ANSYS Inc. continually works with new hardware platforms and operating systems.

Analysis types available:

1. Structural static analysis.
2. Structural dynamic analysis.
3. Structural buckling analysis.
   - Linear buckling
   - Non linear buckling
4. Structural non linearities
5. Static and dynamic kinematics analysis.
6. Thermal analysis.
7. Electromagnetic field analysis.
8. Electric field analysis
9. Fluid flow analysis
   - Computational fluid dynamics
   - Pipe flow
10. Coupled-field analysis
11. Piezoelectric analysis.

5.5 Procedure for ANSYS analysis:

Static analysis is used to determine the displacements, stresses, strains and forces in structures or components due to loads that do not induce significant inertia and damping effects. Steady loading in response conditions are assumed. The kinds of loading that can be applied in a static analysis include externally applied forces and pressures, steady state inertial forces such as gravity or rotational velocity imposed (non-zero) displacements, temperatures (for thermal strain).

A static analysis can be either linear or non linear. In our present work we consider linear static analysis.

The procedure for static analysis consists of these main steps:

1. Building the model.
2. Obtaining the solution.
3. Reviewing the results.

Build the model:

In this step we specify the job name and analysis title use PREP7 to define the element types, element real constants, material properties and model geometry element types both linear and non-linear structural elements are allowed. The ANSYS element library contains over 80 different element types. A unique number and prefix identify each element type.

E.g. BEAM 94, PLANE 71, SOLID 96 and PIPE 16

Material properties:

Young's modulus (EX) must be defined for a static analysis .If we plan to apply inertia loads (such as gravity) we define mass properties such as density (DENS). Similarly if we plan to apply thermal loads (temperatures) we define coefficient of thermal expansion (ALPX).

Obtain the solution:

In this step we define the analysis type and options, apply loads and initiate the finite element solution. This involves three phases:

- Pre – processor phase
- Solution phase
- Post-processor phase

Table 5.1: The brief description of steps followed in each phase

PREPROCESSOR PHASE	**SOLUTION PHASE**	**POST-PROCESSOR PHASE**
GEOMETRY DEFINITIONS	ELEMENTMATRIX FORMULATION	POST SOLUTION OPERATIONS
MESH GENERATION	OVERALL MATRIX TRIANGULARIZATION	POST DATA PRINT OUTS(FOR REPORTS)
MATERIAL	(WAVE FRONT)	POST DATA
DEFINITIONS		SCANNING POST DATA DISPLAYS

CONSTRAINT DEFINITIONS	DISPLACEMENT. STRESS,ETC	
LOAD DEFINITION	CALCULATION	
MODEL DISPLAYS		

1. PRE – PROCESSOR:

Pre processor has been developed for the same program is available on micro, mini, super-mini and mainframe computer system. This slows easy transfer of models one system to other.

Pre processor is an interactive model builder to prepare the FE (finite element) model and input data. The solution phase utilizes the input data developed by the pre processor, and prepares the solution according to the problem definition. It creates input files to the temperature etc., on the screen in the form of contours.

Geometrical definitions:

There are four different geometric entities in pre processor namely key points, lines, areas and volumes. These entities can be used to obtain the geometric representation of the structure. All the entities are independent of other and have unique identification labels.

Model generations:

Two different methods are used to generate a model:

- Direct generation.
- Solid modeling

With solid modeling we can describe we can describe the geometric boundaries of the model, establish controls over the size and desired shape of the elements and then instruct ANSYS program to generate all the nodes and elements automatically. By contrast, with the direct generation method, we determine the location of every node and size, shape and connectivity of every element prior to defining these entities in the ANSYS model. Although, some automatic data generation is possible (by using commands such as FILL, NGEN, EGEN etc) the direct generation method essentially a hands on numerical method that requires us to keep track of all the node numbers as we develop the finite element mesh. This detailed book keeping can become difficult for large models, giving scope for modeling errors. Solid modeling is usually more powerful and versatile than direct generation and is commonly preferred method of generating a model.

Mesh generation:

In the finite element analysis the basic concept is to analyze the structure, which is an assemblage of discrete pieces called elements, which are connected, together at a finite number of points called Nodes. Loading boundary conditions are then applied to these elements and nodes. A network of these elements is known as Mesh.

Finite element generation:

The maximum amount of time in a finite element analysis is spent on generating elements and nodal data. Pre processor allows the user to generate nodes and elements automatically at the same time allowing control over size and number of elements. There are various types of elements that can be mapped or generated on various geometric entities.

The elements developed by various automatic element generation capabilities of pre processor can be checked element characteristics that may need to be verified before the finite element analysis for connectivity, distortion-index, etc.

Generally, automatic mesh generating capabilities of pre processor are used rather than defining the nodes individually. If required, nodes can be defined easily by defining the allocations or by translating the existing nodes. Also one can plot, delete, or search nodes.

Boundary conditions and loading:

After completion of the finite element model it has to constrain and load has to be applied to the model. User can define constraints and loads in various ways. All constraints and loads are assigned set 1D. This helps the user to keep track of load cases.

Model display:

During the construction and verification stages of the model it may be necessary to view it from different angles. It is useful to rotate the model with respect to the global system and view it from different angles. Pre processor offers this capability. By windowing feature pre processor allows the user to enlarge a specific area of the model for clarity and details. Pre processor also provides features like smoothness, scaling, regions, active set, etc for efficient model viewing and editing.

Material definitions:

All elements are defined by nodes, which have only their location defined. In the case of plate and shell elements there is no indication of thickness. This thickness can be given as element property. Property tables for a particular property set 1-D have to be input. Different types of elements have different properties for e.g.

Beams: Cross sectional area, moment of inertia etc

Shells: Thickness

Springs: Stiffness

Solids: None

The user also needs to define material properties of the elements. For linear static analysis, modules of elasticity and Poisson’s ratio need to be provided. For heat transfer, coefficient of thermal expansion, densities etc are required. They can be given to the elements by the material property set to 1-D.

2. SOLUTION:

The solution phase deals with the solution of the problem according to the problem definitions. All the tedious work of formulating and assembling of matrices are done by the computer and finally displacements are stress values are given as output. Some of the capabilities of the ANSYS are linear static analysis, non-linear static analysis, transient dynamic analysis, etc.

3. POST – PROCESSOR:

It is a powerful user-friendly post-processing program using interactive colour graphics. It has extensive plotting features for displaying the results obtained from the finite element analysis. One picture of the analysis results (i.e. the results in a visual form) can often reveal in seconds what would take an engineer hour to asses from a numerical output, say in tabular form. The engineer may also see the important aspects of the results that could be easily missed in a stack of numerical data.

Employing state of art image enhancement techniques, facilities viewing of:

- Contours of stresses, displacements, temperatures, etc.
- Deform geometric plots
- Animated deformed shapes
- Time-history plots
- Solid sectioning
- Hidden line plot
- Light source shaded plot
- Boundary line plot etc.

The entire range of post processing options of different types of analysis can be accessed through the command/ menu mode there by giving the user added flexibility and convenience.

5.6 OVERVIEW OF STRUCTURAL ANALYSIS

Structural analysis is probably the most common application of the finite element method. The term *structural* (or *structure*) implies not only civil engineering structures such as bridges and buildings, but also naval, aeronautical, and mechanical structures such as ship hulls, aircraft bodies, and machine housings, as well as mechanical components such as pistons, machine parts, and tools.

5.6.1 Types of Structural Analysis

Static Analysis--Used to determine displacements, stresses, etc. under static loading conditions. Both linear and nonlinear static analyses. Nonlinearities can include plasticity, stress stiffening, large deflection, large strain, hyper elasticity, contact surfaces, and creep.

Modal Analysis--Used to calculate the natural frequencies and mode shapes of a structure. Different mode extraction methods are available.

Harmonic Analysis--Used to determine the response of a structure to harmonically time-varying loads.

Transient Dynamic Analysis--Used to determine the response of a structure to arbitrarily time-varying loads. All nonlinearities mentioned under Static Analysis above are allowed.

Spectrum Analysis--An extension of the modal analysis, used to calculate stresses and strains due to a response spectrum or a PSD input (random vibrations).

Buckling Analysis--Used to calculate the buckling loads and determine the buckling mode shape. Both linear (Eigenvalue) buckling and nonlinear buckling analyses are possible.

Explicit Dynamic Analysis--This type of structural analysis is only available in the ANSYS LS-DYNA program. ANSYS LS-DYNA provides an interface to the LS-DYNA explicit finite element program. Explicit dynamic analysis is used to calculate fast solutions for large deformation dynamics and complex contact problems.

In addition to the above analysis types, several special-purpose features are available:

- Fracture mechanics
- Composites
- Fatigue
- p-Method
- Beam Analyses

5.7 MATERIAL PROPERTIES OF RUBBER

Physical Properties	**Metric**
Density	1.34 - 1.60 g/cc
Water Absorption	0.155 - 0.920 %
Linear Mold Shrinkage	0.00110 - 0.00790 cm/cm
Mechanical Properties	**Metric**
Hardness, Rockwell E	43.0 - 76.0
Tensile Strength, Ultimate	34.0 - 74.0MPa
Elongation at Break	0.730 - 1.47 %
Modulus of Elasticity	4.50 - 9.60GPa
Flexural Yield Strength	56.0 - 115MPa (or) N/mm^2
Flexural Modulus	3.60 - 8.90GPa
Compressive Yield Strength	82.0 - 157MPa
Izod Impact, Notched	0.233 - 0.470 J/cm
Charpy Impact, Notched	0.281 - 0.450 J/cm^2
Electrical Properties	**Metric**
Electrical Resistivity	2.00e+11 - 6.40e+11 ohm-cm

Dielectric Constant	4.50 - 5.80
Dielectric Strength	10.5 - 13.2 kV/mm
Dissipation Factor	0.0770 - 0.0830
Arc Resistance	67.0 - 135 sec
Comparative Tracking Index	150 - 175 V
Thermal Properties	**Metric**
CTE, linear	53.0 - 53.0 µm/m-°C @Temperature 40.0 - 130 °C
Thermal Conductivity	0.440 - 0.440 W/m-K @Temperature 100 - 100 °C
Maximum Service Temperature, Air	92.0 - 244 °C
Deflection Temperature at 1.8 MPa (264 psi)	136 - 241 °C
Oxygen Index	24.6 - 37.0 %
Shrinkage	0.0700 - 0.390 %
Processing Properties	**Metric**
Processing Temperature	150 - 180 °C
Cure Time	0.583 - 3.00 min

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6. STRUCTURAL ANALYSIS

6.1 SKODA CAR TYRE

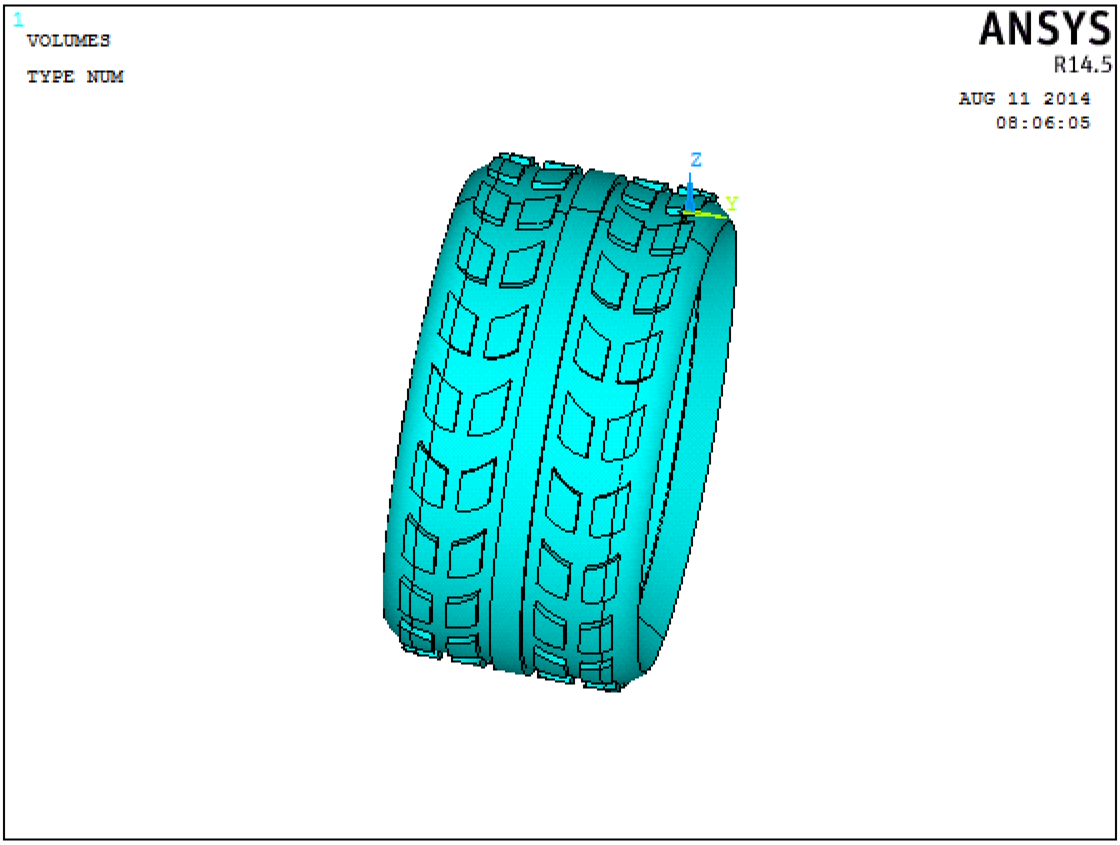

Fig 6.1 Imported Model from Pro-E software to Ansys software

Material properties : Rubber

Density =0.00000233Kg/mm^3

Young's modulous =50000N/mm^2

Poission's ratio=0.49

Solid Element – 3D Solid 186

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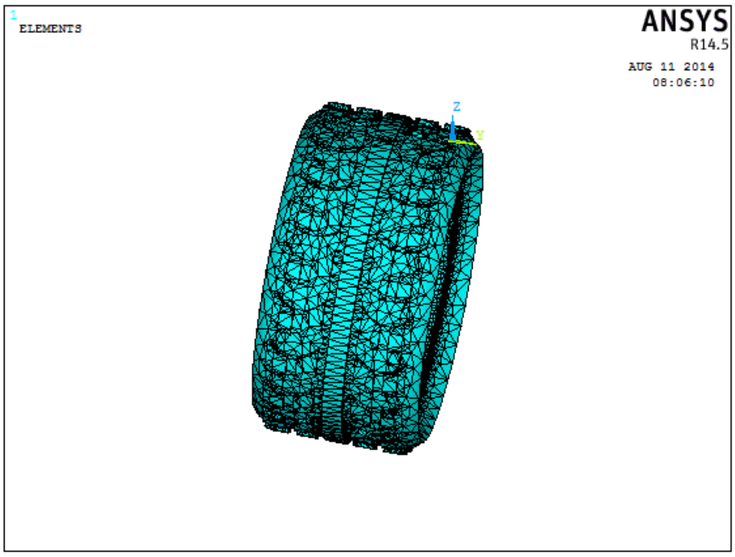

Fig 6.2 Meshed model of Skoda car tyre part

6.1.1 CAR WEIGHT + 5 PERSONS WEIGHT

At pressure 1.12N/mm^2

5 persons weight each 70Kgs (350) + Kerb Weight (w) = 1850kg

Road contact ellipse Area (a) =1649.3 mm^2

Tyre inside Pressure(P) = $\frac{w}{a}$ = 1.12N/mm^2

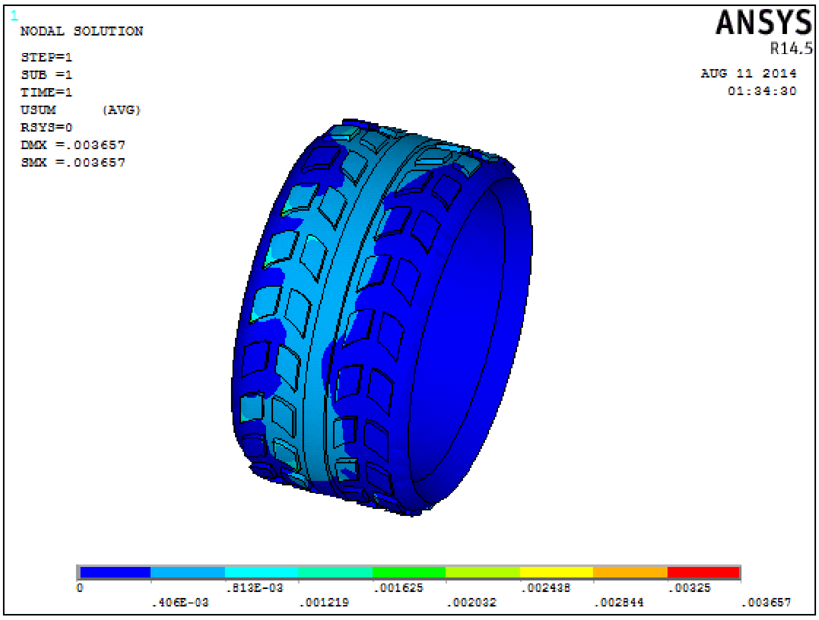

Fig 6.3 Displacement of tyre at pressure 1.12 N/mm^2

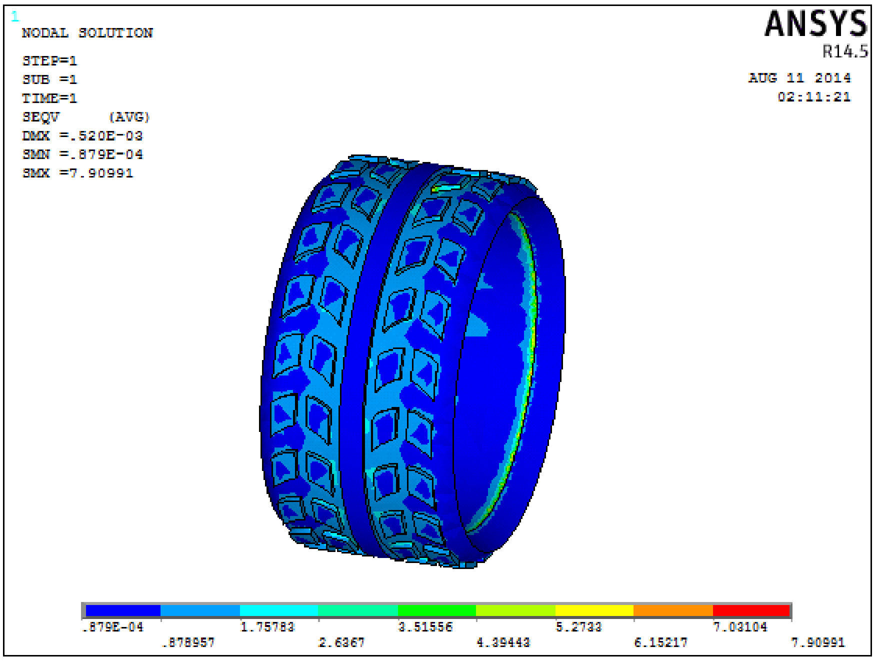

Fig 6.4 Stress of tyre at pressure 1.12 N/mm^2

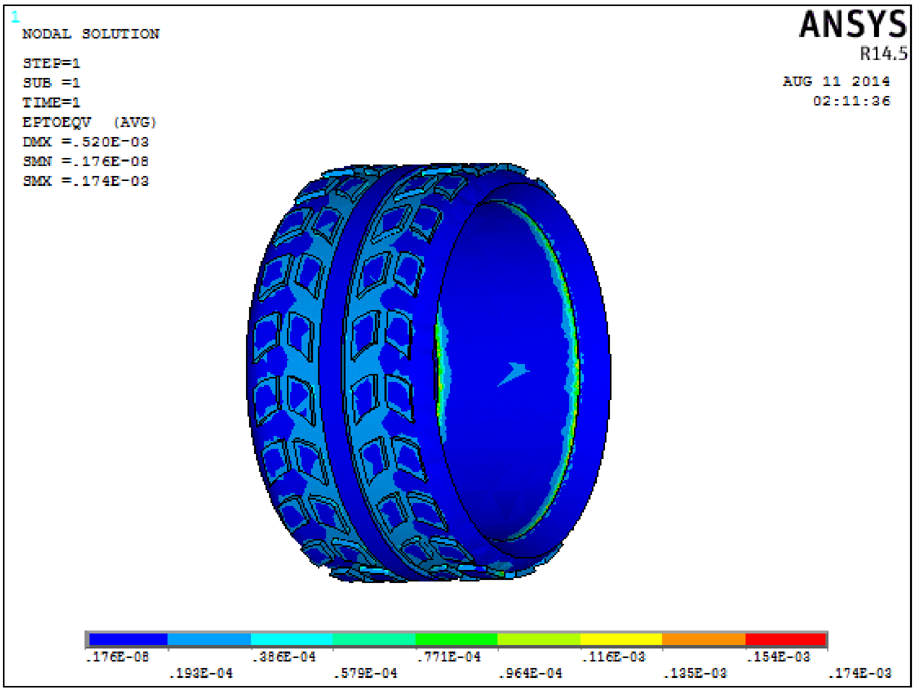

Fig 6.5 Strain of tyre at pressure 1.12 N/mm^2

6.1.2 CAR WEIGHT + 6 PERSONS WEIGHT

At Pressure - 1.13 N/mm^2

6 persons weight each 70Kgs (420) + Kerb Weight (w) =1920kg

Road contact ellipse Area (a) =1691.53 mm^2

Tyre inside Pressure(P) = $\frac{w}{a}$ = 1.13N/mm^2

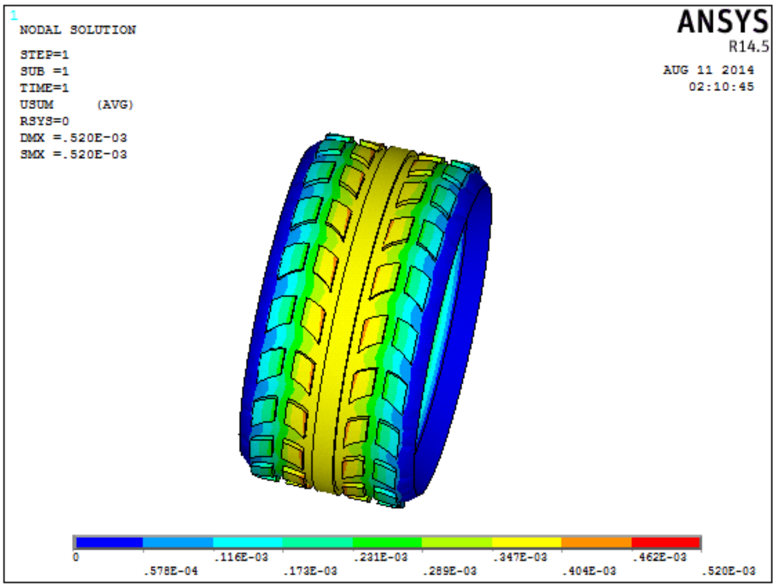

Fig 6.6 Displacement of tyre at pressure 1.13 N/mm^2

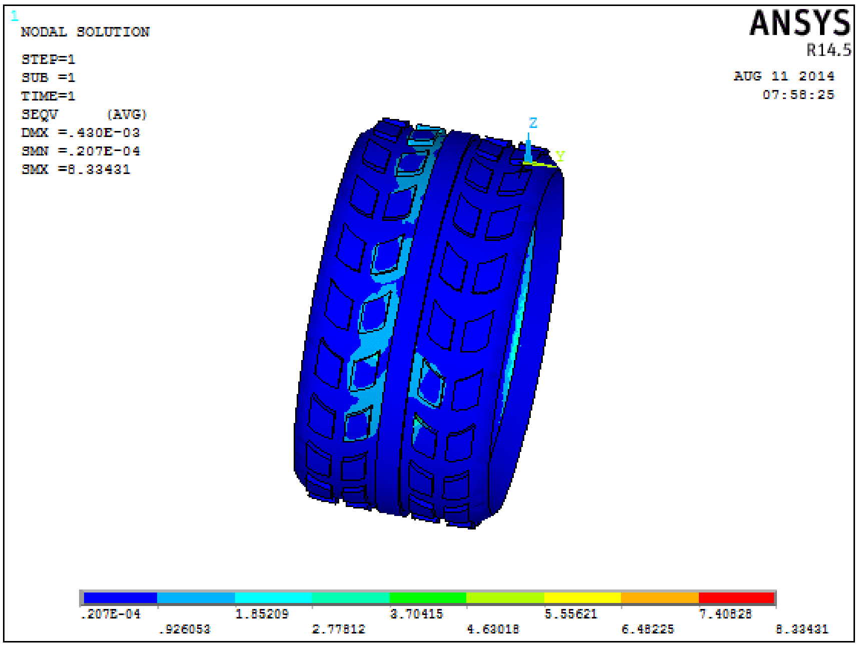

Fig 6.7 Stress of tyre at pressure 1.13 N/mm^2

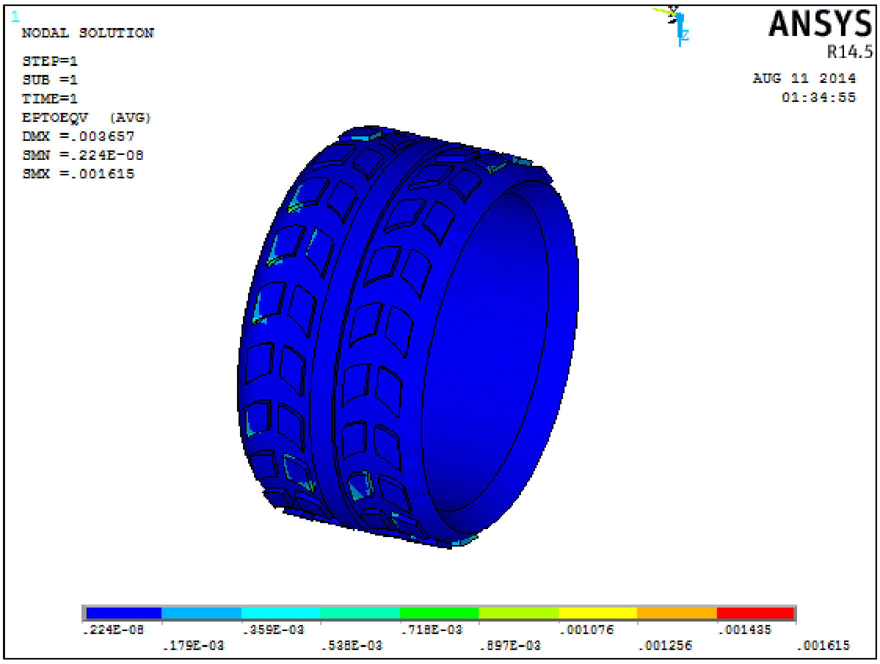

Fig 6.8 Strain of tyre at pressure 1.13 N/mm^2

6.1.3 CAR WEIGHT + 7 PERSONS WEIGHT

At 1.14 N/mm^2

7 persons weight each 70Kgs (490) + Kerb Weight (w) =1990kg

Road contact ellipse Area (a) =1733.32 mm^2
Tyre inside Pressure(P) = $\frac{w}{a}$ = 1.14N/mm^2

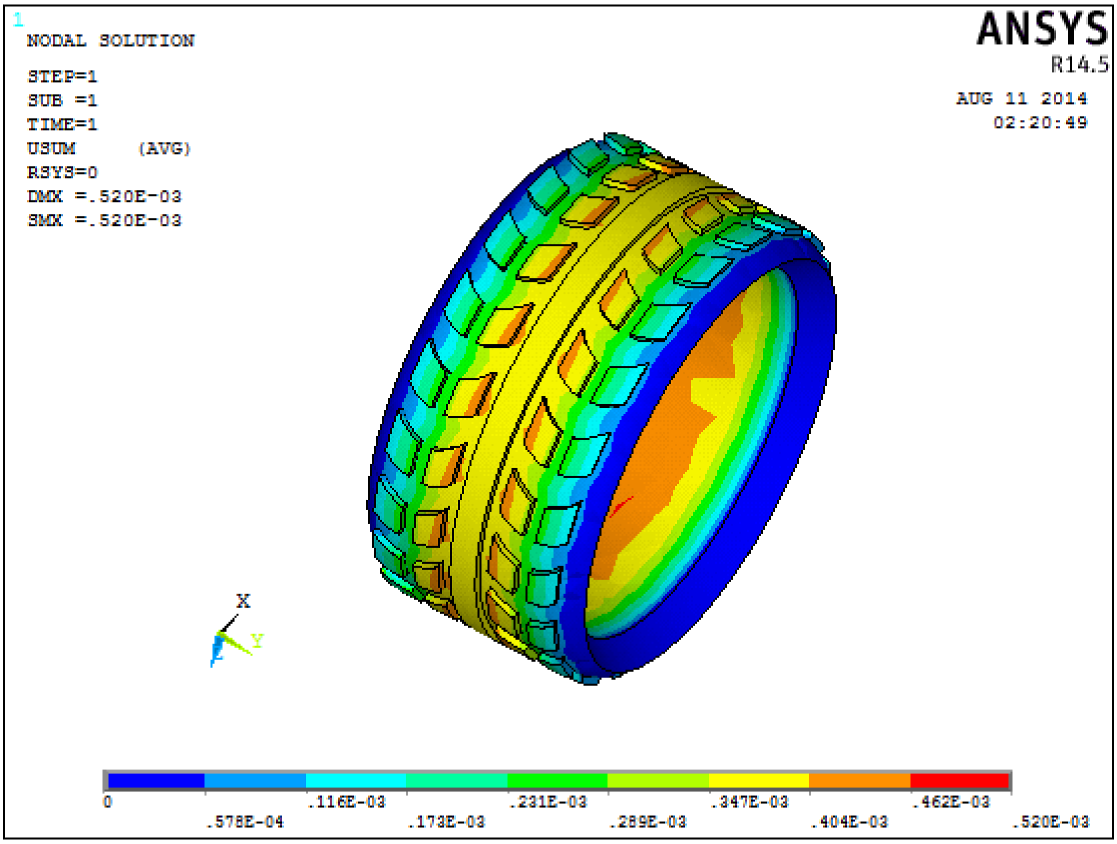

Fig 6.9 Displacement of tyre at pressure 1.14 N/mm^2

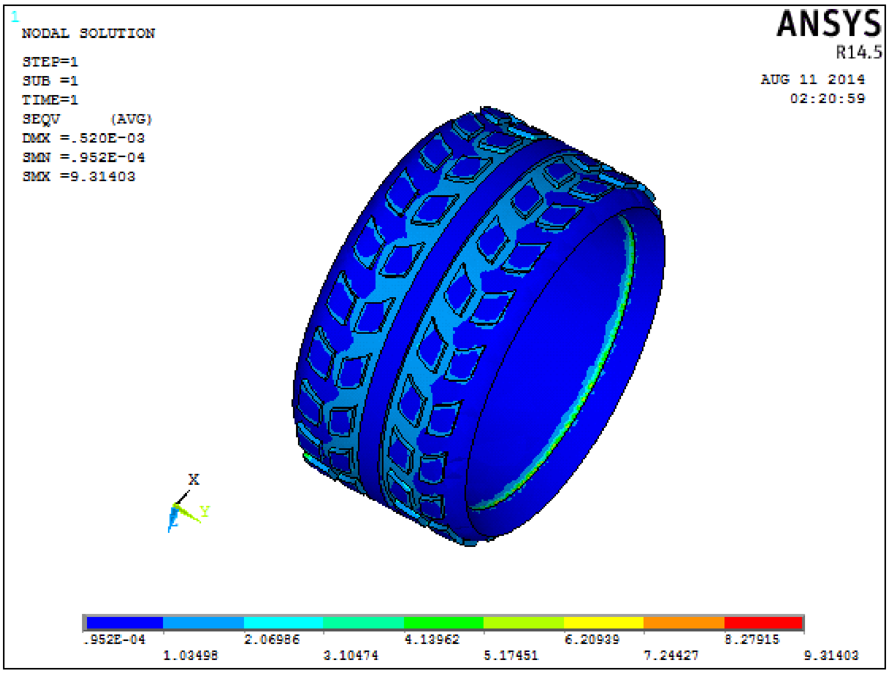

Fig 6.10 Stress of tyre at pressure 1.14 N/mm^2

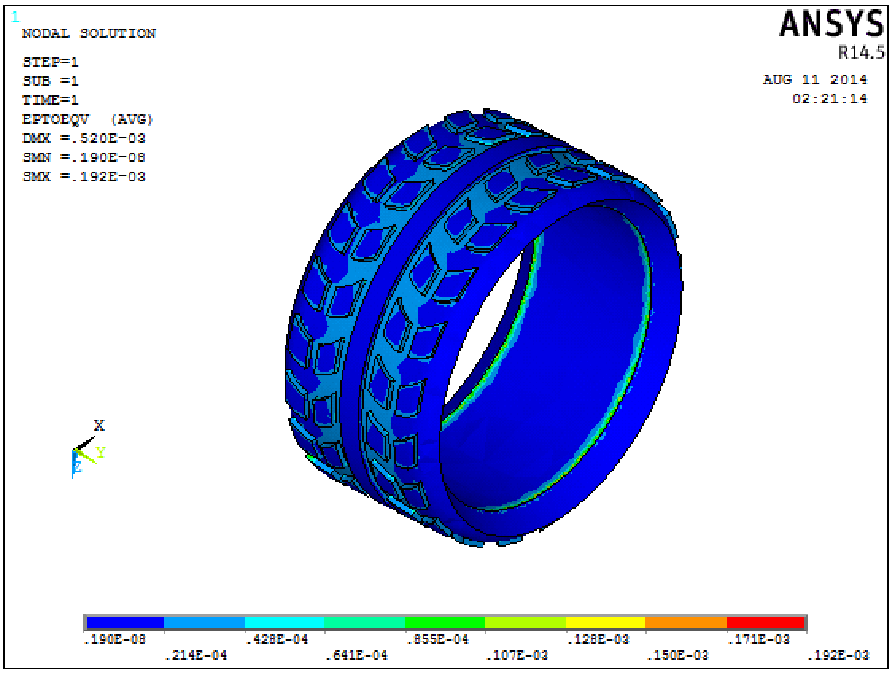

Fig 6.11 Strain of tyre at pressure 1.14 N/mm^2

6.2 FORD TYRE

Material properties: Rubber

Density =0.00000233Kg/mm^3

Young's modulus =50000N/mm^2

Poisson's ratio=0.49

Solid Element – 3D Solid 186

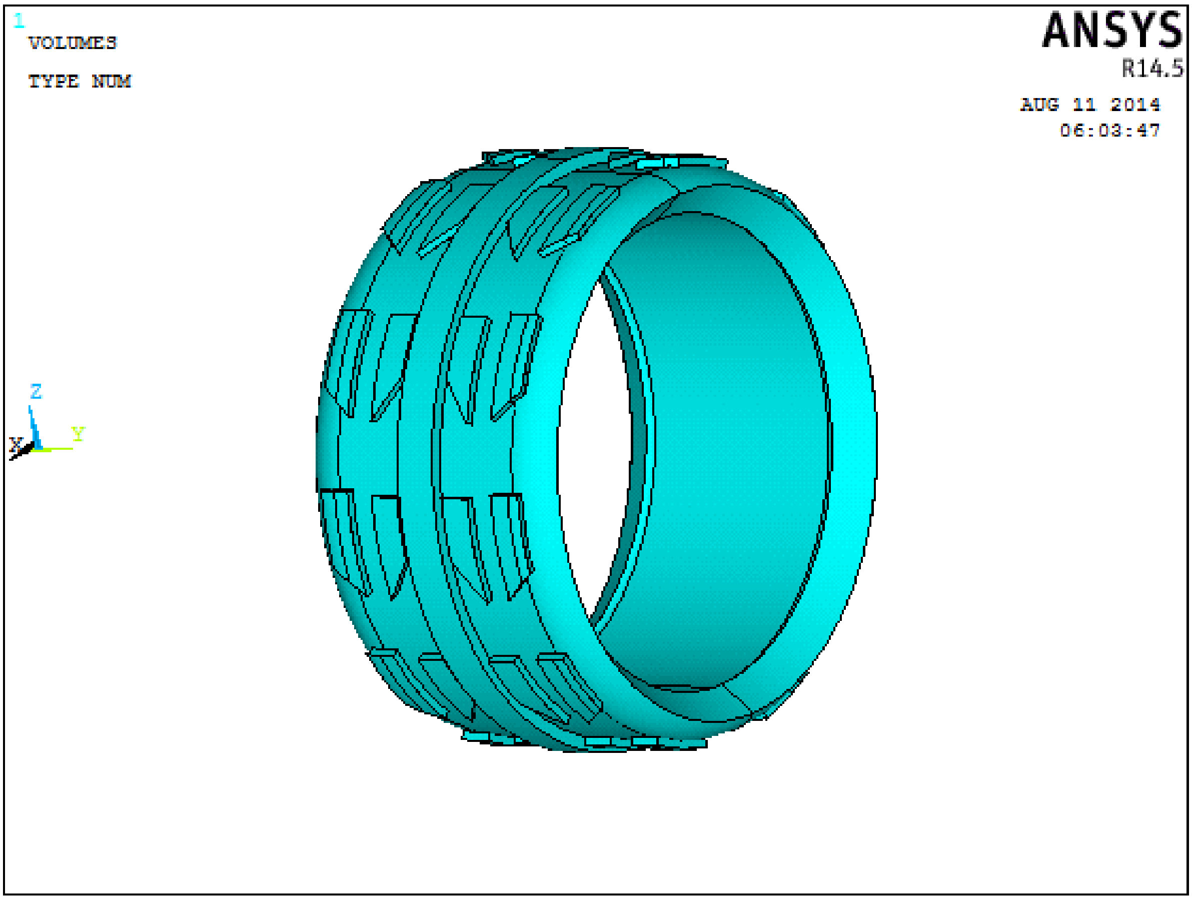

Fig 6.12 Imported Model from Pro-E software to Ansys software

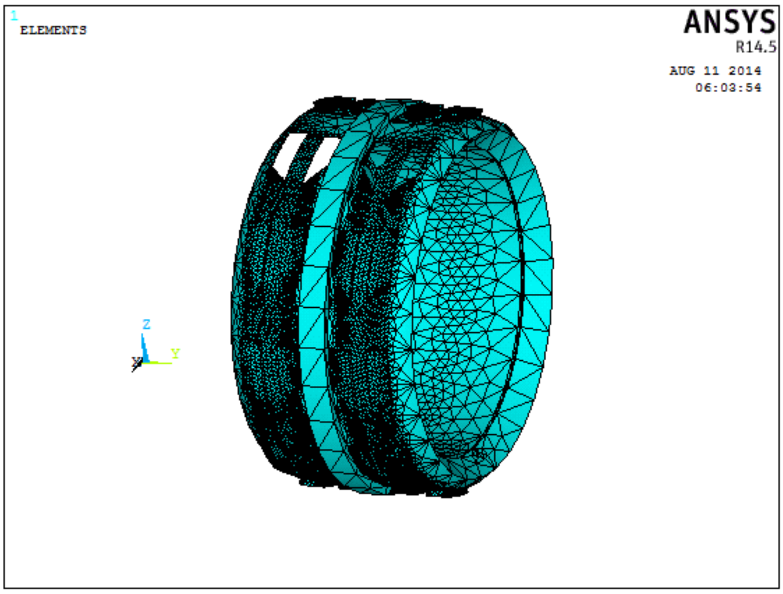

Fig 6.13 Meshed model of Ford car tyre part

6.2.1 CAR WEIGHT + 5 PERSONS WEIGHT

Pressure At 1.04 N/mm^2

5 persons weight each 70Kgs (350) + Kerb Weight (w) = 1500kg

Road contact ellipse Area (a) =1430.13 mm^2

Tyre inside Pressure(P) = $\frac{w}{a}$ = 1.04 N/mm^2

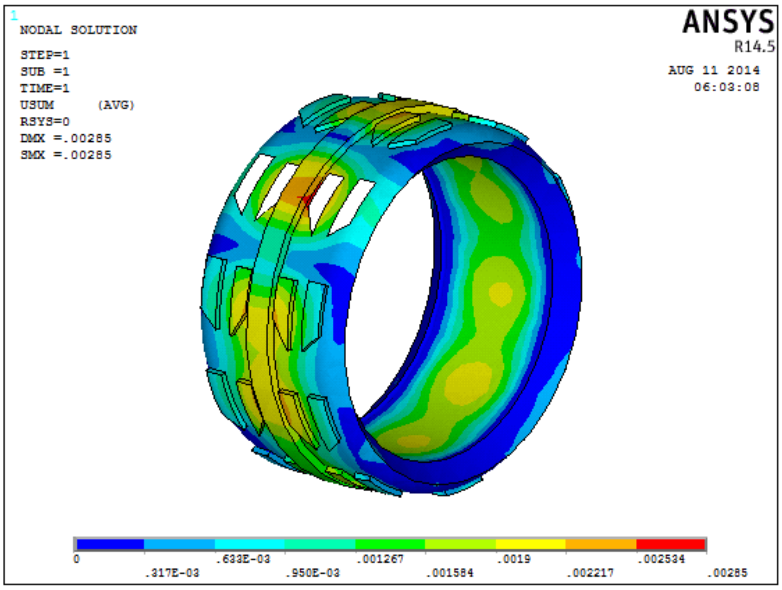

Fig 6.14 Displacement of tyre at pressure 1.04 N/mm^2

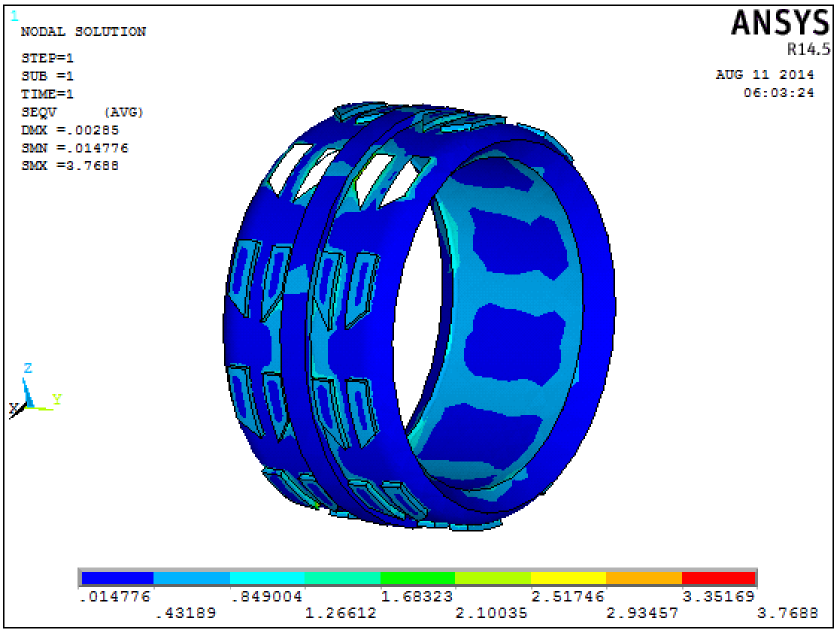

Fig 6.15 Stress of tyre at pressure 1.04 N/mm^2

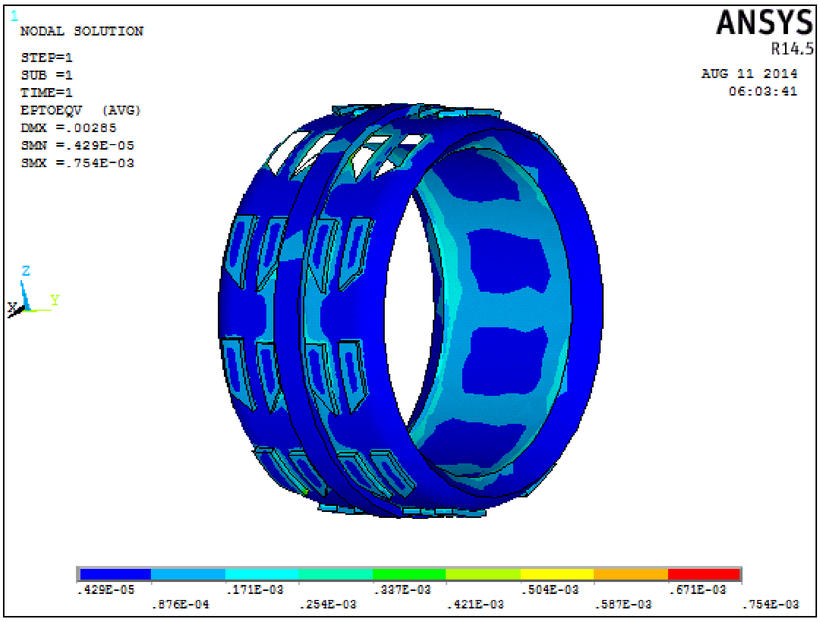

Fig 6.16 Strain of tyre at pressure 1.04 N/mm^2

6.2.2 CAR WEIGHT + 6 PERSONS WEIGHT

At pressure 1.06 N/mm^2

6 persons weight each 70Kgs (420) + Kerb Weight (w) = 1570kg

Road contact ellipse Area (a) =1475.18 mm^2

Tyre inside Pressure(P) = $\frac{w}{a}$ = 1.06 N/mm^2

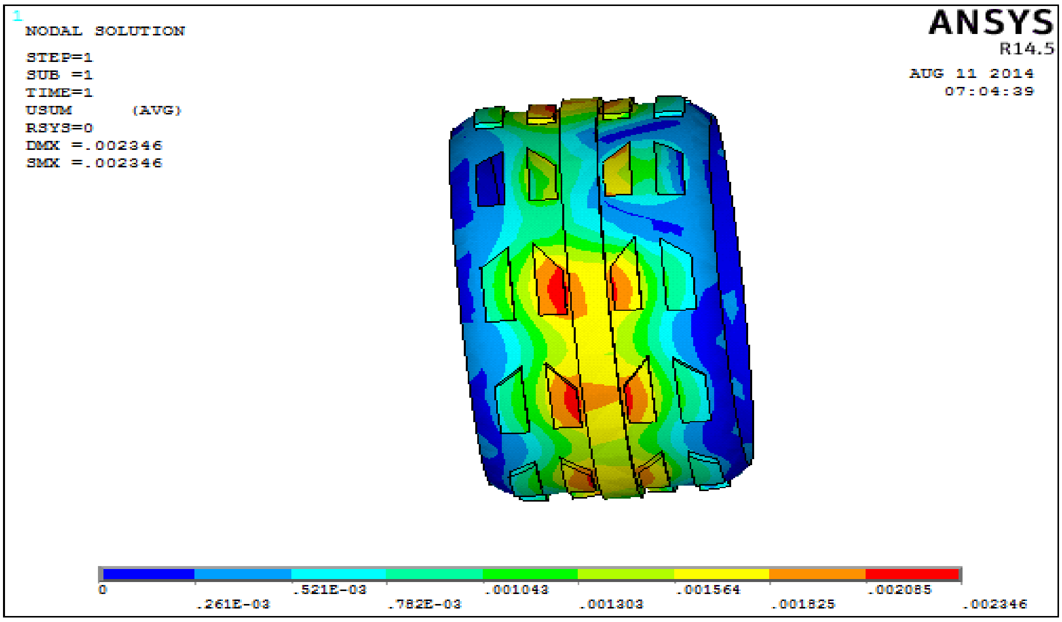

Fig 6.17 Displacement of tyre at pressure 1.06 N/mm^2

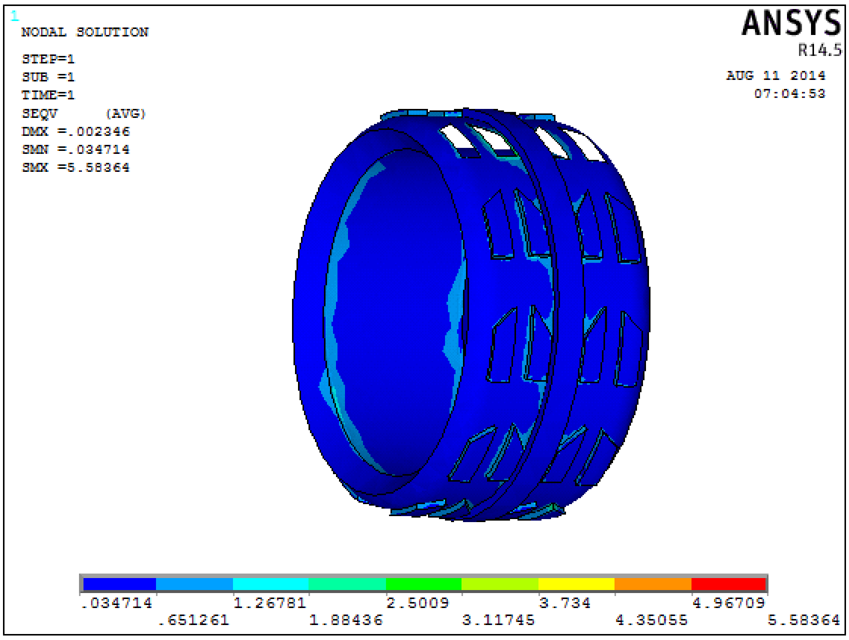

Fig 6.18 Stress of tyre at pressure 1.06 N/mm^2

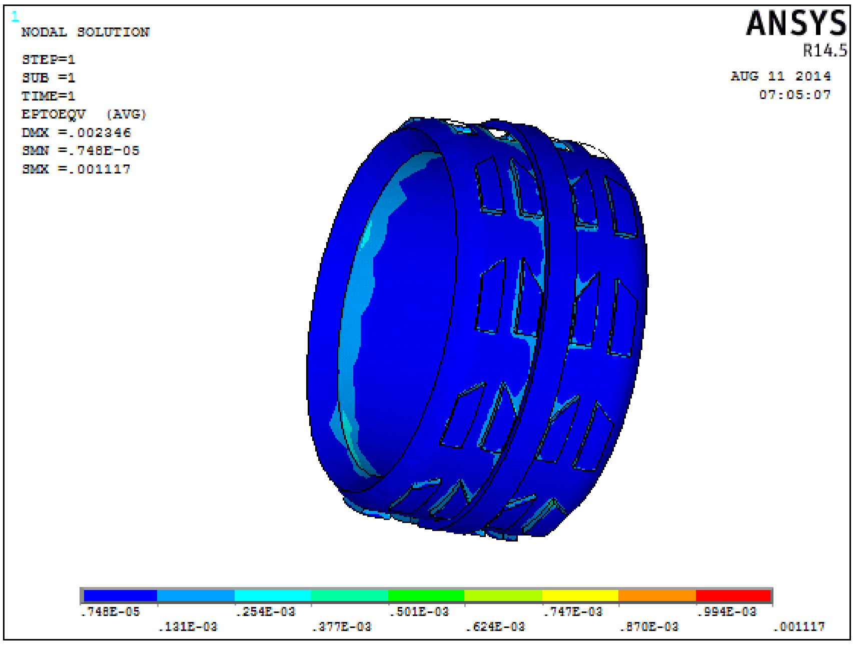

Fig 6.19 Strain of tyre at pressure 1.06 N/mm^2

6.2.3CAR WEIGHT + 7 PERSONS WEIGHT

At pressure 1.07 N/mm^2

7 persons weight each 70Kgs (490) + Kerb Weight (w) = 1640kg

Road contact ellipse Area (a) = 1519.59 mm^2

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Tyre inside Pressure(P) = $\frac{w}{a}$ = 1.07 N/mm^2

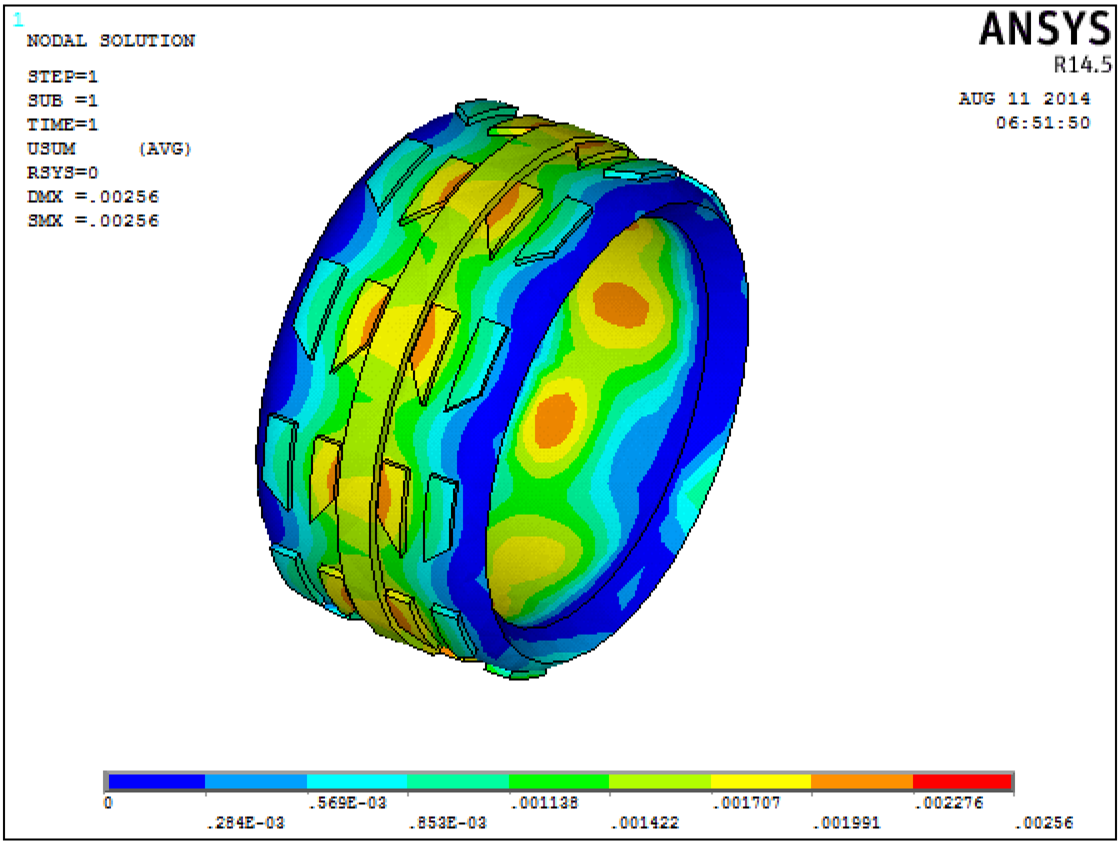

Fig 6.20 Displacement of tyre at pressure 1.07 N/mm^2

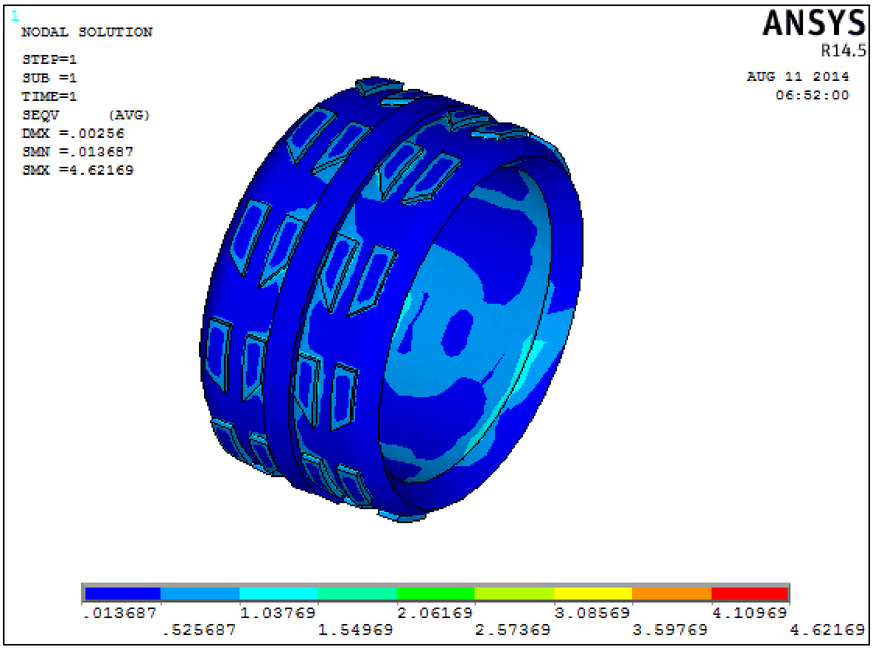

Fig 6.21 Stress of tyre at pressure 1.07 N/mm^2

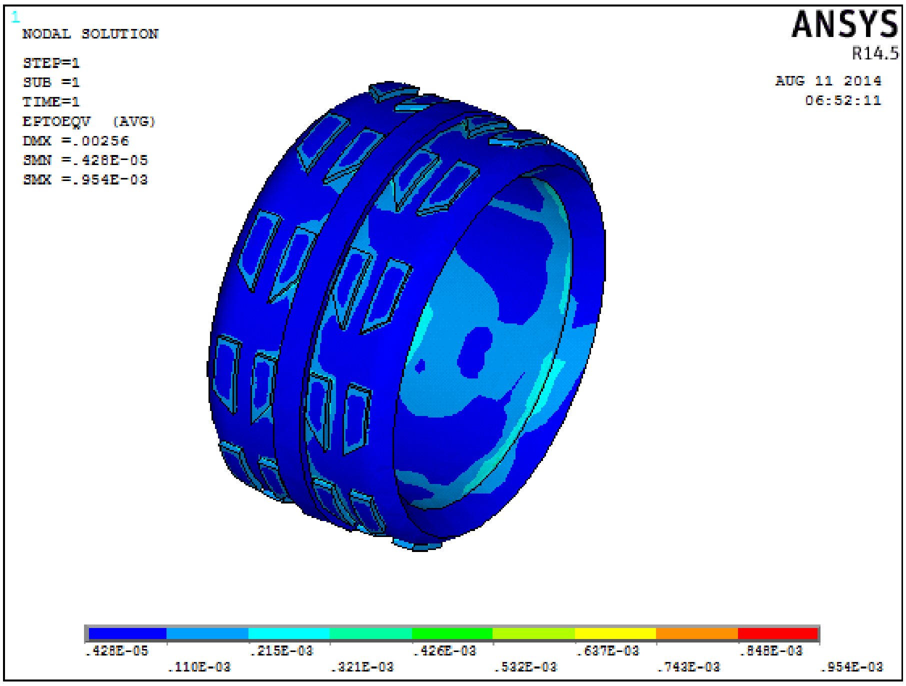

Fig 6.22 Strain of tyre at pressure 1.07 N/mm^2

6.3 SKODA TYREAT INFLATION PRESSURE - 0.036N/mm^2

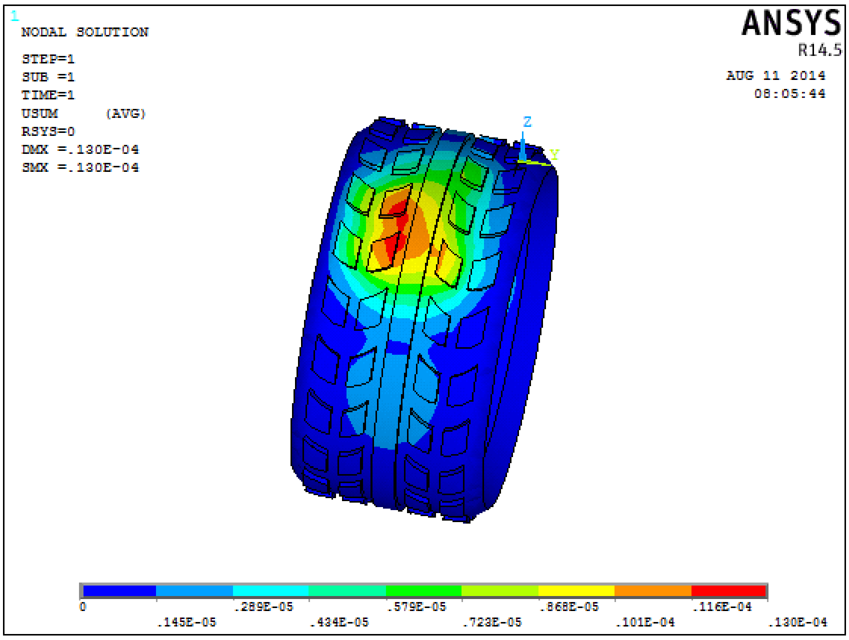

Fig 6.23 Displacement of tyre at pressure 0.036 N/mm^2

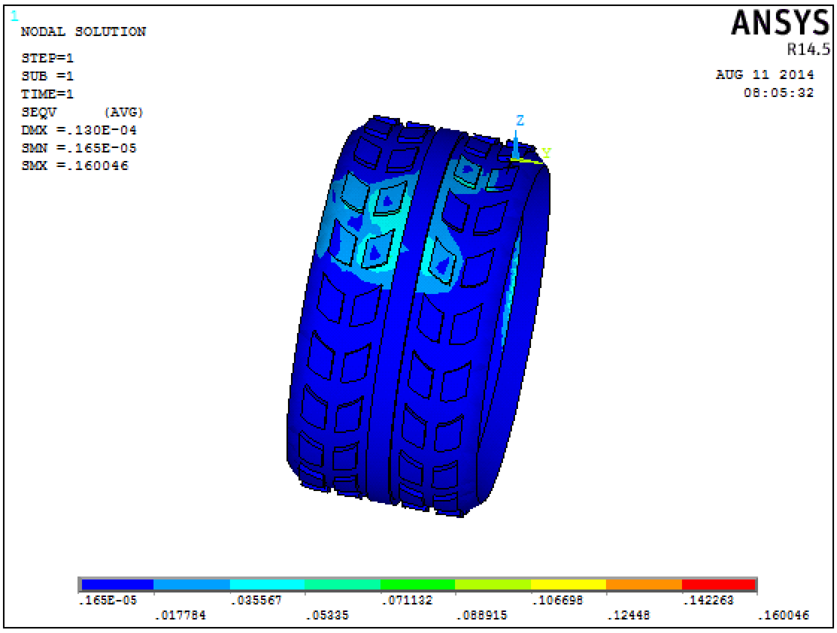

Fig 6.24 Stress of tyre at pressure 0.036 N/mm^2

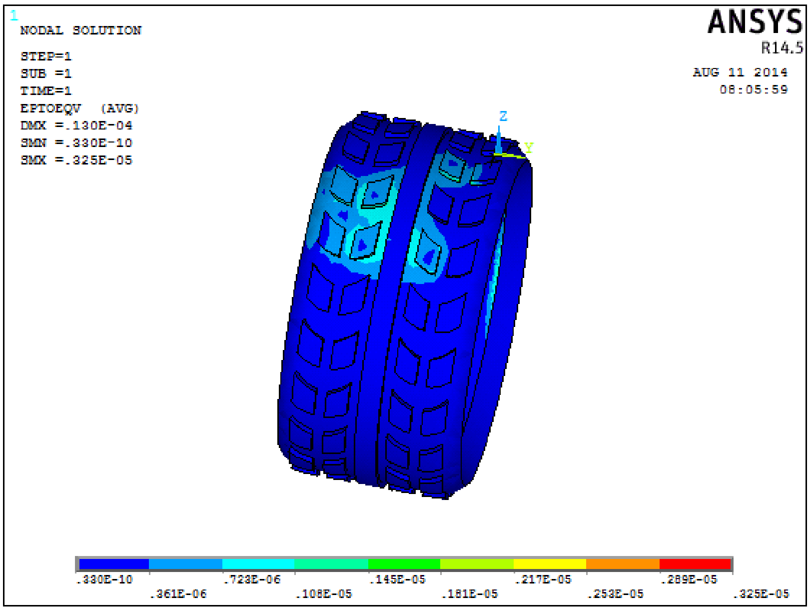

Fig 6.25 Strain of tyre at pressure 0.036 N/mm^2

6.4 FORD TYREAT INFLATION PRESSURE-0.036N/mm²

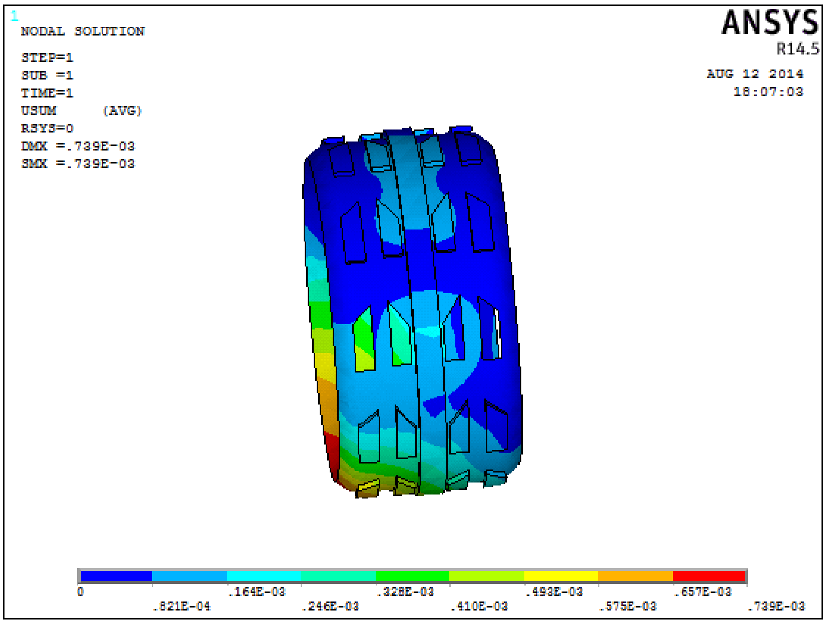

Fig 6.26 Displacement of tyre at pressure 0.036 N/mm²

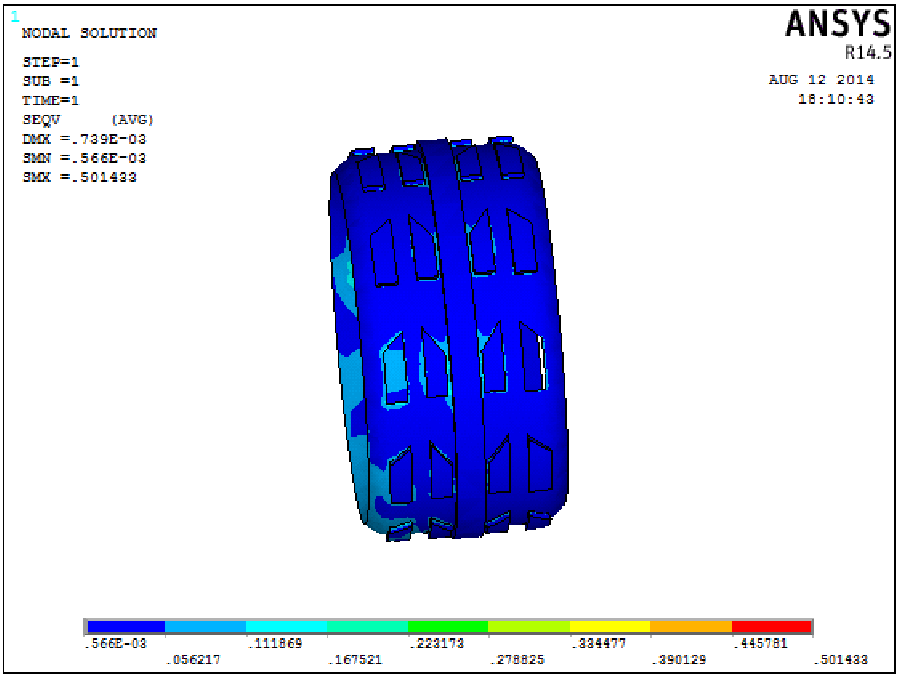

Fig 6.27 Stress of tyre at pressure 0.036 N/mm²

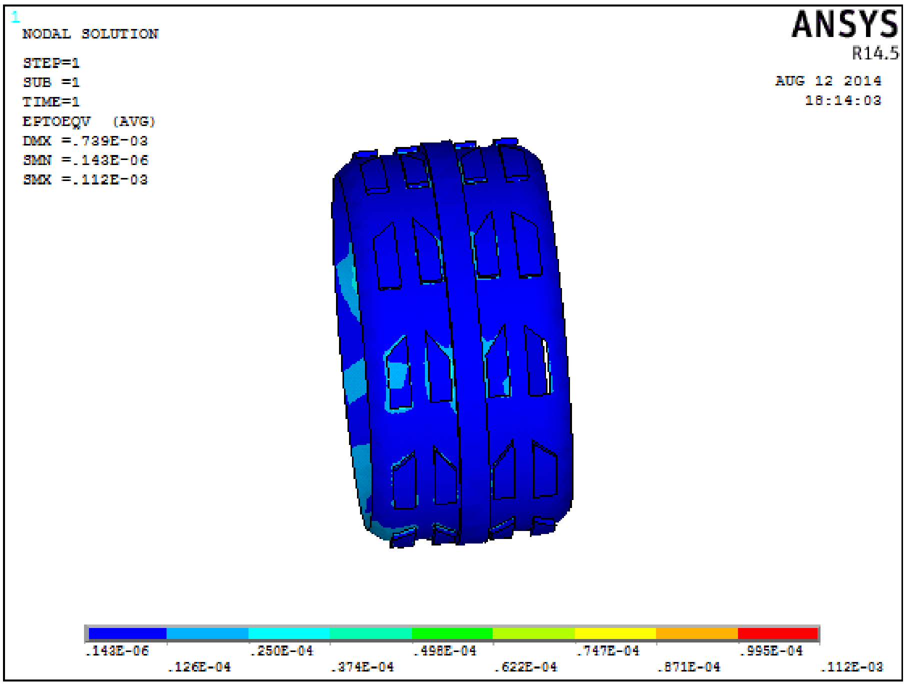

Fig 6.28 Strain of tyre at pressure 0.036 N/mm^2

7. RESULTS TABLE

SKODA RAPIDCAR TYRE

Table 7.1 Analysis Results of Skoda Rapid Car Model

Pressure (N/mm^2)	Displacement(mm)	Stress(N/mm^2)	Strain
At 1.12	0.000520	7.90991	0.001641
At 1.13	0.003657	8.33431	0.001715
At 1.14	0.00520	9.31402	0.001925
Inflation pressure(0.036)	0.130e-04	0.160046	0.325e-05

FORD CLASSIC CAR TYRE

Table 7.2 Analysis Results of Ford Classic Car Model

Pressure (N/mm^2)	Displacement(mm)	Stress(N/mm^2)	Strain
At 1.04	0.000285	3.7688	0.00754
At 1.06	0.00346	4.62169	0.00954
At 1.07	0.00516	5.58364	0.01117
Inflation pressure(0.036)	0.739e-03	0.510433	0.112e-03

8. CONCLUSION

In this project, the effect of tyre over load and inflation pressure on the rolling loss with fuel consumption is analyzed. The investigations are made on two car tyre models of Skoda Rapid car and Ford Classic car. The rolling losses mainly depending upon load and inflation pressure using relation rolling losses $R= C_1W$ and $R = C_1*1/p^{0.5}$ (where C_1 is constant and for passenger car tyre's the value is 0.0078 as shown in page from SAE Journal J1269 & IJEMS Journal Volume 11, Oct 2004.) were calculated and also fuel consumption using Schuring's rolling resistance versus fuel consumption results, it can be concluded that a rolling resistance of a tyre is increased for applied load's (car weight with persons weight) and fuel consumption is also increased.

The given below table 8.1 & 8.2 shows the results of Rolling loss change percentage and Fuel consumption change percentage with respect to rolling loss (R).

Skoda Rapid car:

Table 2.1: Values of Rolling loss change & Fuel consumption Change in Percentage of Skoda Rapid car

Load(W) in Kg (Car + Person's wt)	**Rolling loss(R) in N** ($R=C_1W$)	**Rolling loss change in percentage (%)** (Max-Min)/Max	**Fuel consumption change in percentage (%)**
1500+350 (5 members) 1500+420 (6 members) 1500+490 (7 members)	R_1= 141.55 N R_2 =146.91N R_3 = 152.27N	3.64% (R_2-R_1/ R_2) (From 5 to 6 members) 7.04% (R_3-R_1/ R_3) (From 5 to 7 members)	1.094% (using Schuring's eq) 2.11% (using Schuring's eq)

(The Schruing's equation is taken as reference in IJEMS VOL.11 Oct 2004)

Ford Classic car :

Table 2.2: Values of Rolling loss change & Fuel consumption Change in Percentage of Ford Classic car

Load(W) in Kg (car + Person's wt)	**Rolling loss(R) in N** ($R=C_1W$)	**Rolling loss change in percentage (%)** **(Max-Min)/Max**	**Fuel consumption change in percentage (%)**
1100+350 (5 members) 1100+420 (6 members) 1100+490 (7 members)	R_1= 114.77 N R_2 =120.13 N R_3 = 125.13N	4.46% (R_2-R_1/ R_2) (From 5 to 6 members) 8.55% (R_3-R_1/ R_3) (From 5 to 7 members)	1.33% (using Schuring's eq) 2.56% (using Schuring's eq)

(The Schruing's equation is taken as reference in IJEMS VOL.11 Oct 2004)

By observing the analysis results shown in above Tables 2.1 & 2.2, when load increases with increase of rolling resistance and also increases of fuel consumption and also by prepared 3D model is imported to the ANSYS Software and analysis Results Table 7.1 & 7.2 the stresses produced 3.0 N/mm^2 to 9.0 N/mm^2 only, But the property of Rubber Material Stresses 56 to 115 N/mm^2 (In the page Rubber Material Properties) the stresses produced are less than the yield strength value of rubber material even the tyre is overloaded so the car tyre is in safe position. The Displacement, Stress and Strain values are calculated at different pressures. The Wear is indicated shown in figures, **6.1 – 6.28 .** The color vary from Blue, Sky Blue, Green, Yellow, Orange and Red. It indicates the wear is increases by varying color from Blue to Red, Red indicates more wear. Generally the more wear in the middle of the tyre because of more contact in the middle of the tyre.

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