ANALYSIS OF ENERGY PRODUCED AND DISTRIBUTED IN RIGID PAVEMENT

A Project Submitted in Partial Fulfilment of the Requirements for the Degree of

MASTER OF TECHNOLOGY

in

Transportation Engineering

by

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LUCKNOW

(June, 2018-20)

CERTIFICATE

Certified that **ABHILEKH SRIVASTAVA** (1180465001), has carried out the research work presented in his thesis entitled, **“ANALYSIS OF ENERGY PRODUCED AND DISTRIBUTED IN RIGID PAVEMENT”** for the award of **Master of Technology** from Babu Banarasi Das University, Lucknow under my supervision. The thesis embodies result of original work, and studies are carried out by the student himself and the contents of the thesis do not form the basis of for the award of any other degree to the candidate or to anybody else from this or any other University/Institution.

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DECLARATION

I hereby certify that the work presented in this thesis entitled **"ANALYSIS OF ENERGY PRODUCED AND DISTRIBUTED IN RIGID PAVEMENT"** submitted to the Department of Civil Engineering, Babu Banarasi Das University, Lucknow in partial Fulfillment for the award of degree of **Master Of Technology** in **Transportation Engineering** is an authentic record of my own work carried out during the period from **August 2018 – June 2020** under the own guidance and supervision of **Prof. D.S. Ray**. I have not plagiarized or submitted the same work for the award of any other degree to this or any other university. All the tests were performed in the University campus and under the supervision of guide sir.

In case this declaration is found incorrect, I accept that my degree may unconditionally be withdrawn.

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(Abhilekh Srivastava)

ABSTRACT

In the modern world transportation has reached to a new level with enhanced technology and different material for the construction. Modern time requires higher speed and lesser time of travel between origin and destination hence expressways have attained more priority than the other category of pavement. They have a design module of lesser intersections, lesser obstruction hence providing higher speeds even >100 kmph. The rigid pavement design of the expressways has given higher speed but has somehow compromised in the surface friction part too and to balance this part there has been a provision of higher texture depths which has given better griping value both in dry and wet conditions. But now it has come into notice that there is a tyre bursting phenomenon that is occuring in the rigid pavement hence this paper has analysed the amount of energy that is contributed by the higher texture depths into the rolling tires. This paper tries to make study of the energy produced when a tire rolls on the surface of rigid pavement and how it gets distributed into the atmosphere and some absorbed by the rolling tire. This paper will more give emphasis on the portion of energy produced because of the textures provided on the pavement; and will not include the loss of energy due to any other cause. Texture provided on the pavement is basically a series of repeating figures drawn transverse to the moving direction in order to attain a desired value of skid resistance and friction so as to avoid skidding in any condition. But in view of this there is an abrupt increase in the amount of energy being produced and this is causing the problem of tire bursting. So for the analysis tests were conducted at the site and the initial and the final pressure of the tires were noted down. The kinetic theory of gases has given the kinetic energy of the enclosed gas before the test and after the test. Since there is an increase in the pressure of the tires hence using Gay Lussac's law we concluded there will be an increase in the temperature also hence final temperature was calculated. The increase in the kinetic energy gave us the conclusion about the mean texture depth that can be adopted. For a minimum case it was concluded that the texture depth of about <1.8-1.9 mm is optimum considering

the energy increase within the tires. For the test site it was concluded that texture depth >2.75 mm is not suitable though providing high amount of resistance hence causing tire burst accidents. Therefore it was concluded that the ideal texture depth for the site would be recommended to be < 2.75 mm for future activity of maintenance. Friction analysis and the contact area patch analysis has also given the reasons why low inflation pressure and the poor quality of the tires can lead to the tire bursting phenomenon.

There has not been a lot of research going on regarding this issue but research paper related to few key problems involved in this study on combining will pave the foundation for the advance research on this issue.

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LIST OF ABBREVIATIONS

J	Joule
kJ	KiloJoule
K	Kelvin
PCC	Portland Cement Concrete
GSB	Granular Sub Base
CC	Cement Concrete
PQC	Pavement Quality Concrete
BPN	British Pendulum Number

CHAPTER 1

INTRODUCTION

The stability of the roadway surface is very important aspect in the design of the pavement and should be non-yielding to allow the heavy wheel loads of traffic to move with minimum possible rolling resistance. The surface of road should also be uniform along the longitudinal profile so as to provide the fast moving vehicles move safely and comfortably at the design speed. The main objective of a well designed and constructed pavement is to have elastic deformation within the permissible limits so that the roadway can sustain a large number of repeated load applications during its design life.

1.1 TYPES OF PAVEMENT STRUCTURE

Pavements are generally categorised into two types on the basis of structural behaviour:

- Flexible Pavement
- Rigid Pavement

1.1.1 FLEXIBLE PAVEMENT

These pavements have very less flexural strength and are defined by this characteristic. These types of pavements transmit the load to the lower layer by grain to grain transfer. A basic flexible pavement has four major components:

- Soil Subgrade
- Sub base course
- Base course
- Surface course

Bituminous concrete, granular materials with or without bituminous binders, water bound macadam etc. are the common examples of flexible pavement. No joints are provided in these type of pavements; neither expansion nor contraction joints. These type of pavement's construction cost is less but the maintenance cost is high. IRC-37:2012 is the design code for the design of flexible pavement which is being reviewed time to time.

1.1.2 RIGID PAVEMENT

Rigid Pavements are the type of pavements which possess high flexural strength. The rigid pavement transfer the stresses generated due to wheel load through a wider and larger area below by the slab action. They are generally made up of portland cement concrete. The plain cement concrete slabs are assumed to take up about 40 kg/cm^2 flexural stress. Joints are also used in its construction and constitutes high completion cost but has a low maintenance cost. They are designed using elastic theory. IRC-58:2012 is the design code for the design of rigid pavement.

They are generally used in the construction of airports and major highways, expressways, such as those used in the inter-state highway systems. They also serve as heavy duty industrial flooring slabs, ports and harbour yards pavement, and heavy vehicle or terminal pavements.

1.1.2.1 COMPONENTS OF RIGID PAVEMENT

The basic components of a typical rigid pavement or cement concrete (CC) pavement structure includes (from bottom towards the top):

- Compacted soil subgrade
- Granular sub- base(GSB) layer and drainage layer
- Base course
- CC/ PQC pavement slab

A typical rigid pavement or cement concrete pavement structure and its component layers are shown below in figure:

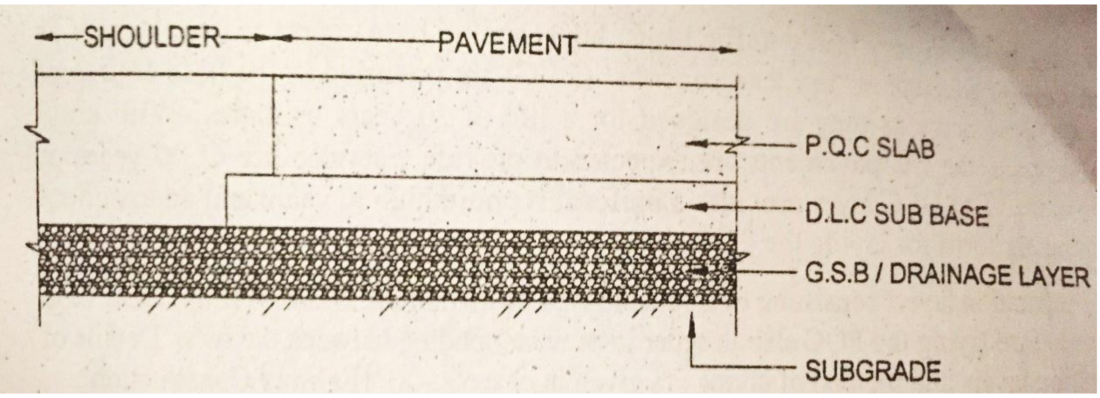

Fig 1.1.2.1.1 Components of the Rigid Pavement

As the CC pavement slab has to bear high flexural stresses which is caused by moving traffic loads and warping action of the slab due to the daily variation in temperatures, the CC slab is constructed of high quality cement concrete and is called “Pavement Quality Concrete” (PQC). The CC pavement slab can serve both purpose of the base course and surface course of pavements. A thin separation membrane is also placed on the top of the base course before the process of laying of the PQC slab.

1.1.2.2 FACTORS AFFECTING DESIGN OF CC PAVEMENTS

The major factors which affect design and performance of rigid or CC pavement are given below:

(a) Wheel Load

(b) Temperature Variations at the location of the road

(c) Types of Joints and their spacing

(d) Subgrade and the other supporting layers of the CC pavement

(e) Drainage characteristics

Due to the heavy wheel loads of the traffic there is formation of flexural stresses. The flexural strength of plain cement concrete is very lower than its compressive strength and that is why the wheel load affects the design of these pavements. The wheel load factors that should be considered are the magnitude, loaded area or contact pressure, location of the loading on the slab and the number of repeated application of the heavy loads.

The daily variation of temperature between the day and night generally depends on the geographical location of the pavement surface. These variations in the temperature results in the differential heating of the top and bottom of the CC pavement slab and this causes warping or bending action in the slab.

1.1.2.3 TYPES OF CEMENT CONCRETE PAVEMENT

There are different types of cement concrete (CC) pavements:

- Plain concrete pavements
- Reinforced concrete pavements
- Continuously concrete pavements with elastic joints
- Fibre reinforced concrete pavements

1.1.2.4 MATERIALS USED IN CONSTRUCTION OF CC PAVEMENTS

The materials that are required for the construction of cement concrete pavements can be classified in two parts,:

(i) selection of the basic component materials

(ii) mix design and construction of pavement quality concrete (PQC) mix required to construct the pavement

- The basic materials used in process of construction of CC pavements include Portland cement, coarse aggregates, fine aggregates, water and admixtures and also steel used in the construction of joints in the form of dowel bars and tie bars.
    - Portland Cement: Basic types of cement that can be commonly used for the construction of PQC and CC pavements can be (i) Ordinary Portland Cement of 43 grade (ii) Ordinary Portland Cement of 53 grade (iii) Portland-Pozzolana cement with fly ash content up to 20 percent by weight and (iv) Portland Slag Cement.

- Coarse Aggregates: The coarse aggregates should comply with the following design requirements:

  Los Angeles Abrasion value : less than 35 percent

  Combined flakiness and elongation index : less than 35 percent

  Water Absorption : less than 3 percent

  Continuously graded coarse aggregates is being preferred for the construction of CC pavements with maximum size of aggregates being limited to 31.5 mm.
- Fine Aggregates: They comprises of clean natural sand or crushed stone sand or a combination of both; the fine aggregates should be free from coal, clay and lignite. They should be well graded with 100 percent passing through 10 mm sieve.
- Water: Water that should be used for the construction should be clean and potable and should be free from any type of salts, acid, oil and other any organic matter.
- Admixtures: The major work of admixtures in cement concrete is to improve the workability of the concrete and to provide the extension of setting time of the concrete mix without adversely affecting the desirable properties of the concrete. The total quantity of chemical admixtures is limited to a maximum of about 2.0 percent by weight of the cement or the cement + fly ash.

1.1.2.5 CONSTRUCTION

Different methods can be adopted for the construction of cement concrete pavement depending upon the other factors like the importance and magnitude of the road project, equipment that can be made readily available, location, construction period etc. There are three methods that are used for the construction of CC pavements in India:

- Fully mechanised construction using “slip form paver”
- Mechanised method using “fixed form”
- Semi-mechanised labour-oriented method using fixed form

In all above mentioned methods different operations which are involved are listed below:

a) Spreading of the prepared concrete mix to desired thickness, grade and profile.
b) Compacting.
c) Finishing the surface to desired surface profile.
d) Texturing.
e) Curing.
f) Cutting of contraction joints and longitudinal joints.

1.2 PAVEMENT TEXTURE

Pavement textures are often categorised by the wavelengths in the texture (the length between physically repeating features). A pavement texture is a combination of numerous wavelengths ranging from microscopic level to macroscopic level. The categories for the texture wavelengths comprises of megatexture (50 to 500 mm), macrotexture (0.5 to 50 mm) and microtexture (<0.5 mm).

The geometric profile of the pavement in the vertical plane has been divided ino different scales depending on the dynamic response of interest to vehicles eg.comfort of the ride, skidding resistance, rolling noise and vehicle operating cost factors. In the below given figure it should be noted that, generally large amplitudes are desirable when wavelengths are below 10 mm and small amplitudes are desirable for wavelengths above 10 mm.

Type of Texture	**Lengths**	**Affects**
Micro- Texture	< 0.5 mm	Skid Resistance
Macro- Texture	0.5 mm – 50 mm	Skid Resistance Tire – Pavement Noise
Mega- Texture	50 mm – 500 mm	Skid Resistance Tire- Pavement Noise Smoothness

Table 1.2.1 Types of Textures

The characteristics of the surface has been divided into four general types:

- Unevenness
- Megatexture
- Macrotexture
- Microtexture

1. Unevenness- These in the road surface, with wavelengths ranges from 0.5 m to 50 m and is associated with longitudinal profiles larger than the footprint of the tyre. It affects vehicle dynamics, ride quality, dynamic loads and drainage. In worst cases it can lead to the loss of contact with the pavement surface.
2. Megatexture- These in the road surface refers to the deviations with wavelengths from 50 mm to 500 mm. Examples include ruts, potholes, major joints and cracks. It basically affects vibration in the tyre walls but not the vehicle suspension and that is why it is associated with noise and rolling resistance. This type of textures could influence tyre/road contact.
3. Macrotexture- These type of textures ranges with wavelengths from 0.5 mm to 50 mm and is influenced by the size, shape, spacing and arrangement of coarse aggregate particles. It basically affects the tyre noise and water drainage from the tyre footprint. This texture scale is sought to be important for hysteretic friction especially at high speed.
4. Microtexture- These ranges from the amplitudes of deviations with wavelengths less than or equal to 0.5 mm. It is basically found on the surface of coarse aggregate particles or between the bituminous mortar and fine material. It mainly affects skid resistance at all speeds for dry and wet conditions.

1.3 TIRES

A tire is basically a ring shaped component that helps in surrounding the wheel’s rim so as to transfer the load of the vehicle from the axle through the wheel to the ground and also to provide the necessary traction on the surface.

The basic materials that are used in its construction are synthetic rubber, natural rubber, fabric and wire in combination with carbon black and other necessary chemical compounds. Pneumatic type rubber tires are mainly used in many types of vehicles like cars, bicycles, motorcycles, buses, trucks, heavy equipment and aircrafts. Metal tires are being used in rail cars and locomotives. Solid rubber tires are used in other non- automotive applications such as casters, carts, lawn movers and wheel barrows.

1.3.1 COMPONENTS OF A TIRE

Regardless of any category of tire, all the passenger cars, or trucks they all share some basic parts i.e. (i) Tread (ii) Sidewall (iii) Beads (iv) Body plies (v) Belt plies.

- Beads- The beads in the tire hold the tire to the rim or with the outer edge of the wheel. They are mainly made up of copper, brass or bronze plated tensile steel wires wound into a rubber band. It helps in preventing the tire from sliding out of place when the wheel rotates.
- Bead filler- It is basically a rubber compound inside the tire's beads. It helps in providing the stability to the lower sidewall and bead area. It also helps in determining the tire's performance characteristics through its density and stiffness.
- Belt plies- The major and primary function of the plies is to provide strength and stability to the tire tread. They play a major role in improving the mileage of the tires, the impact resistance and traction.
- Sidewall- The area of a tire from the tread to the bead- i.e. the side of the tire- is known as sidewall. All the information about the tire is printed on the sidewall and forms a protective covering for the cord. It is designed to resist the damage from ozone, cuts and snags.
- Tread- It is that portion of the tire that comes in contact with the pavement surface. The compound and design of the tread have to balance wear, traction, handling, fuel economy, resistance and other characteristics of the tire. The designs on the tread vary differently with respect to the category of the tire.

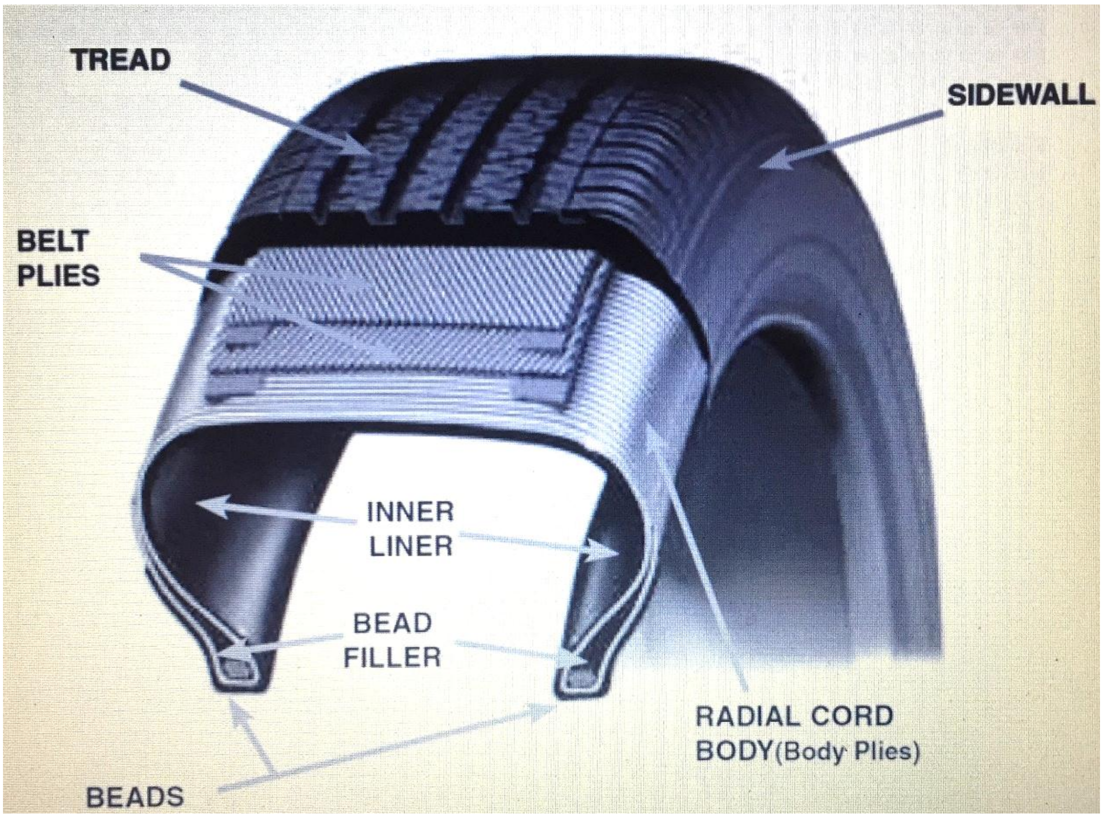

Fig. 1.3.1.1 Components of a Tire

1.4 BURSTING OF TIRES

This is one of the common cause in the accidents that have been occuring in the major highway and expressway systems. Broadly bursting of a tyre occurs when there is a rapid loss of pressurized air from within the tyre. When there is a compromise with respect to the structural integrity of the tire, the tire is unable to hold all that air inside. Due to this situation, the pressurized air escapes out tearing apart the tyre and rapidly causing an explosion and severe damage to the tyre surface. The major causes of the tyre burst are listed below:

I. Direct Impact- Due to the poor condition of the pavement surface there is a high possibility of a direct impact of the tyre resulting in slashing of the tyre surface at some point which becomes an open invitation for all the pressurized air to escape out thus leading to tyre burst.

II. High Temperature- Since most of India lies in the tropical or a subtropical region so it is prone to hot weather resulting in high temperatures and in general heat is the enemy for different parts of the vehicle especially the tyre. Due to high temperature there is an excessive build-up of heat in the tyres and this increase in temperature inside the moving tyre results in an increase in the pressure within the tyre. The friction between the pavement surface and the moving tyre helps this process and weakens the tyre which may result in bursting of tires due to this heat build-up.

III. Under Inflation- Another one of the major causes of the bursting of the tyres, Over inflation is not of a major concern under inflation is the reason behind more than 75 % of tyre burst induced accidents. Such under inflation tyres suffer from excessive flexing and that increases the contact patch with the pavement surface which leads to the accumulation of excessive frictional force and in turn builds up the heat inside the tyre. The building up of heat is much higher than those induced during the hot summer.

IV. High Speed- Every tyre is meant to function best at a particular speed and there is a maximum speed that the tyre can hold. Beyond the particular speed will increase the friction levels and wear quickly so in this case more than one factors are responsible for the bursting of tires.

1.4.1 PREVENTION OF TYRE BURST

i. To ensure that the tyres are in good condition and shape and the depth of the tread should be 1.5 mm.

ii. Always run the tyre with correct tyre pressure mentioned in the car manual since this factor has its effects on the friction build up and in turn the heat build- up.

iii. Always choose the tyre with the appropriate speed rating.

Given below is the chart for its relation:

Speed Symbol	**Maximum Rated Speed**
L	120 km/h
P	150 km/h
S	180 km/h
T	190 km/h
H	210 km/h
V	240 km/h
W	270 km/h
(W)	>270 km/h
ZR	>240 km/h

Table 1.4.1.1 Maximum Speed – Speed Symbol Rating

CHAPTER 2

LITERATURE REVIEW

2.1 GENERAL

Afzali B (2006)[9] This paper studied the effect of change in one step of production of tire on the thermal properties and temperature distribution of the rolling tire by performing a finite element modelling of heat transfer and temperature distribution of a steady state rolling tire. It provided the critical points and the maximum temperature in a rolling tire and it helps in choosing best structure and material of the tire. The tire considered is divided into various zones and it says that each zone has its own boundary conditions for heat transfer analysis and its starting assumption will be useful in making our theoretical study.

L.Tighe (2008)[1] This paper performed its study to determine the optimum surface friction and the mean texture depth for cement concrete surface and it was found that mean texture depth of about 1.8 mm provided the maximum friction on textured PCC surface. It calculated the British Pendulum Number (BPN) for measuring the skid resistance and the study evaluated the true effect of asphalt concrete surfaces and pozzolanic cement concrete surfaces on different macro texture and its corresponding surface friction. The different combinations of textures used in preparing the specimen are screed finish, burlap, corn broom and plastic turf drag, exposed aggregate.

Woodside (2011)[10] This paper has done laboratory tests to measure the dynamic vertical, transverse and longitudinal contact forces under tires with varying inflation pressure and loads. It gave a point that longitudinal contact stresses at the trailing edge of the contact patch were on the higher side when the inflation pressure was low. For furthur research this paper results can be useful and the effect of these forces in the design of pavement can also be incorporated for a better design.

Yuanmang Xia (2012)[4] An important paper that has developed a new wireless temperature measurement system that aims to measure the interior temperature distribution of the rolling tire. It gave a vital point with respect to the temperature distribution in a rolling tire that at the beginning the tire temperature is in equilibrium with the ambient air temperature and starts absorbing energy and there is an increase in temperature and after much time it attains an equilibrium or steady state when all the heat generated is transferred to the ambient air and road through the tire boundary. Using this technique the measurement of temperature can be possible and this will enable us in finding out the change in temperature inside the rolling tire when moved at a certain velocity and distance.

Zuraulis (2014)[11] This paper made an analysis of the impact of the road micro profile on the duration and the type tire road contact with the pavement moving at different speed. It provides a precise data on different types of irregularities relation with the contact time of moving tire with the surface. The results will allow us in quantifying other aspects of the moving vehicle like passenger comfort, suspension system, energy production and distribution.

Sadok Sassi (2015)[8] This paper gives a model analysis of the vehicle whose one tire is burst and provides result on the stability and geometry of the vehicle and the driver when phenomenon of tire burst occur. Since tire burst is a fatal phenomenon it relates all the changes that occur in a moving vehicle when the tire blows out. The assumptions involved in this study can be helpful in our study. It gave the point that the blast coming from the tyre blowout generates enough energy to excite the wheel structure resonances but has relatively less effect on the stability of the driver.

Grinchuk(2016)[6] This paper made a study on the heat exchange with air and gave the temperature profile of moving oversize tire. A very important paper regarding the problem which is being considered under this paper as it gave the mathematical model of heat transfer in a tire and its heat exchange with air; The mean temperature profiles are calculated by considering transition to a stationary thermal regime and the influence of the rate of energy dissipation and of effective thermal conductivity of rubber on the temperature field is investigated ; It will help in finding out the portion of energy exchanged with air theoretically and if we get total energy produced in the system we can be able to find the energy produced by other source.

2.2 CONCLUSION OF REVIEW PAPERS

- Maximum temperature inside a tire increases non- linearly with the rate of energy dissipation and an increase in the thermal conductivity of the tire material reduces the maximum temperature inside the oversize tire.
- The temperature inside the tire increases sharply during the first few hours and then attain a more or less a constant value due to more intense heat exchange with air.
- The energy that comes out of the tire during bursting phenomenon effects the stability of the vehicle and brings about changes in the road tire interaction.
- During vehicle acceleration the impact of road irregularities to the motion of vehicle is observed in case of 10 mm or more and it has been observed that at speed of 80 kmph or more and irregularities of 30 mm or more, the wheel motion increases in vertical direction and the wheel does not come in contact with the road surface.
- There are no temperature gradients in rolling tire in circumferential direction.
- When the load is heavy and inflation pressure is low, the contact force is highly non uniform.
- An increase in Cross Link Density by increasing the curing time, thermal conductivity falls and it causes an increase in maximum temperature when tire rolls.
- The temperature profiles of the change in temperature going inside the rolling tire has been obtained and the critical points with respect to temperature has been concluded from the previous research works.
- The change in skid resistance value with respect to different types of macro textures is concluded in PCC and AC surfaces.

CHAPTER 3

METHODOLOGY

Modelling:

There is a finite temperature model for its distribution of a rolling tire in standard conditions. In this case, a sketch of a tire has been divided into various zones and each zone has its own boundary condition for the analysis of heat transfer. The energy equation between the energy inputs, energy saves and energy outputs is as below:

$$E_{gen} + E_{in} = E_{out} + E_{stored} \tag{3.1}$$

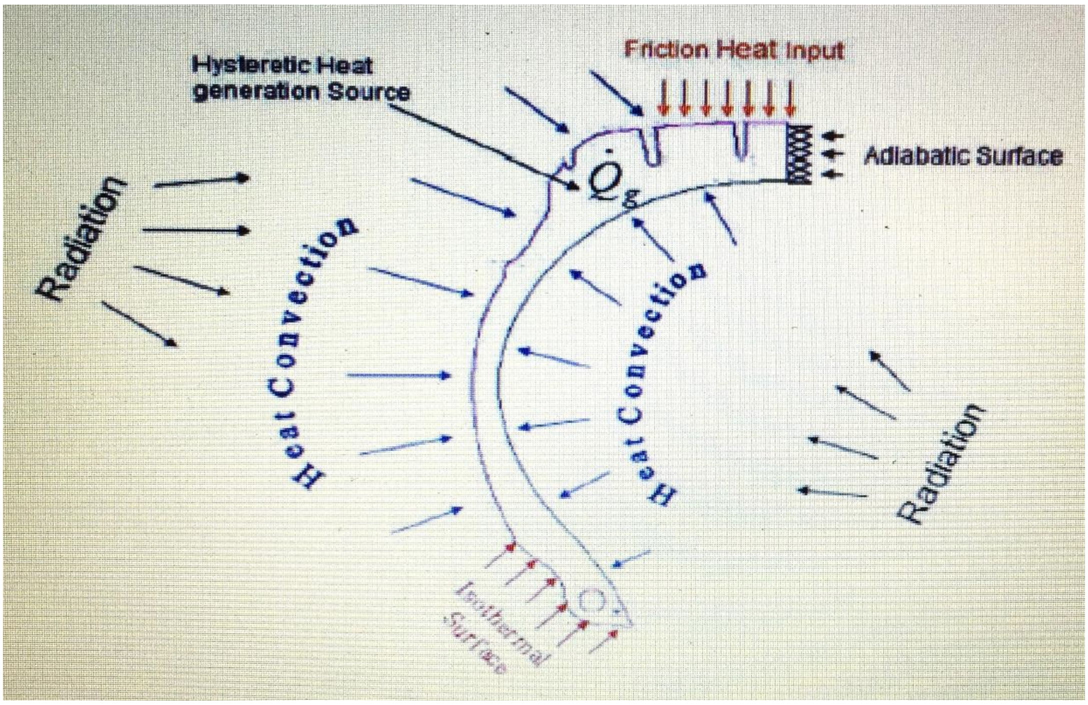

Fig. 3.1 Boundary conditions of a Rolling tire

When a tire roles energy is generated because of hysteresis loops and frictional force through the pavement surface, combining by conduction from road and radiation from environment, storing it by increase in temperature and thereby exiting by heat transfer with the environment through convection, conduction and radiation methods.

In the thickness of the tire material, a two dimensional heat transfer has been assumed in Cartesian coordinates (or one direction in cylindrical mode, radial) which follows the below equation:

$$\frac{d^2T}{dx^2} + \frac{g}{k} + \frac{d^2T}{dx^2} = 0 \qquad (3.2)$$

Where T is the temperature, g is the heat generation rate, K is conductivity coefficient, x, y are the ordinates and d is gradient operator.

From the study by Basirat Tabrizi (2006) in computer simulation of the finite element model of rolling tire it is found that the maximum temperature is found in the shoulder zones where the tire tread and sidewall join each other. The middle section of the tire exhibits two critical zones one is the shoulder zone and other is around the bead zone.

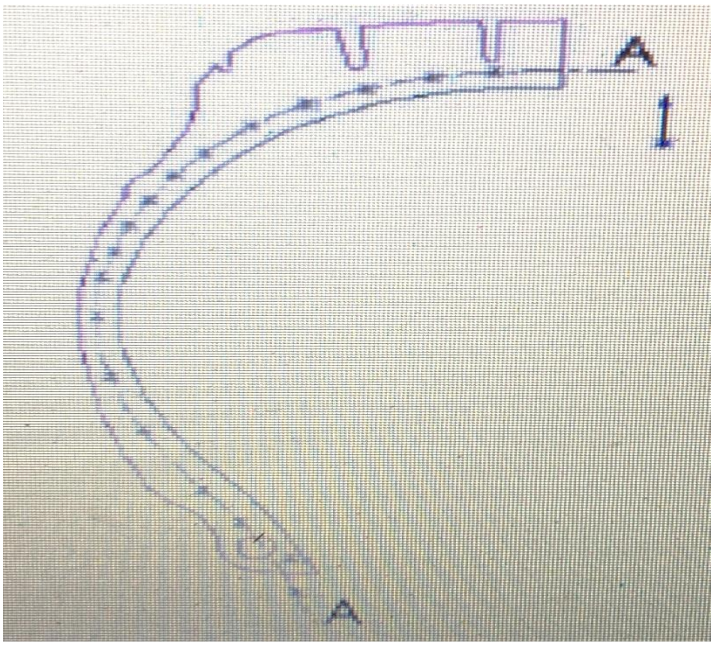

Fig. 3.2 Mid – Section temperature of a Rolling tire

Since the tire is made up of different materials a mid-section line is formed by joining the critical points and this section is the most important line in tire as shown in the above figure.

The research that is being carried out is primarily concerned in finding out the amount of energy inside the tire contributed by the texture but before that there is a need to understand the phenomenon that occurs when a tire rolls on the pavement surface.

3.1 RUBBER FRICTION

The properties of tyres are very important and rubber being, both natural and synthetic, is composed of polymers linked by covalent bonding; it is a viscoelastic material. Kummer in 1966 gave a model for sliding tyres:

$$F_T = F_A + F_{Hb} + F_c \tag{3.1.1}$$

Where F_T is the total frictional resistance developed between a tyre and a dry pavement, F_A is the frictional resistance contribution from adhesion of the two surfaces, F_{Hb} is the frictional contribution from bulk deformation hysteresis in the rubber and F_c is the contribution from rubber wear. There is a consideration of relatively small (1-2 %) force due to wear. In emergency braking situations, when F_c is more, it depends largely on the tyre composition and is assumed to be highest on those surfaces which are already providing high F_A and F_{Hb}.

The study in 1942 investigated the friction between rubber and hard surfaces and various loads were applied to the rubber specimens and it was found out that the coefficient of friction was decreasing with the increase in load. They also gave a conclusion that specimens of different sizes exhibited different friction coefficients, and μ was dependent on area. Similar experiments in 1946 gave the same conclusions such that μ decreased with load and is area dependent.

3.2 RUBBER ADHESION

The frictional force due to adhesion is because of the molecular interaction at the sliding surface and the bonding, stretching and breaking cycle resulting in the retarding force. Below figure give the diagrammatic representation of the adhesion component of friction. Adhesion can be basically considered as a summation of forces between individual points of contact so that:

$$F_A = \sum n_i j_i \tag{3.2.1}$$

where n_i is the number of molecular junctions between the surfaces at location i and j_i is the effective junction or the bond strength. Hence it implies that more points of contact, greater is the adhesive friction.

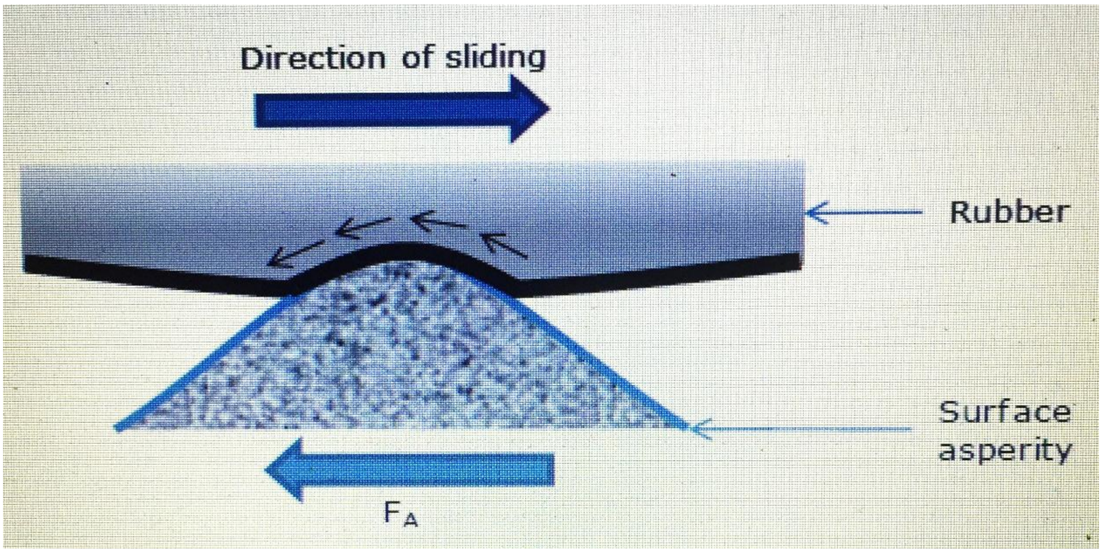

Fig. 3.2.1 Friction due to Adhesion

Research work given by Shallamach showed that the frictional force was dependent on the true area of contact and that for rubbers its variation with load was consistent with Hertz's formula:

$$d = 2.2\left(\frac{Wr}{2E}\right)^{\frac{1}{3}} \tag{3.2.2}$$

where d is the diameter of the circle formed when an elastic sphere is being flattened against a hard surface, W is the normal load, r is the sphere's radius and E is Young's modulus of sphere. Then the coefficient of friction becomes:

$$\mu = cW^{\frac{1}{3}} \tag{3.2.3}$$

where c is a factor which has to be determined empirically.

`3.3 HYSTERESIS IN RUBBER

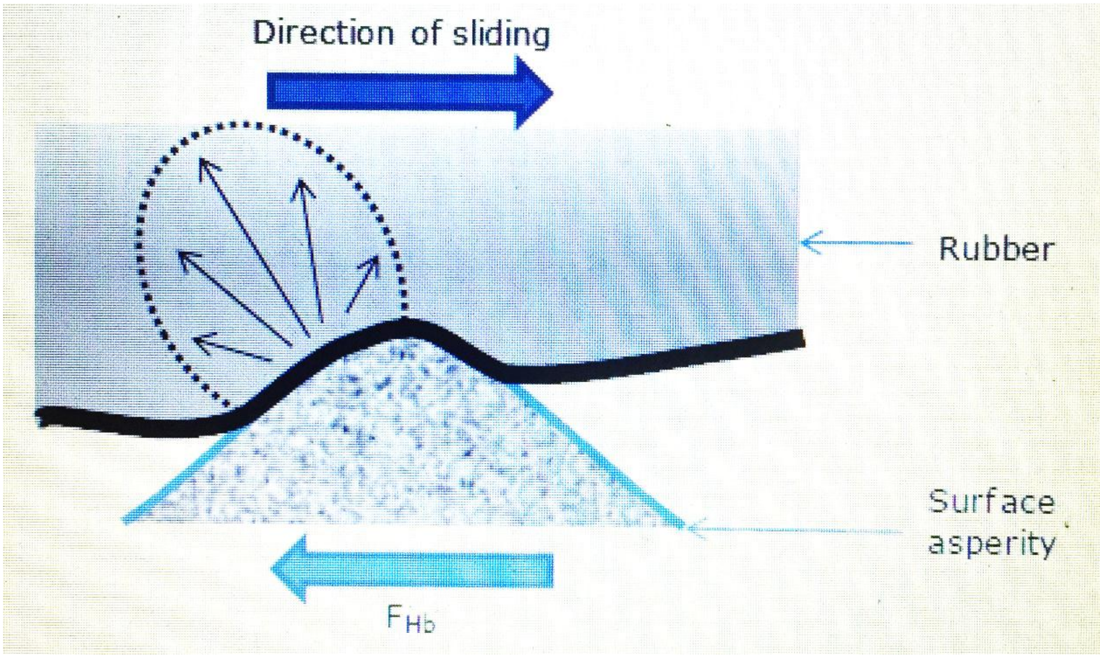

Fig. 3.3.1 Friction force due to Hysteresis

Rubber, being a viscoelastic material, does not obey the third law of friction (Coulomb's) which states that friction is independent of sliding velocity. When a viscoelastic material deforms it possess properties of both viscous and elastic materials and to differentiate between them it is necessary to consider stress and strain. Viscoelastic materials have the properties of both and the relationship between stress and strain is dependent upon time and the viscous materials do not completely return to their original shape when the stress is removed.

When the stress is being applied to the rubber, the deformation is not proportional to the amount of stress which is being applied. When the stress is removed, the reformation of the material is not proportional to the amount of stress nor opposite to the amount of deformation that occurred when the stress was applied.

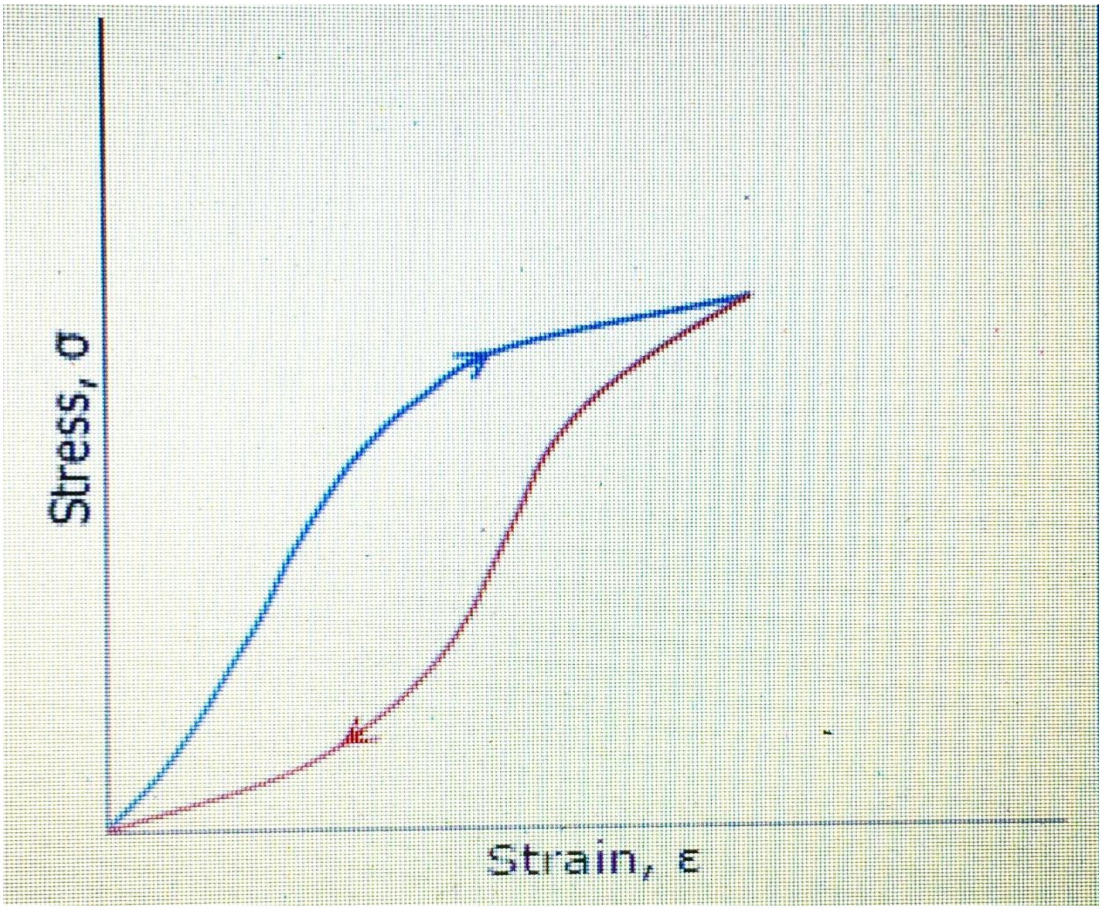

Fig. 3.3.2 Stress – Strain loop of Rubber

The area under stress-strain curves will be given by:

$$\int_0^{\varepsilon} \sigma d\varepsilon = \int \frac{F}{A}\frac{dl}{l} = \frac{1}{V}\int F dl \qquad (3.3.1)$$

where F is the force applied per area A of the material and dl is the amount of deformation in the material with respect to the original size. The area under the curve is equal to the amount of work done per unit volume of the material. In the hysteresis loop, the amount of energy that is required to deform the material is more than the energy that is released when the material reforms. This difference in the energy is being dissipated as heat and energy is lost as a tyre rolls over a rough surface when the pavement surface causes a deformation. Since reformation is slower than deformation, the motion of the rolling tyre causes an asymmetrical draping of rubber over the pavement surface

3.4 PAVEMENT SURFACE UNDER WET CONDITIONS

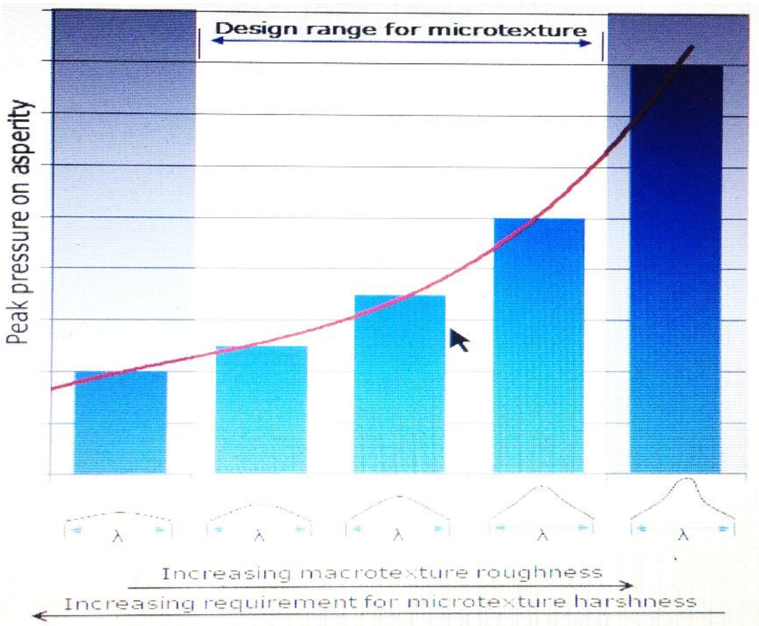

Fig. 3.4.1 Texture Depth vs Pressure

Analysis from the experiments done by Moore gave the conclusion that the surface macrotexture is necessary in wet conditions so that the bulk of water that is present on the pavement can be drained away and also sufficient tyre friction is achieved through tyre deformation. If the pavement is provided with relatively smoother macrotexture then the surface will have insufficient drainage and there will be minimal chance of contact with the tyre regardless of the amount of microtexture present. It is seen that the macrotexture is enough to provide the necessary friction and break through any water present with non-presence of microtexture.

In another test conducted by Sabey it is concluded that the coefficient of friction under wet conditions is related to the pressure over the contact area between the rubber and the pavement. It was also concluded that the pavement surface should be such that the average pressure of approximately 6.9 MPa.

3.5 TEXTURE DEPTH MEASUREMENT

There are many methods for the measurement of the surface texture but the most commonly used method in India is “Sand Patch method”. This test method is basically used to evaluate the surface texture depth (the average depth of voids below the high points of the surface) of the pavement surface be it bituminous or a concrete pavement. In previous years there was a provision of using either graded sands or the glass beads which is used in line marking but in coming years it has been revised that only glass beads will be used.

Basic apparatus includes:

a) A brass cylinder of known volume, either being 28.7 ml or 50 ml ± 0.25 ml.
b) A standard ‘Drop on’ type B glass beads which will be used for line marking.
c) An airtight container of suitable capacity for the storage of these glass beads.
d) Brush and “Sand” spreader for spreading beads.
e) Steel ruler of atleast 300 mm readable to 1 mm.

Selection of the test sites has its own effects on the test results. The site which has more or less the same visual appearance should be selected. Three test sites at the quarter points and mid point of the lot should be marked, in whichever the path of the wheel has the lowest surface texture.

3.5.1 PROCEDURE

a) Make sure that the test site is clean, dry and there should be no presence of grease or oil and all the dust and other loose particles should be sweeped off.
b) The brass cylinder should be filled with beads by dipping into the container.

c) Then tap the base of the cylinder on a hard surface so as to remove all the excess.

d) After this the contents of the cylinder should be poured onto the road surface in a small pile on the test site.

e) Then use the sand spreader to work down the beads into the surface voids. Continue this spreading motion until the diameter of the circle stabilises and till the beads are completely filled in the voids.

f) Then calculate the diameter of the formed circle to the nearest 5 mm and record the above recorded values. Average of the 4 readings will give the average diameter of the circle.

After following the above steps of the test, the texture depth of each site(T mm) will be calculated from the following equation:

$$T=\left(\frac{4000}{\pi} x \frac{V}{D^2}\right) = \frac{1273\,V}{D^2}$$

where:

V= volume of the glass beads in mm

D= average diameter of the sand patch in mm

Mean texture depth of the lot can be calculated as:

$$T = \frac{\sum T}{n}$$

3.6 SPECIFICATIONS OF THE TYRE

In the above figure the sidewall of the tyre contains few coding type words and numbers but they have a definite meaning and tell us about the tyre's construction, size and type.

i. <u>Cross Section width</u>- The first three numbers in the tyre basically refers to the section width of the tyre in millimetres i.e. from the tyre's inner sidewall to its outer sidewall.

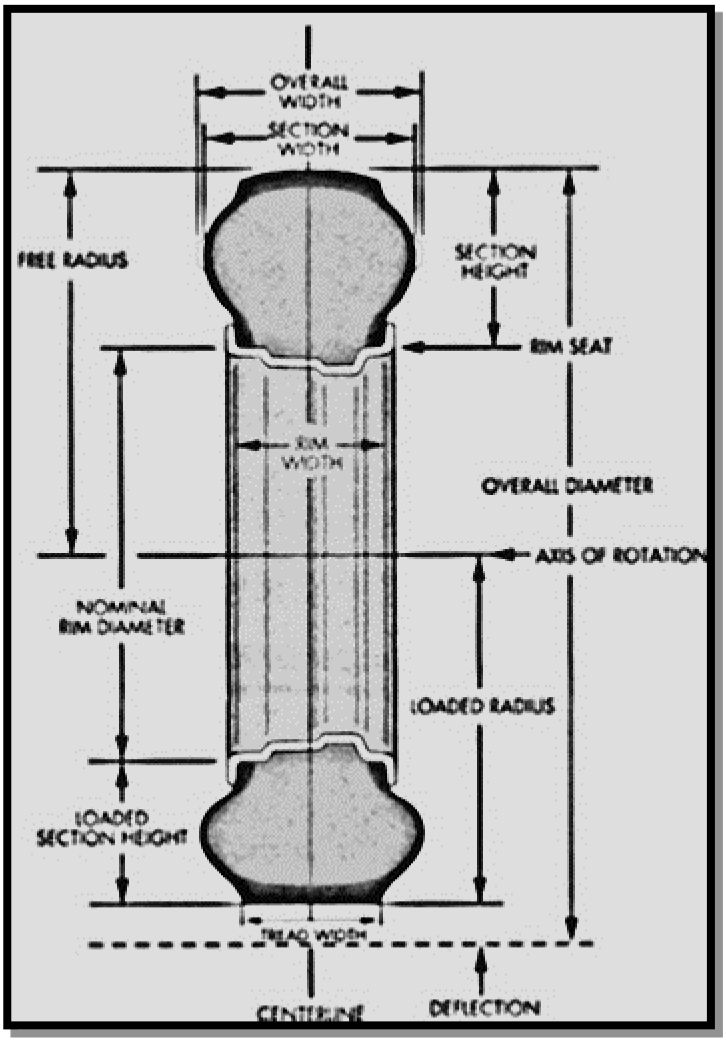

Fig. 3.6.1 Cross-section of a wheel tire

ii. Aspect Ratio- This aspect ratio basically refers to the height of the sidewall as % of the section width. Higher the aspect ratio, bigger the sidewall will be.

iii. Construction type- The letter R written here means that the tyre has a radial construction and almost all new car tyres are radials.

iv. Rim- The number that is written to the right of the construction type is the rim diameter in inches.

v. Load Index- And the final number is called the load index i.e. the maximum load in kg that the tyre can carry. Below is the chart for the relation:

Load Index	Load in kg	Load Index	Load in kg	Load Index	Load in kg
62	265	79	437	96	710
63	272	80	450	97	730
64	280	81	462	98	750
65	290	82	475	99	775
66	300	83	487	100	800
67	307	84	500	101	825
68	315	85	515	102	850
69	325	86	530	103	875
70	335	87	545	104	900

Table 3.6.1 Speed – Load Index Rating

CHAPTER 4

DATA COLLECTION

Since the approach to this research is more or less based on the theoretical approach but still some efforts has been made to give the practical relation in the research work and for this purpose the first thing that is being calculated is the inflation pressure inside the tyre and using certain formulas and certain theoretical relations related to the energy, conclusion is being made about the work done but with lots left for the coming research which is to be done in this respect.

Inflation pressure of the tyre is one of basic aspect that can be calculated with utmost surity and with less error. The selection of site is also done on the requirement basis and since total rigid pavement expressway is needed and for this Yamuna Expressway connection Greater Noida with Agra was found suitable.

4.1 YAMUNA EXPRESSWAY

Yamuna expressway also known as Taj Expressway is basically a 6 lane, extendable to 8 lanes, 165 km long access controlled expressway which connects Greater Noida with Agra in the territory of Uttar Pradesh. It is one of the India’s longest six lane expressway. This expressway starts from Pari chowk in Greater Noida and ends at Kuberpur in Agra. It is monitored and maintained by a body called Yamuna Expressway Industrial Development Authority (YEIDA).

Fig.4.1.1 View of Yamuna Expressway

With due permission from the concerned authority some basic technical features of the expressway were obtained. Below is the table of features of the Expressway:

S.NO.	**DESCRIPTION**	
1.	Total number of lanes	6 : 3.5 m width each
2.	Permissible speed	100 kmph for LMV 60 kmph for HMV
3.	Maximum Allowable speed	120 kmph
4.	Total length	165.5 km
5.	Right of Way	100 m wide
6.	Pavement Width	15.70 m
7.	Maximum axle load design	20 tonnes
8.	Shoulder Width	5.10 m
9.	Thickness of PQC	320 mm (main carriageway)
10.	Thickness of DLC	150 mm
11.	Top Width of Embankment	47.60 m (including 6.0 m wide Median)
12.	Vehicle underpass	70
13.	Minor bridges	41
14.	Interchanges	6
15.	Box Culverts	182
16.	Main Toll Plaza	3 (26 lanes at each location)
17.	Concrete	33.2 lakh cum
18.	Cement	12.0 lakh tonnes
19.	Steel	1.30 lakh tonnes
20.	Stone Aggregate	130 lakh tonnes
21.	Bitumen	7500 tonnes
22.	Admixtures	12500 tonnes

Table 4.1.1 Design aspects of Yamuna Expressway

4.2 TIRE PRESSURE GAUGE

A tire pressure gauge is a pressure gauge devise that is used to determine the pressure of tires on a vehicle. As the tires are designed for specific loads at specific pressure, it becomes very important to keep the pressure of the tire at the proper level as prescribed in the manuals. Every pressure measuring device has different precision and the precision for a typical mechanical gauge is ±3 psi (21 kPa). There are certain high precision devices of upto ±1 psi (6.9 kPa).

Fig. 4.2.1 Pressure Gauge instrument

4.3 ACCIDENT DATA

The accident data of the Yamuna Expressway, of the past three years, was made available to us. There was not much classification of the accidents by which cause they have occurred but tyre bursting was one of the many causes due to which those accidents have occurred. The number of road accidents have been on the decrement side but the number of fatal casualties increased.

JAYPEE GROUP

JAYPEE INFRATECH

COMPARATIVE STATEMENT OF ROAD ACCIDENTS

(Last three years)

S. No.	Month	Road Accidents				Number of Fatal Casualties				Number of Injuries			
		2016	2017	2018	2019	2016	2017	2018	2019	2016	2017	2018	2019
1	Jan	77	82	37	39	11	11	4	16	162	132	74	72
2	Feb	75	72	32	40	6	10	4	22	64	94	87	76
3	Mar	91	90	39	56	12	11	11	16	112	143	97	132
4	Apr	129	68	54	44	3	19	11	8	151	150	132	142
5	May	102	60	94	57	10	16	7	10	161	111	140	146
6	Jun	108	60	85	64	16	11	10	33	126	120	202	120
7	Jul	131	53	62	57	10	13	19	40	156	95	136	134
8	Aug	110	54	44	25	17	5	7	13	116	111	99	60
9	Sep	84	40	49	42	8	11	5	10	102	74	97	100
10	Oct	118	64	59	50	12	13	7	10	105	132	138	106
11	Nov	98	59	61	42	9	11	11	5	141	152	114	114
12	Dec	96	61	43		19	15	15		129	112	72	
	Total	1219	763	659	516	133	146	111	183	1525	1426	1388	1202

2

Table 4.3.1 Accident data of Yamuna Expressway

4.4 EXPERIMENTAL RESULTS

The process of data collection began in the month of March when certain high temperature was being recorded in the environment since the work required high temperature for better analysis of the data; though the temperature recorded in the test is less than the average temperature that this particular area experiences during hot summer. The concerned authority of the Yamuna Expressway Industry Development Authority (YEIDA) was being contacted for taking certain data related to the construction of the Yamuna Expressway. The authority was cooperative with me in giving the data and some desired data were made available to me and permission for running of the vehicles as a part of experimental test on the expressway was also granted .

In March, the first trial of the experiment was conducted from the region Etmadpur to Gautam Budhh nagar by taking two vehicles of the same class; one in the morning and the other in the afternoon. There were no stops made in between the journey and constant average speed of about 90 kmph was made. It was ensured that the tires used in this test are new and not worn out from before. Of the concerned moving vehicles the initial pressure readings of both the front and rear side (right and left both) tires were recorded with utmost accuracy that could be made on the road. The picture of the existing texture on the pavement was clicked and is shown below. In both the vehicles it was ensured that the pressure in the tires is maintained at the level as prescribed in the manual. The recorded values at the test site is noted in proper sheet and is shown below.

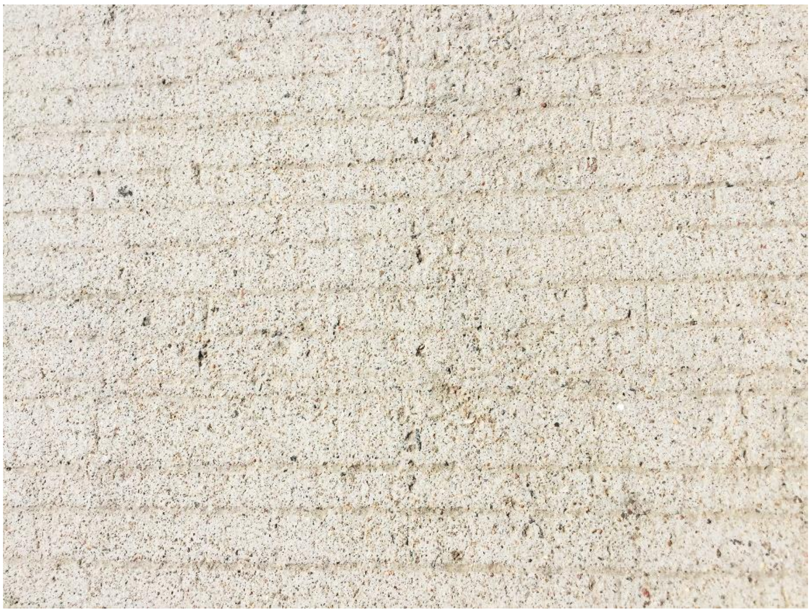

Fig. 4.4.1 Textures on the pavement

On completing the total length of the expressway then again the pressure of the tires is being recorded with all the precision and is noted in the sheet shown above. After analysing the sheet we could observe an increase in the pressure reading by about 2 psi in all the four tires of both the vehicles when the vehicle is loaded with the load of two persons of around 75 kg.

SHEET NO.-1

FROM- ETMADPUR TO GAUTAMBUDHH NAGAR

DATE- MARCH 2020

DAY TEMPERATURE- 24^0C

AVERAGE SPEED – 90 KMPH

TYRE COMPANY	TYRE MODEL	JOURNEY START TIME	JOURNEY END TIME	INITIAL TYRE PRESSURE				FINAL TYRE PRESSURE				NUMBER OF STOPS
				FRONT		REAR		FRONT		REAR		
				RIGHT	LEFT	RIGHT	LEFT	RIGHT	LEFT	RIGHT	LEFT	
MRF	FRONT- ZLX REAR- ZVTS	9:00 AM	11:00 AM	28 psi	28 psi	28 psi	28 psi	30 psi	30 psi	30 psi	30 psi	0
				34 psi	34 psi	32 psi	32 psi	36 psi	36 psi	36 psi	34 psi	0
				28 psi	28 psi	28 psi	28 psi	30 psi	30 psi	30 psi	30 psi	0
				27 psi	28 psi	28 psi	26 psi	28 psi	30 psi	29 psi	31 psi	0
				30 psi	30 psi	30 psi	32 psi	34 psi	34 psi	32 psi	36 psi	0

Table 4.4.1 Sheet 1: From Etmadpur to GautamBudhh Nagar

Another trial was made on the next day but this time peak temperature was chosen so as to have the effect of high temperature on the test results also. This time the journey was made from the Gautam Budhh Nagar area to Etmadpur region. The loading conditions was kept the same and again the travel speed was maintained at 90 kmph. The concerned initial pressure reading was again taken with utmost precision. There was no stop in between the journey and the journey was completed in about the same time that was taken in the first test trial.

SHEET NO.-2

FROM- GAUTAMBUDHH NAGAR TO ETMADPUR

DATE- MARCH 2020

DAY TEMPERATURE- 32^0C

AVERAGE SPEED – 90 KMPH

TYRE COMPANY	TYRE MODEL	JOURNEY START TIME	JOURNEY END TIME	INITIAL TYRE PRESSURE				FINAL TYRE PRESSURE				NUMBER OF STOPS
				FRONT		REAR		FRONT		REAR		
				RIGHT	LEFT	RIGHT	LEFT	RIGHT	LEFT	RIGHT	LEFT	
MRF	FRONT- ZLX REAR- ZVTS	12:15 PM	3:00 PM	26 psi	26 psi	28 psi	26 psi	32 psi	30 psi	30 psi	30 psi	0
				32 psi	34 psi	32 psi	32 psi	34 psi	36 psi	36 psi	34 psi	0
				28 psi	28 psi	28 psi	28 psi	30 psi	30 psi	30 psi	30 psi	0
				28 psi	28 psi	28 psi	26 psi	32 psi	30 psi	29 psi	31 psi	0
				30 psi	28 psi	30 psi	30 psi	34 psi	30 psi	32 psi	36 psi	0

Table 4.4.2 Sheet 2: From Gautambudhh Nagar to Etmadpur

From the above trial test we observed a significant increase in the pressure of the tires. The pressure in the front side tyres of the vehicle were kept 2 psi less than that of the prescribed value in the manual and those tires showed an increase of about 5-6 psi pressure value while the rear side tires which were filled with designated pressure value showed an increase of about 2-4 psi. This made us to think that there was an effect of texture and friction in the increment of the pressure but as soon as the air temperature increases there is an abrupt increase in the pressure value of the tires since frictional force and texture on the pavement is accompanied by the temperature even when the tires in all the vehicles used were new and have not been used and wear.

4.5 TEST ON FLEXIBLE PAVEMENT

In order to have some co relationship between the performance of flexible pavement and the rigid pavement in the respect of friction provided and the changes in the inflation pressure of the rolling tire, a test was conducted in the month of May during the scorching summer heat from Lucknow to Gonda with a span of 110 km. Same steps were followed as adopted in the test conducted on the rigid pavement and the average speed was about 75-80 kmph. It was observed there was an increase of about 1-2 psi in the reading of the final pressure. Below is the sheet of the data:

SHEET NO.-3

FROM- LUCKNOW TO GONDA

DATE- 20 MAY 2020

DAY- WEDNESDAY

DAY TEMPERATURE- 40^0 C

AVERAGE SPEED – 75 KMPH

TYRE COMPANY	TYRE MODEL	JOURNEY START TIME	JOURNEY END TIME	INITIAL TYRE PRESSURE				FINAL TYRE PRESSURE				NUMBER OF STOPS
				FRONT		REAR		FRONT		REAR		
				RIGHT	LEFT	RIGHT	LEFT	RIGHT	LEFT	RIGHT	LEFT	
MRF	FRONT- ZLX REAR- ZVTS	11:00 am	1:15 pm	28 psi	28 psi	28 psi	28 psi	30 psi	30 psi	29 psi	28 psi	0

Table 4.5.1 Sheet 3: From Lucknow to Gonda

Above test was conducted to show the comparison between the rigid pavement and flexible pavement.

Fig. 4.4.2 Rigid Pavement: Yamuna Expressway

Fig. 4.4.3 Toll Plaza

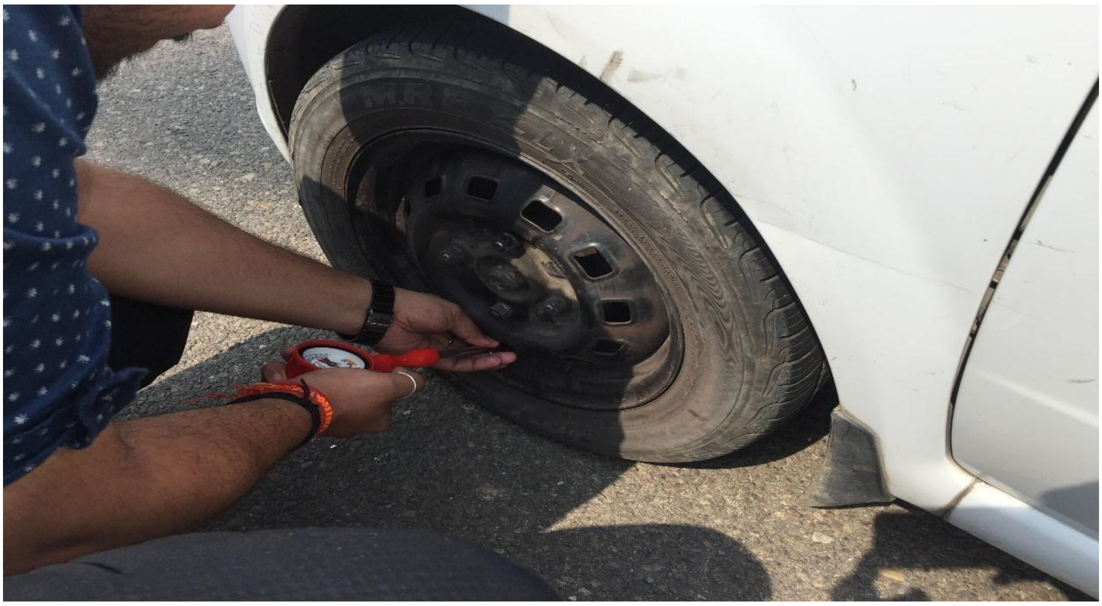

Fig.4.4.4 Collection of Data

CHAPTER 5

DATA ANALYSIS

After the collection of data the analysis portion involved many concepts of science and engineering taking into consideration assumptions as and when required. The calculation of the energy and other various aspects were calculated based from the perspective of the gas filled inside the tire and not from the perspective of the tire road contact since it required high and advanced technology for the calculation. Assumptions have been taken of the various laws and concept that are used for the calculation purpose. The one major assumption that has been taken is that the gas filled inside the tire is behaving as an ideal gas and undergoes perfectly elastic collision.

5.1 GAY-LUSSAC'S LAW

The first major concept used in our analysis is Gay-lussac's law which relates the pressure with the absolute temperature of a given mass of gas. When there is a rigid container filled with a gas and its temperature is increased then the pressure of the gas increases and this results in increase in the kinetic energy ass the molecules of the gas starts striking the wall of the container with a greater force. Therefore Joseph Gay-Lussac proposed a law named Gay-Lussac's Law which states that the pressure of a given mass of gas varies directly with the absolute temperature of the gas when the volume is kept constant. This concept is valid for ideal gases. The mathematical expression for the law is as follows:

$$\frac{P_1}{T_1} = \frac{P_2}{T_2} \qquad \text{………………………………………….(i)}$$

Taking this law we decided to calculate the value of the temperature T_2 considering the value of initial temperature T_1 as 24^oC (normal average temperature).

1psi=0.068 atm

Considering first set value of data collected:

(1) P_1= 28psi = 28*0.068=1.904 atm

T_1= 24+273.15 K=297.15 K

P_2= 30psi=30*0.068=2.04 atm

Using the relation of Gay Lussac's law:

$$\frac{P_1}{T_1} = \frac{P_2}{T_2}$$

$$\frac{1.904}{297.15} = \frac{2.04}{T_2}$$

T_2=318.375 K

T_2=45.225^{o}C

(2) for the second set of data collected:

P_1=26psi=26*0.068=1.768 atm

T_1=297.15 K

P_2=32psi=32*0.068=2.176 atm

Using the relation of Gay Lussac's law:

$$\frac{P_1}{T_1} = \frac{P_2}{T_2}$$

$$\frac{1.768}{297.15} = \frac{2.176}{T_2}$$

T_2=365.72 K

T_2=92.5^{o}C

(3) for the third set of data collected:

P_1= 26psi=26*0.068=1.768 atm

T_1=297.15 K

P_2= 30psi=30*0.068=2.04 atm

Using the relation of Gay Lussac's law:

$$\frac{P_1}{T_1} = \frac{P_2}{T_2}$$

$$\frac{1.768}{297.15} = \frac{2.04}{T_2}$$

T_2= 342.86 K

T_2= 69.71^{o}C

All the three set of values, the final temperature T_2 is calculated and it is observed that the value with less inflation pressure has shown a tremendous increase in the temperature taking the assumptions. The above three values of final temperature is below the temperature that was obtained in the experiment conducted by researcher Basirat Tabirizi (2006) considering the critical condition of the tire because of the thermal stress.

5.2 KINETIC THEORY OF GASES

Since the analysis is involving the study of ideal gas therefore the kinetic theory of gases concept comes into the picture. Kinetic theory of gases is based on the molecular level of the matter. A gas is basically a collection of large number of molecules (in the order of Avogadro's number) that are in constant random motion in which at ordinary pressure and temperature the intermolecular distance between the molecules is in the factor of 10Å or more than the typical size of a molecule. Thus it is assumed that the molecules move freely in straight lines according to Newton's first Law but that's not the case. These molecules come close to each other and strike each other called as "collisions" and this collision changes their velocity.

In this theory it is considered that these collisions either with each other or with the walls are elastic meaning that the total kinetic energy and the total momentum is conserved and the velocity after the collision does not change.

If we consider a cube enclosed with gas and take side 1 and consider a molecule and its velocities in the three axes (v_x, v_y, v_z) which hits the plane parallel to yz plane of area A. Since there is an elastic collision hence the molecule rebounds with the same velocity in the y and z components axes but the velocity in the x axis reverses its sign therefore the velocity after the rebound will be ($-v_x$, v_y, v_z). Hence the change in momentum of the molecule will be $-mv_x-(mv_x) = -2mv_x$. According to the conservation of momentum, the momentum imparted to the wall in the collision will be $2mv_x$.

Therefore for the calculation of force, pressure and temperature it is important to calculate the momentum per unit time. For a small time interval Δt, the number of molecules with the velocity (v_x, v_y, v_z) will hit the wall will be $Av_x\Delta tn$ where n is the number of molecules per unit volume. The total momentum transferred to the wall by these molecules will be in time Δt will be:

$$Q = (2mv_x)\ (nAv_x\Delta t)$$

Therefore the force on the walls is the rate of change of momentum i.e. Q/Δt and pressure is force per unit area:

$$P = Q/\ (A\Delta t) = nmv_x^2$$

n is the number density of the group of molecules

And since all the molecules do not move with the same velocity there is a distribution in velocities and therefore the total pressure is calculated by summing over the contribution:

$$P = nm\sum v_x^2$$

And as the gas is isotropic; there is no preferred direction of velocity of the molecules, hence = $1/3[\sum v_x^2 + \sum v_y^2 + \sum v_z^2]$

Pressure exerted on the wall, $P = (1/3)nm\sum v^2$

5.3 KINETIC INTERPRETATION OF TEMPERATURE

We know that

$PV = (1/3)\ nVm\sum v^2$

$PV = (2/3)\ N\sum v^2$ where N is the number of molecules in the gas sample

This quantity is the average translational kinetic energy of the molecules in the gas and hence E = (1/3) nVm$\sum v^2$

Therefore the final equation of the interpretation of temperature is as:

$E = (3/2)\ k_b NT$ or $= (3/2)\ k_b\ T$

i.e. the average kinetic energy of a molecule is proportional to the absolute temperature of the gas and is independent of pressure, volume or the nature of gas. The two parameters are connected by the Boltzmann constant, k_b. With this relation the kinetic energy of an ideal gas is consistent with the ideal gas equation and other gas laws equation. For a mixture of non-reactive ideal gases the total pressure gets contribution from each of the gas involved and the equation becomes:

$$P = (1/3)[n_1 m_1 v_1^2 + n_2 m_2 v_2^2 + \ldots\ldots\ldots\ldots\ldots]$$

5.4 LAW OF EQUIPARTITION OF ENERGY

Every molecule is free to move in space and it needs three coordinates to specify its movement as we can say a molecule moving in a line has one degree of freedom or movement in a plane symbolises two degree of freedom and three for its movement in space and motion of a body as a whole from one point to another is called translation and each translational degree of freedom contributes square of some variable.

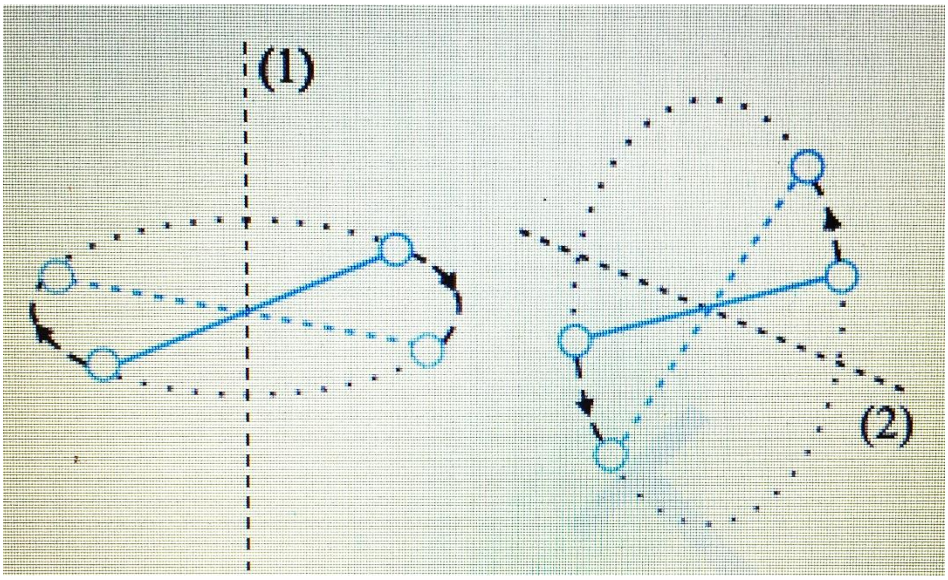

Fig. 5.4.1 axes of Rotation of Diatomic molecule

As here in our study, the work is going on for a diatomic gas like O_2, N_2 etc. hence the translational degree of freedom for the diatomic gas is three and it also spins about its centre of mass about two axes so therefore the total degree of freedom for a diatomic gas is five.

In thermal equilibrium at absolute temperature it is seen that each translational mode of motion has an energy equal to $(1/2)k_BT$. Hence the average kinetic energy for a monoatomic gas having three degree of freedom will be $(3/2)k_bT$ and similarly for a diatomic gas it will be $(5/2)k_bT$ since it has three translational motion and two rotational motion.

Considering the above concepts of ideal gas we can calculate the kinetic energy initially in the molecules of oxygen within the tire and the final increment in the total kinetic energy possessed by the molecules.

The tire used in the test is of the specification 155/70 R13 75T and using this information we can calculate the volume of the tire (approximate):

Diameter of the rim = 13 inches= 0.33 m

Hence radius of the rim = 0.165 m

Width of the tire = 155 mm

Height of the sidewall = 0.7*155 = 108.5 mm =0.1085 m

Therefore the radius of the outer surface of the tire = 0.165+0.1085=0.2735 m

Considering the spherical shape of the surfaces concerned we get

Volume of the area that fills with air = $(4/3)\pi\{(0.2735)^3 – (0.165)^3\}$

$= 0.06690\ m^3$ = 66.9 litre

The number of molecules in one mole of gas = $6.022 *10^{23}\ mole^{-1}$ which is called the Avogadro's number, therefore the mass of the air inside = density * volume

Taking density of air as $1.225\ kg/m^3$ we get the mass of air as = 1.225 * 0.0669 *1000

=81.95 gram

Now the molar mass of the oxygen molecule is 32 gram therefore the number of moles will be equal to mass of air / molar mass of oxygen which equals to 81.95/32 =2.56 moles.

And we know that kinetic energy of one molecule of a diatomic gas = $(5/2)\ k_bT$

For first value of temperature,

T_1 = 318.375 K

k_b = Boltzmann's constant = $1.38 * 10^{-23}\ J\ K^{-1}$

N_A = Avogadro's number = $6.022 * 10^{23}$

Kinetic energy per mole = $2.5 * 1.38 * 10^{-23} * 318.375$

$= 1098.39 * 10^{-23}\ J\ mol^{-1}$

Hence kinetic energy for 2.56 moles at temperature 318.375 K, $KE_1 = 1098.39 * 10^{-23} * 2.56 * 6.022 * 10^{23}$

KE_1 = 16.93 kJ…………………………………………………………………….. (1)

Similarly for the second value of temperature

T_2 = 365.72 K

Kinetic energy per mole = 2.5 * 1.38 * 10^{-23} * 365.72

= 1261.73 * 10^{-23} J mol^{-1}

Hence kinetic energy for 2.56 moles at temperature 365.72 K, KE_2 = 1261.73 * 10^{-23} * 2.56 * 6.022 * 10^{23}

KE_2 = 19.45 kJ…………………………………………………………………... (2)

Again for the third set of value of temperature,

T_3 = 342.86 K

Kinetic energy per mole = 2.5 * 1.38 * 10^{-23} * 342.86

= 1182.86 * 10^{-23} J mol^{-1}

Hence kinetic energy for 2.56 moles at temperature 342.86 K, KE_3 = 1182.86 * 10^{-23} * 2.56 * 6.022 * 10^{23}

KE_3 = 18.23 kJ…………………………………………………………………... (3)

And now for the standard temperature of T_{stan} = 297.15 K

Kinetic energy per mole = 2.5 * 1.38 * 10^{-23} * 297.15

= 1025.16 * 10^{-23} J mol^{-1}

Hence kinetic energy for 2.56 moles at temperature 297.15 K, KE_{stan} = 1025.16 * 10^{-23} * 2.56 * 6.022 * 10^{23}

KE_{stan} = 15.80 kJ……..………………………………………………………... (4)

In all the above calculations done it is seen that the kinetic energy increament is going in proportional to the increase in the pressure inside the tire. We have initially considered that the temperature at rest condition of the tire to be 24^{o}C or 297.15 K and to this corresponding temperature we get the kinetic energy to be 15.80 kJ. This is the total kinetic energy in the molecules in initial stage.

Standard temperature = 24^{o}C = 297.15 K

$K.E_{stan}$ = 15.80 kJ

S. NO.	INITIAL PRESSURE, P_1	FINAL PRESSURE, P_2	FINAL TEMPERATURE, T_2	FINAL KINETIC ENERGY, $K.E_{1,2,3}$	$\Delta K.E = K.E_{1,2,3} - K.E_{stan}$
1.	28 psi	30 psi	318.375 K	16.93 kJ	1.13 kJ
2.	26 psi	32 psi	365.72 K	19.45 kJ	3.65 kJ
3.	26 psi	30 psi	342.86 K	18.23 kJ	2.43 kJ

Table 5.4.1 Tabulation of the collected and calculated data

From the above calculations it is clear that the temperature of the enclosed gas molecules has increased and it has increased the pressure and molecules kinetic energy. Since the energy dissipation through rubber is a complicated process it becomes difficult to categorise parts of energy contributed by different mechanisms. The two major contribution is the friction and the texture of the pavement.

Every tire has its maximum pressure that it can withstand based on its manufacturing and constituent materials and it decreases with the years and the kms it rolls on the pavement surface. Hence it becomes a major part in the provision of design of the rigid pavement since friction remaining constant in every situation the bearing capacity of the rolling tires will reduced with increase in age and deterioration level and may prove fatal for the vehicle. Based on the data collected we can summarise the different situations of the tire at subsequent 1 year of interval and its decrease in the holding maximum pressure. Various other aspects which can be formulated has been discussed below.

Case I: when the maximum pressure = 50 psi = 3.4 atm and initial pressure = 28 psi =1.904 atm

For t = 0 it means that the tire is new and can sustain maximum 50 psi pressure; for this condition the kinetic energy of the gas is calculated and at 1 year interval for different pressure conditions kinetic energies are calculated.

Age of tire, t (in years)	P_1 (in atm)	T_1 (in K)	P_2 (in atm) (in psi)	T_2 (in K)	$K.E_1$ (in kJ)	$K.E_2$ (in kJ)	$\Delta K.E = K.E_2 - K.E_1$
0	1.904	297.15	3.40 (50)	530.625	15.80	28.22	12.42
1	1.904	297.15	3.264(48)	509.40	15.80	27.09	11.29
2	1.904	297.15	3.128(46)	488.175	15.80	25.96	10.16
3	1.904	297.15	2.992(44)	466.95	15.80	24.83	9.03
4	1.904	297.15	2.856(42)	445.725	15.80	23.70	7.90
5	1.904	297.15	2.72(40)	424.50	15.80	22.57	6.77

Table 5.4.2 Increase in kinetic energy at different age of tires (maximum pressure=50 psi)

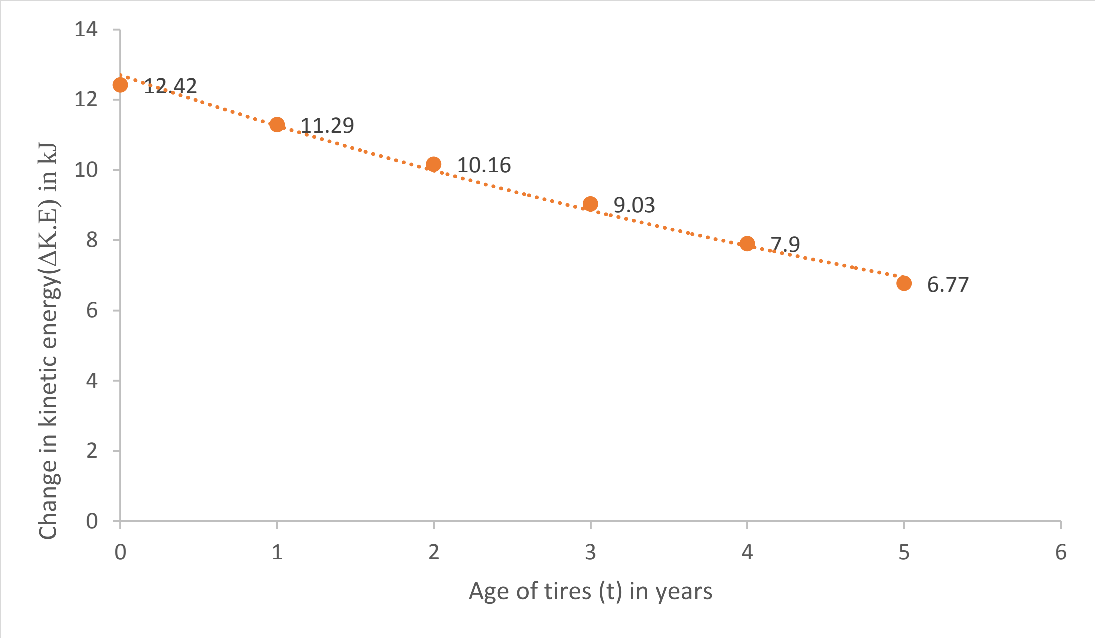

Fig. 5.4.2 Graph between age of tires and change in kinetic energy (maximum pressure =50 psi)

From the above graph it is estimated that with coming time the capacity of the tires to bear the kinetic energy decreases, not in a constant manner, and therefore if we limit the friction contribution in this energy we can come to the conclusion about the amount of texture that should be provided and of which particular depth.

Case II: when the initial pressure = 28 psi and the maximum pressure = 51 psi=3.468 atm

Age of tire, t (in years)	P_1 (in atm)	T_1 (in K)	P_2 (in atm) (in psi)	T_2 (in K)	$K.E_1$ (in kJ)	$K.E_2$ (in kJ)	$\Delta K.E = K.E_2 - K.E_1$
0	1.904	297.15	3.468(51)	541.23	15.80	28.78	12.98
1	1.904	297.15	3.332(49)	520.01	15.80	27.65	11.85
2	1.904	297.15	3.196(47)	498.78	15.80	26.52	10.72
3	1.904	297.15	3.06(45)	477.56	15.80	25.39	9.59
4	1.904	297.15	2.924(43)	456.33	15.80	24.27	8.47
5	1.904	297.15	2.788(41)	435.11	15.80	23.14	7.34

Table 5.4.3 Increase in kinetic energy at different age of tires (maximum pressure=51 psi)

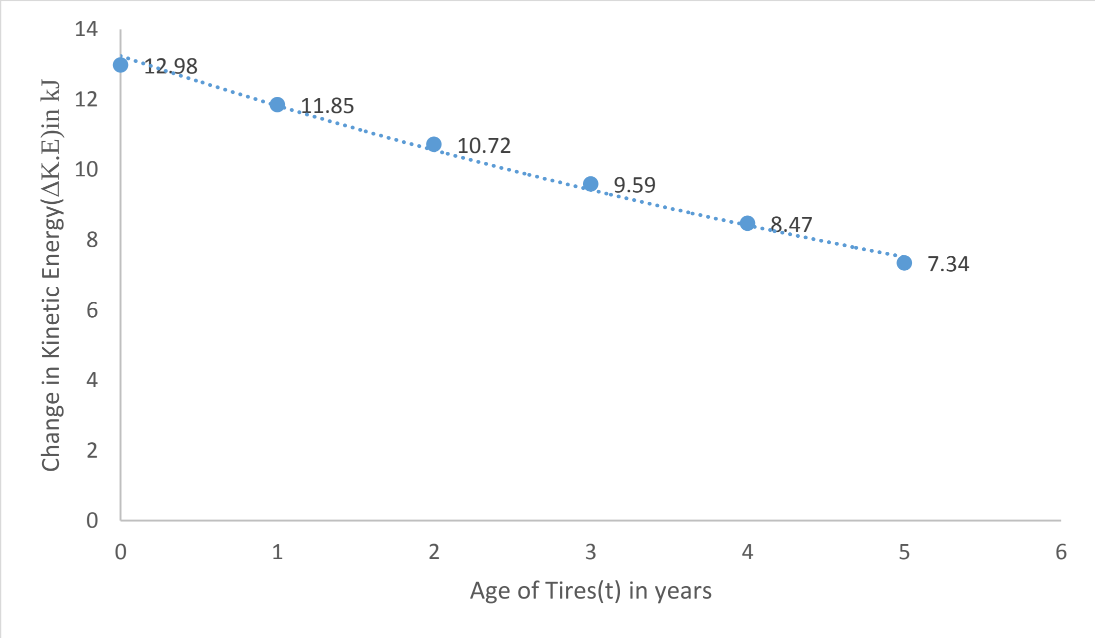

Fig. 5.4.3 Graph between age of tires and change in kinetic energy (maximum pressure= 51 psi)

<u>**Case III**</u>: when the maximum pressure = 51 psi and the initial pressure = 28 psi

In this case we assume that the reduction in the maximum pressure is not constant.

Age of tire, t (in years)	P_1 (in atm)	T_1 (in K)	P_2 (in atm) (in psi)	T_2 (in K)	$K.E_1$ (in kJ)	$K.E_2$ (in kJ)	$\Delta K.E = K.E_2 - K.E_1$
0	1.904	297.15	3.468(51)	541.23	15.80	28.78	12.98
1	1.904	297.15	3.40(50)	530.625	15.80	28.22	12.42
2	1.904	297.15	3.196(47)	498.78	15.80	26.52	10.72
3	1.904	297.15	2.856(42)	445.725	15.80	23.70	7.90
4	1.904	297.15	2.856(42)	445.725	15.80	23.70	7.90

Table 5.4.4 Increase in kinetic energy at different age of tires (maximum pressure=51 psi)

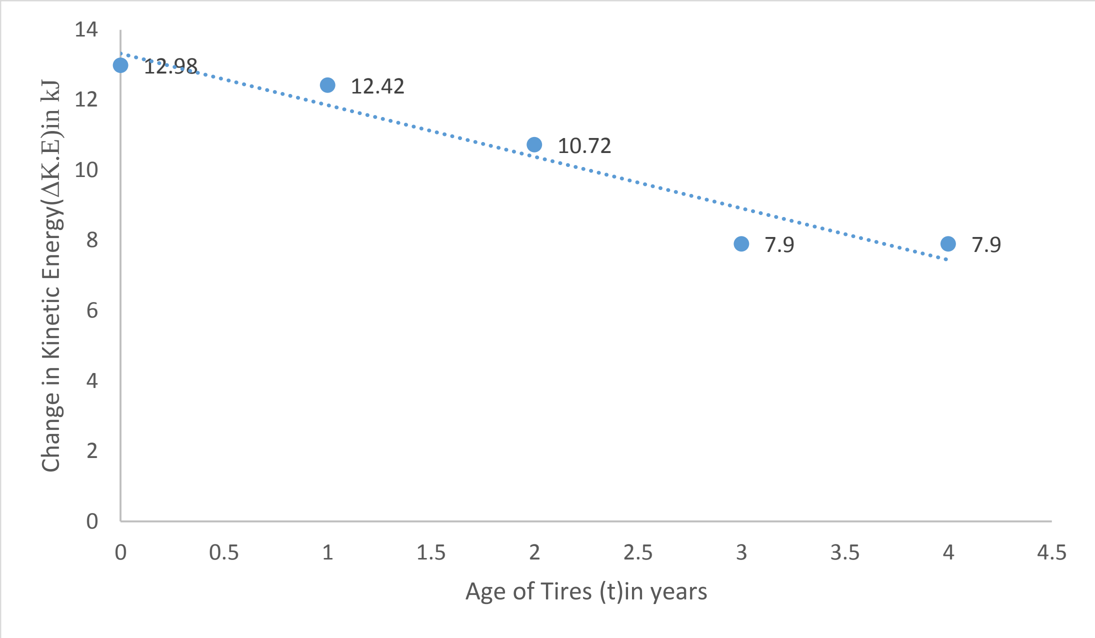

Fig. 5.4.4 Graph between age of tires and change in kinetic energy (maximum pressure= 51 psi)

<u>Case IV</u>: when the normal pressure = 30 psi and the maximum pressure of the tire= 44 psi =2.992 atm

Age of tire, t (in years)	P_1 (in atm)	T_1 (in K)	P_2 (in atm) (in psi)	T_2 (in K)	$K.E_1$ (in kJ)	$K.E_2$ (in kJ)	$\Delta K.E= K.E_2- K.E_1$
0	2.04(30)	297.15	2.992(44)	435.82	15.80	23.17	7.37
1	2.04	297.15	2.856(42)	416.01	15.80	22.12	6.32
2	2.04	297.15	2.720(40)	396.20	15.80	21.07	5.27
3	2.04	297.15	2.584(38)	376.39	15.80	20.01	4.21
4	2.04	297.15	2.448(36)	356.58	15.80	18.52	2.72

Table 5.4.5 Increase in kinetic energy at different age of tires (maximum pressure=44 psi)

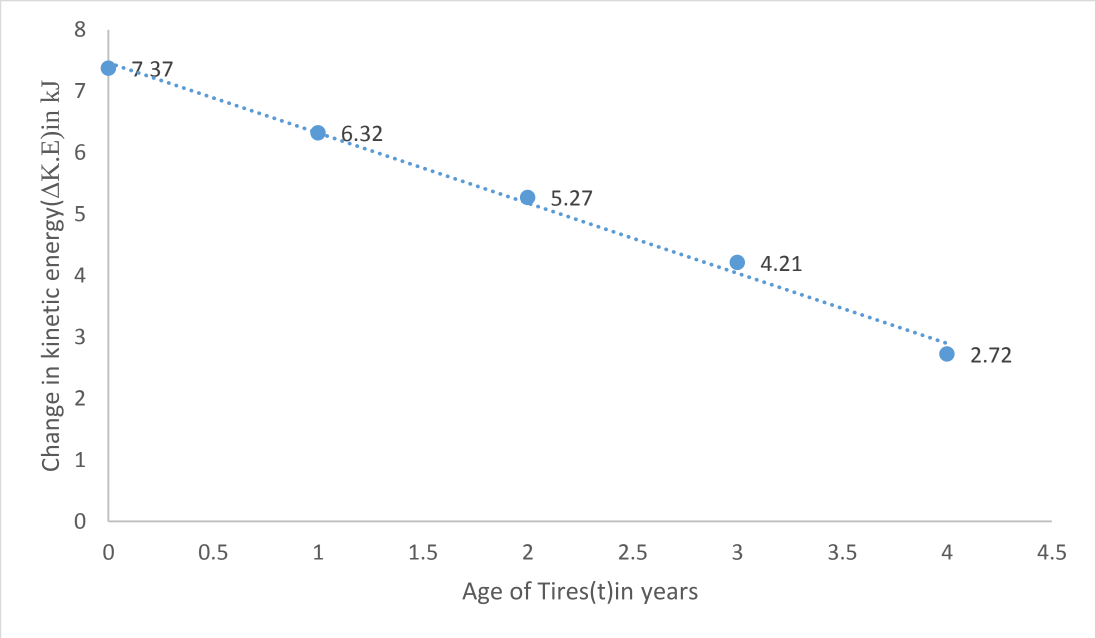

Fig. 5.4.5 Graph between age of tires and change in kinetic energy (maximum pressure =44 psi)

<u>Case V</u>: when the normal pressure = 30 psi and the maximum pressure of the tire= 44 psi =2.992 atm

Age of tire, t (in years)	P_1 (in atm)	T_1 (in K)	P_2 (in atm) (in psi)	T_2 (in K)	$K.E_1$ (in kJ)	$K.E_2$ (in kJ)	$\Delta K.E = K.E_2 - K.E_1$
0	2.04	297.15	2.992(44)	435.82	15.80	23.17	7.37
1	2.04	297.15	2.924(43)	425.91	15.80	22.65	6.85
2	2.04	297.15	2.788(41)	406.10	15.80	21.59	5.79
3	2.04	297.15	2.652(39)	386.29	15.80	20.54	4.74
4	2.04	297.15	2.516(37)	366.48	15.80	19.49	3.69

Table 5.4.6 Increase in kinetic energy at different age of tires (maximum pressure=44 psi)

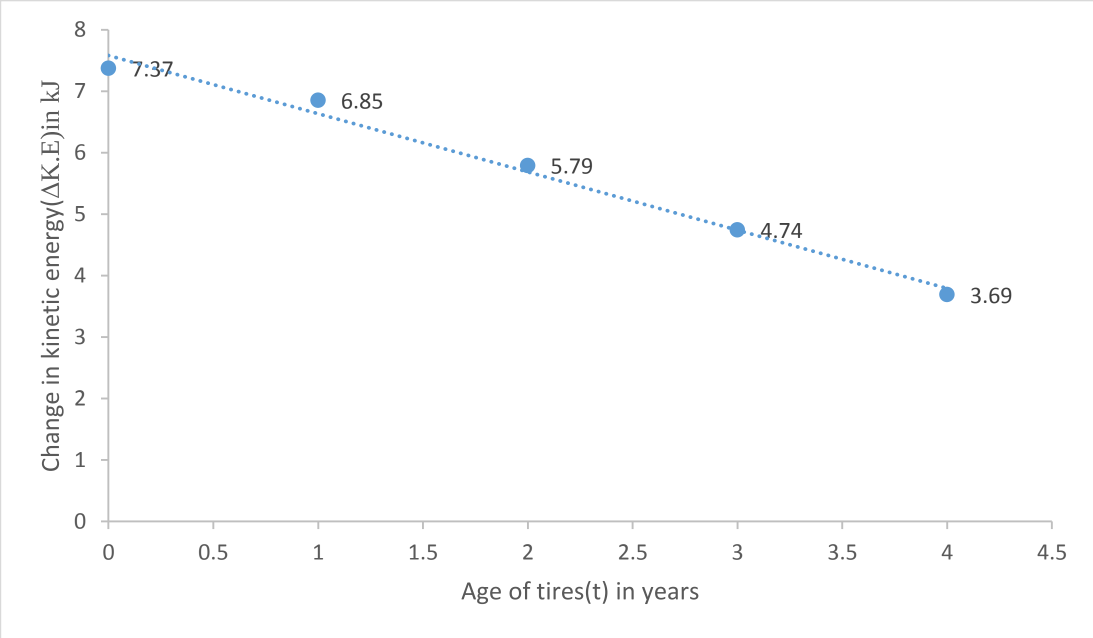

Fig. 5.4.6 Graph between age of tires and change in kinetic energy (maximum pressure =44 psi)

<u>Case VI</u>: when the normal pressure = 30 psi and the maximum pressure of the tire = 44 psi

In this case the deterioration is not taken as constant and accordingly graph is plotted.

Age of tire, t (in years)	P_1 (in atm)	T_1 (in K)	P_2 (in atm) (in psi)	T_2 (in K)	$K.E_1$ (in kJ)	$K.E_2$ (in kJ)	$\Delta K.E = K.E_2 - K.E_1$
0	2.04	297.15	2.992(44)	435.82	15.80	23.17	7.37
1	2.04	297.15	2.788(41)	406.10	15.80	21.59	5.79
2	2.04	297.15	2.788(41)	406.10	15.80	21.59	5.79
3	2.04	297.15	2.72(40)	396.20	15.80	21.07	5.27
4	2.04	297.15	2.516(37)	366.48	15.80	19.49	3.69

Table 5.4.7 Increase in kinetic energy at different age of tires (maximum pressure=44 psi)

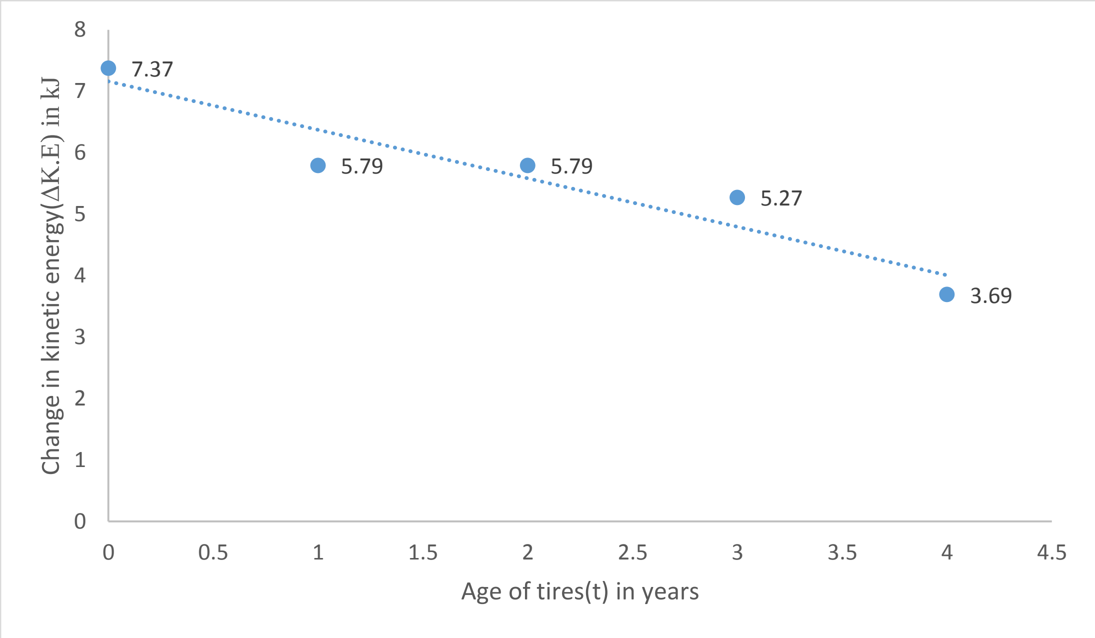

Fig. 5.4.7 Graph between age of tires and change in kinetic energy (maximum pressure =44 psi)

<u>Case VII</u>: when the normal pressure = 33 psi and the maximum pressure of the tires =61 psi

Age of tire, t (in years)	P_1 (in atm)	T_1 (in K)	P_2 (in atm) (in psi)	T_2 (in K)	$K.E_1$ (in kJ)	$K.E_2$ (in kJ)	$\Delta K.E = K.E_2 - K.E_1$
0	2.244(33)	297.15	4.148(61)	549.27	15.80	29.21	13.41
1	2.244	297.15	4.012(59)	531.26	15.80	28.25	12.45
2	2.244	297.15	3.876(57)	513.25	15.80	27.29	11.49
3	2.244	297.15	3.74(55)	495.25	15.80	26.34	10.54
4	2.244	297.15	3.604(53)	477.24	15.80	25.38	9.58

Table 5.4.8 Increase in kinetic energy at different age of tires (maximum pressure=61 psi)

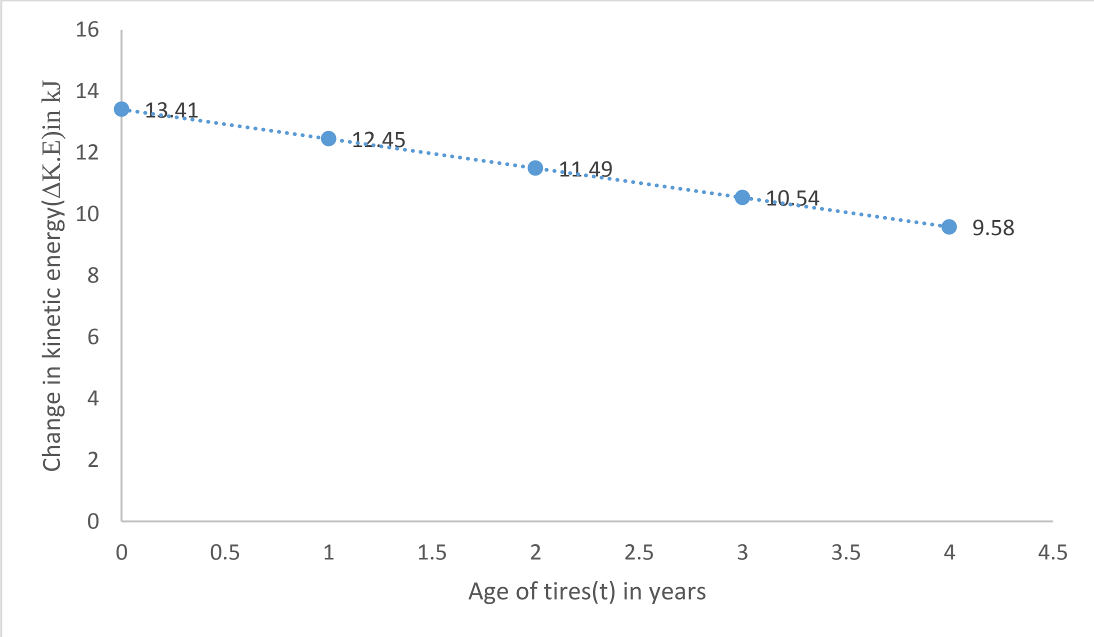

Fig. 5.4.8 Graph between age of tires and change in kinetic energy (maximum pressure =61 psi)

Case VIII: when the normal pressure = 33 psi and the maximum pressure of the tires= 60 psi

Age of tire, t (in years)	P_1 (in atm)	T_1 (in K)	P_2 (in atm) (in psi)	T_2 (in K)	$K.E_1$ (in kJ)	$K.E_2$ (in kJ)	$\Delta K.E = K.E_2 - K.E_1$
0	2.244	297.15	4.08(60)	540.27	15.80	28.73	12.93
1	2.244	297.15	3.944(58)	522.26	15.80	27.77	11.97
2	2.244	297.15	3.808(56)	504.25	15.80	26.81	11.01
3	2.244	297.15	3.672(54)	486.24	15.80	25.86	10.06
4	2.244	297.15	3.536(52)	468.23	15.80	24.90	9.10

Table 5.4.9 Increase in kinetic energy at different age of tires (maximum pressure=60 psi)

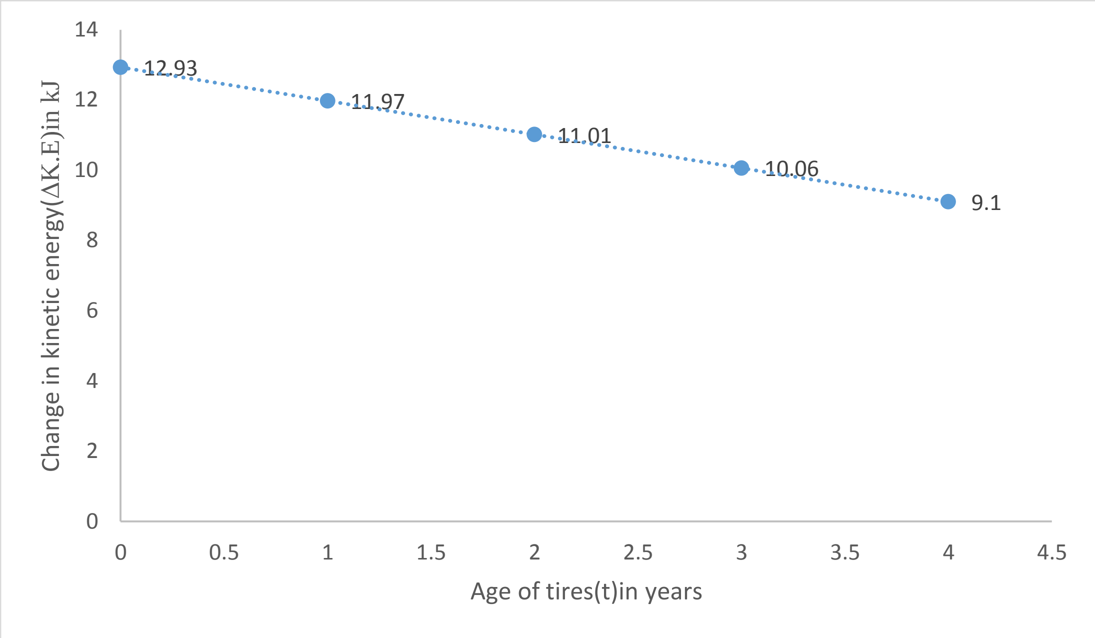

Fig. 5.4.9 Graph between age of tires and change in kinetic energy (maximum pressure =60 psi)

<u>Case IX</u>: when the normal pressure = 33 psi and the maximum pressure of the tires = 61 psi

And the rate of deterioration is not constant.

Age of tire, t (in years)	P_1 (in atm)	T_1 (in K)	P_2 (in atm) (in psi)	T_2 (in K)	$K.E_1$ (in kJ)	$K.E_2$ (in kJ)	$\Delta K.E= K.E_2-K.E_1$
0	2.244	297.15	4.148(61)	549.27	15.80	29.21	13.41
1	2.244	297.15	4.012(59)	531.26	15.80	28.25	12.45
2	2.244	297.15	3.74(55)	495.25	15.80	26.34	10.54
3	2.244	297.15	3.672(54)	486.24	15.80	25.86	10.06
4	2.244	297.15	3.468(51)	459.23	15.80	24.42	8.62

Table 5.4.10 Increase in kinetic energy at different age of tires (maximum pressure=61 psi)

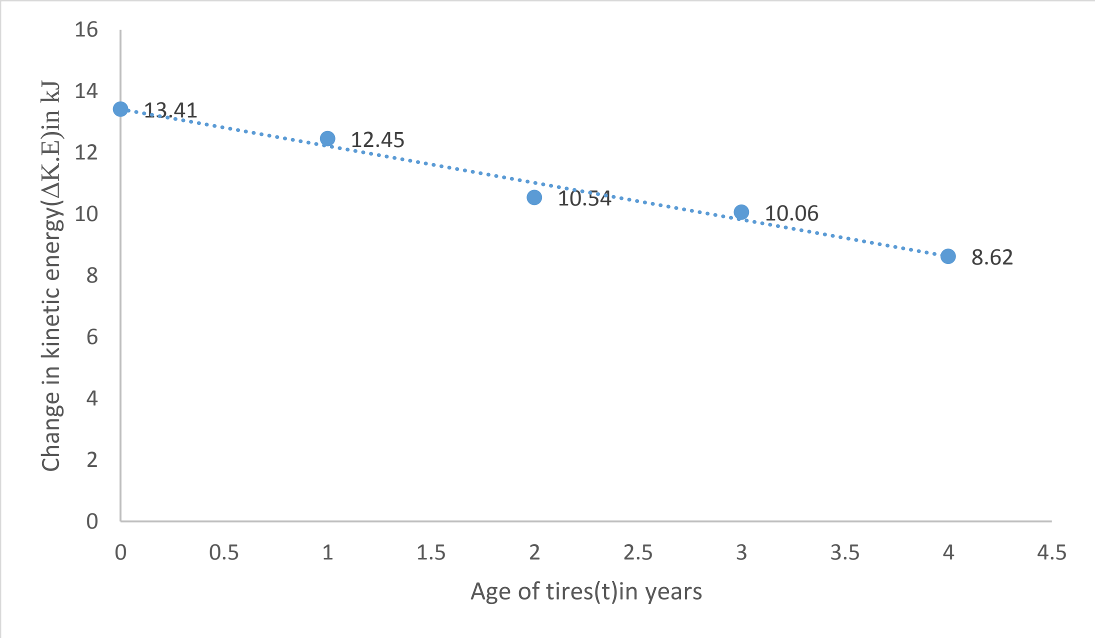

Fig. 5.4.10 Graph between age of tires and change in kinetic energy (maximum pressure =61 psi)

<u>Case X</u>: when the normal pressure = 40 psi and the maximum pressure of the tires = 65 psi

Age of tire, t (in years)	P_1 (in atm)	T_1 (in K)	P_2 (in atm) (in psi)	T_2 (in K)	$K.E_1$ (in kJ)	$K.E_2$ (in kJ)	$\Delta K.E = K.E_2 - K.E_1$
0	2.72	297.15	4.42(65)	482.86	15.80	25.68	9.88
1	2.72	297.15	4.284(63)	468.01	15.80	24.89	9.09
2	2.72	297.15	4.148(61)	453.15	15.80	24.10	8.30
3	2.72	297.15	4.012(59)	438.29	15.80	23.31	7.51
4	2.72	297.15	3.876(57)	423.43	15.80	22.52	6.72

Table 5.4.11 Increase in kinetic energy at different age of tires (maximum pressure=65 psi)

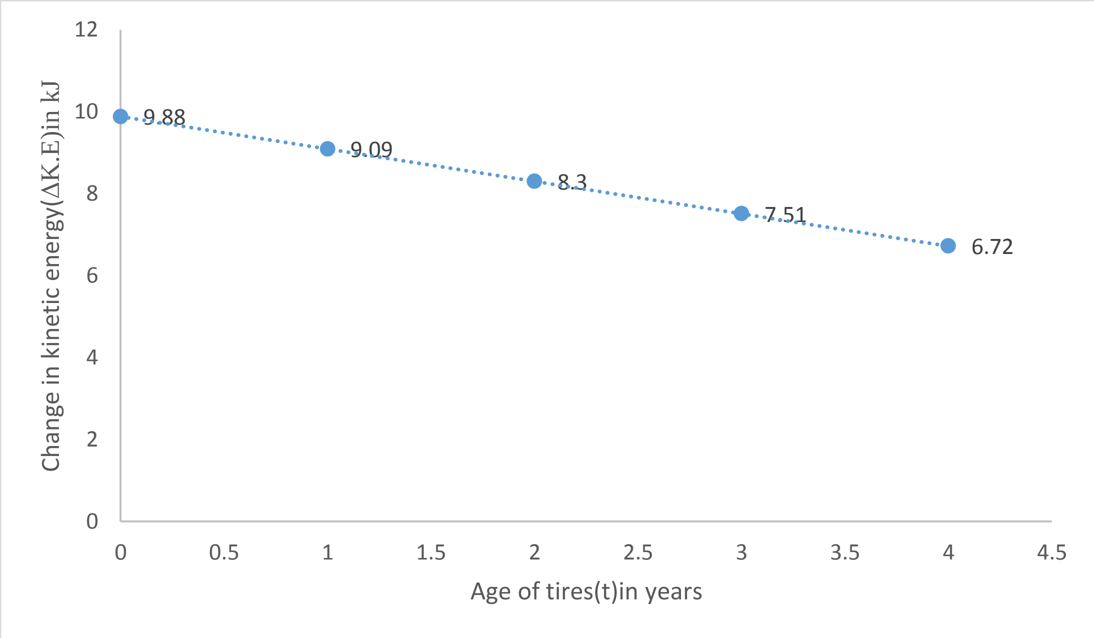

Fig. 5.4.11 Graph between age of tires and change in kinetic energy (maximum pressure =65 psi)

<u>Case XI</u>: when the normal pressure = 40 psi and the maximum pressure of the tires = 66 psi

Age of tire, t (in years)	P_1 (in atm)	T_1 (in K)	P_2 (in atm) (in psi)	T_2 (in K)	$K.E_1$ (in kJ)	$K.E_2$ (in kJ)	$\Delta K.E = K.E_2 - K.E_1$
0	2.72	297.15	4.488(66)	490.29	15.80	26.07	10.27
1	2.72	297.15	4.352(64)	475.44	15.80	25.28	9.48
2	2.72	297.15	4.216(62)	460.58	15.80	24.49	8.69
3	2.72	297.15	4.08(60)	445.72	15.80	23.70	7.90
4	2.72	297.15	3.944(58)	430.86	15.80	22.91	7.11

Table 5.4.12 Increase in kinetic energy at different age of tires (maximum pressure=66 psi)

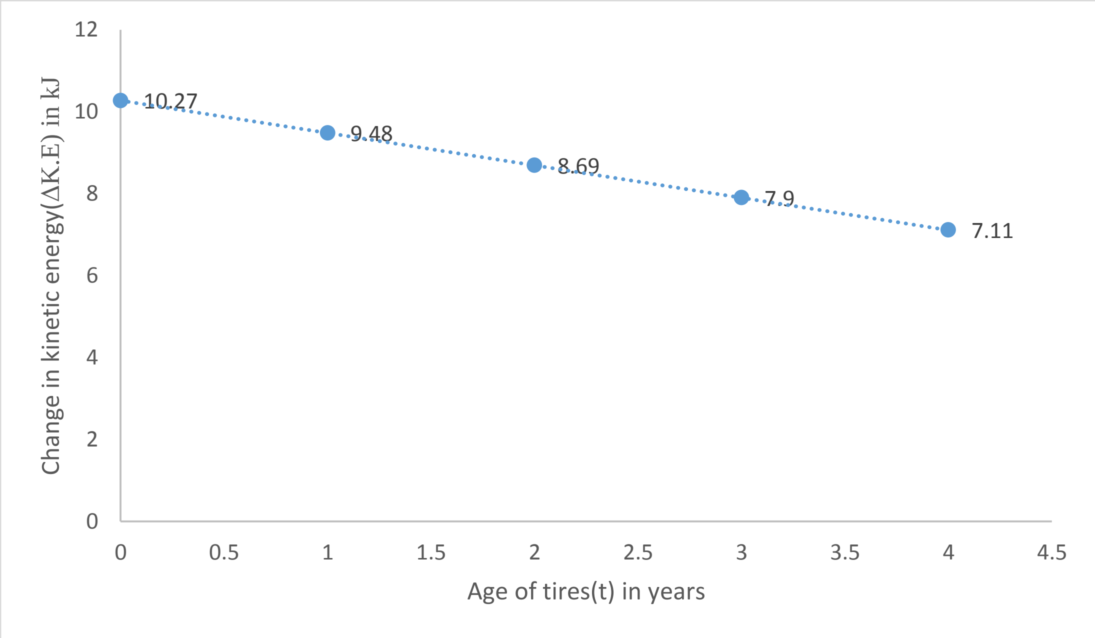

Fig. 5.4.12 Graph between age of tires and change in kinetic energy (maximum pressure =66 psi)

From the above analysis of different cases of nominal and maximum pressure of different tires we can obtain a range of texture depths that can be constructed on the pavement considering the worst case involved in the tires.

Hence we take the weight of the unladen vehicle= 870 kg

Weight on single wheel (considering equal distribution of weight on four wheels) = 870/4 = 217.5 kg

As we know that force * displacement = work done

The texture depths are considered as a vertical distance and as soon as the rubber tires rolls over it tends to deflect a small distance x, because of its weight so for different deflection different energies for different depth of deflection can be obtained and has been tabulated below.

Texture depth, in mm	2.0	2.2	2.5	2.75	2.8	3.0	3.5	3.75	4.0
Work done, in J	0.435	0.478	0.543	0.598	0.609	0.652	0.761	0.815	0.875

Table 5.4.13 Work done by single different texture depths

Taking average life of tires as 3 years and considering that the increase in kinetic energy is 1% because of friction and rest by the texture depth we get that for tire with 28 psi nominal pressure 10.16 kJ as minimum energy to reach to the case of maximum holding pressure, for 30 psi 5.27 kJ, for 33 psi 11.01 kJ and for 40 psi 8.30 kJ. But since all these calculations are the cases involving the optimum conditions which is not the case in the present situation. The texture depth of about <1.8 mm is optimum for every situation but the test site involved had more depth so considering the basic number of texture depth as 150 we can give the conclusion of having optimum texture depth that is required for this pavement.

Going by the same methods of analysis for different texture depths starting from 4.0 mm we get the following calculations for different depths:

For 4.0 mm depth: taking number of texture depths as 150 per km of the pavement, we get the energy contributed by all texture depth for 1 km as =150*0.87 J

Similarly for 150 km length = 150*150*087 =19.575 kJ

Since the tire had initial energy = 15.80 kJ for 24^{o}C

Therefore the total energy attributed by texture will be 15.80 + 19.575 = 35.37 kJ

35.37*1000=20.5*1.38*2.56*6.022*T

T=665.02 K

From Gay –Lussac’s law,

$$\frac{P_1}{T_1} = \frac{P_2}{T_2}$$

For P_1= 30 psi T_1=297.15 K, T_2=665.02 K

We get P_2 =67 psi

Similarly for other depths 3.75 mm, 3.5 mm, 3.0 mm, 2.8 mm, 2.75 mm, 2.5 mm, 2.2 mm different values of final pressure has been calculated and tabulated below:

Texture Depth (in mm)	Final pressure P_2 (in psi)
4.0	67
3.75	65
3.5	62
3.0	58
2.8	56
2.75	54
2.5	53
2.2	50

Table 5.4.14 Maximum pressure build up for different texture depths

Therefore we can make a conclusion about the pavement that considering the final age of the tires to be 3 years, in this pavement texture depth > 3.5 mm will lead to the bursting of the tires if it satisfies every condition of it so for safety of most vehicle tires depth < 2.5-2.8 mm can be considered the ideal texture depth. More than this can lead to the frequent degradation of the newer tires and bursting of the old tires if not properly handled leading to major accidents.

5.5 FRICTIONAL ANALYSIS

A very important aspect in the motion of the vehicle on the pavement surface is the friction which is positive in some cases and negative in some. Going by its definition friction is basically the force that resists the relative motion of any solid surfaces, or the liquid surfaces or any materials sliding against each other. There are many types of friction like:

- DRY FRICTION – it comes into the picture when two solid surfaces comes in contact with each other and it is also categorised in two ways one is the "static friction" and the other one is "kinetic friction".
- FLUID FRICTION – it tells us about the friction that acts in between layers of the viscous fluid or between two viscous fluids.
- SKIN FRICTION – it is basically a component of the drag force which resists the motion of any fluid on the surface of the body.
- INTERNAL FRICTION – when undergoing deformation the force resisted between the elements that constitutes the solid body.

The three basic laws of friction are as follows:

- Amonton's First Law: which says that the force of friction is directly proportional to the load applied.
- Amonton's Second Law: which says that the force of friction is not dependent on the area of contact.
- Coulomb's Law of Friction: which states that the kinetic friction is independent of the sliding velocity.

The coefficient of friction often expressed as μ is a dimensionless value which is equal to the ratio of the force of friction between two bodies and the normal force acting downwards. For surfaces at rest it is called as the coefficient of static friction, expressed as μ_s and for surfaces in relative motion, it is called coefficient of kinetic friction expressed as μ_k. Below is the table for various values of μ for different surfaces:

Materials		Static Friction, μ_s		Kinetic/Sliding Friction, μ_k	
		Dry and clean	Lubricated	Dry and clean	Lubricated
Aluminium	Steel	0.61[25]		0.47[25]	
Aluminum	Aluminum	1.05-1.35[25]	0.3[25]	1.4[25]-1.5[26]	
Gold	Gold			2.5[26]	
Platinum	Platinum	1.2[25]	0.25[25]	3.0[26]	
Silver	Silver	1.4[25]	0.55[25]	1.5[26]	
Alumina ceramic	Silicon Nitride ceramic				0.004 (wet)[27]
BAM (Ceramic alloy $AlMgB_{14}$)	Titanium boride (TiB_2)	0.04–0.05[28]	0.02[29][30]		
Brass	Steel	0.35-0.51[25]	0.19[25]	0.44[25]	
Cast iron	Copper	1.05[25]		0.29[25]	
Cast iron	Zinc	0.85[25]		0.21[25]	
Concrete	Rubber	1.0	0.30 (wet)	0.6-0.85[25]	0.45-0.75 (wet)[25]
Concrete	Wood	0.62[25][31]			
Copper	Glass	0.68			
Copper	Steel	0.53		0.36[25]	
Glass	Glass	0.9-1.0[25]		0.4[25]	
Human synovial fluid	Cartilage		0.01[32]		0.003[32]
Ice	Ice	0.02-0.09[33]			
Polyethene	Steel	0.2[25][33]	0.2[25][33]		
PTFE (Teflon)	PTFE (Teflon)	0.04[25][33]	0.04[25][33]		0.04[25]
Steel	Ice	0.03[33]			
Steel	PTFE (Teflon)	0.04[25]-0.2[33]	0.04[25]		0.04[25]
Steel	Steel	0.74[25]-0.80[33]	0.16[33]	0.42-0.62[25]	
Wood	Metal	0.2–0.6[25][31]	0.2 (wet)[25][31]		
Wood	Wood	0.25–0.5[25][31]	0.2 (wet)[25][31]		

Table 5.5.1 Table containing values of coefficient of friction between different materials

5.5.1 ROLLING MOTION ANALYSIS OF TIRES

We know that the two forms of motion i.e. translational and rotational motion occurs simultaneously in rolling motion and there are two basic aspects in rolling motion (a) Uniform rolling (b) Accelerated rolling . Since uniform rolling in this real world is of less probability and in our study has no connection therefore we shall not be discussing about it. In our study when the tire rolls over the surface or the pavement there was accelerated rolling of the tire without sliding.

- To calculate the portion of energy that is attributed by the interaction of the rubber with the pavement surface this accelerated rolling concept has to be explained in detail.

- From the above calculation of kinetic energies of different conditions there was proportional increase in the kinetic energy of the molecules after covering the expressway. Now if we take this concept of rolling, it is known that the friction's role in this type of rolling is huge depending upon its line of action. When this friction line of action is through the centre of mass it only produces linear acceleration and it induces the tendency of the body to slide and force of friction appears in the backward direction.
- When the external force does not passes through the centre of mass of the body then it produces angular acceleration along with the linear acceleration resulting in the increase in angular velocity of the body. This process makes the body to slide in the backward direction and here comes the friction which acts in the direction of the force to produce anticlockwise torque to counter act the sliding process hence in helping the body to rotate without sliding with acceleration.
- Therefore in our test the vehicle was in an accelerated motion so the tire rolling on the pavement surface was in an accelerated rolling motion and the frictional force produced was counteracting the sliding movement of the tire by forming a torque in counter clockwise direction hence we can conclude that the work done by the friction in rotation and translational direction is equal but opposite in sign.
- It is seen from the concept of rolling that work done by friction is zero and hence here in our study it is concluded that the work done by friction between the rubber tire and the pavement surface is not completely zero but is very small in contributing the energy inside the tire to the gas filled with respect to other sources of energy. We here conclude that the major dissipation of energy in the form of heat is done to the surroundings and less inside the tire since the materials of the tire with high cross link density decreases the conductivity of the tread material as mentioned in the study done in 2006 and it helps the tires to sustain a high temperature in the critical points.
- It is also concluded due to the continuous rolling of the tire on the surface heats up the shaft axle to which the rim of the tires are attached and there is

dissipation of energy in the form of heat. Thus from the total kinetic energy calculated in above calculations it can be attributed that the major portion of the increase in the kinetic energy of the gas molecules is broadly because of the direct impact of the tire on the textures that are provided on the rigid pavement. Another aspect that is also attributed in the generation of heat is also the contact area of the tire on the pavement which also plays a major role in the increase in the kinetic energy which is discussed below. Since the concept of rolling signifies the work done by friction to be totally zero but in the real situation such is not possible hence we attribute it to be 1 % that this percentage of amount of energy of the total energy attributed inside the tire.

5.5.2 CONTACT AREA PATCH ANALYSIS

The contact area patch plays a vital role in the movement of the tires on the pavement surface. During any journey the vehicle manoeuvres in different directions and performs different phenomenon like accelerating the vehicle, braking of the vehicle, turning movement etc. and every phenomenon has its own science behind it but the one important part of the vehicle that counters all these is the tires of the vehicle. There are finer points that are concluded from the test conducted on the expressway and on the flexible pavement, are listed below:

- Since we all know India adopts the radial type of tires because of its better stability and flexibility of the sidewall at higher speeds and thus they have more contact area on the pavement surface than the other cross ply tires. It was observed that the patch formed was rectangular in shape and the front wheel imprint size was found to be more than that of the imprint from the rear wheels. This is because of the shape of the vehicle and may vary vehicle to vehicle.

Fig. 5.5.2.1 Contact patch of rolling tires

- The design of the radial tire is such that it has the maximum flexibility without destroying the stability of the vehicle at higher speeds on the pavement surface. This is called as the bulging of the tyre walls which is kept a certain value for a particular speed and for the ideal inflation pressure by the tire manufacturers but this has a huge impact on the dissipation of energy when on moving on either flexible pavement or the rigid pavement. Since rigid pavement has textures they give additional aspect to study which effects the heat dissipation phenomenon in the tire which rolls on the surface. This contact area affects the friction formation which is responsible for counter acting the sliding phenomenon when the tire wheel rolls. Hence this flattening and simultaneously the bulging of the sidewalls of the tire is limited so that there is no formation of many high amount of stresses which may heat up the tires and ultimately leads to the disintegration of the tire phenomenon called tire bursting. That is why it is suggested that the inflation pressure of the tire should not be low so as to prevent such phenomenon and this is concluded from the second set of data that showed a greater increase in the kinetic energy of the enclosed gas molecules than the other set of data in which the inflation pressure is kept to the suggested value of the tire's manual.

Since the rubber used in the manufacture of the tires are viscoelastic solid and it has been proved from the study that whenever these materials are stretched or squeezed they absorb the energy which is not recovered completely when the load is removed.

5.6 EFFECT OF TEXTURE ON THE TIRES

Rigid pavement has provided better riding quality than the flexible pavement but due to formation of many different types of stresses it becomes risky for long journey at high speed. The major aspect is providing better friction and better riding quality in wet environment. With the test conducted and studying the nature of tires while rolling we concluded following points:

- In the flexible pavement the friction is mainly provided by the coarser aggregates with proper compaction in combination with the optimum bitumen content in it. In the initial phase of the newly constructed pavement the aggregates are protruded out and it provides the friction but it also impacts the tires of the vehicles and after repetition of loads it tends to get polished and their impact on the tires of the vehicles starts to get reduced. It is seen from the increase in the pressure value of the tires in the test conducted in the flexible pavement.

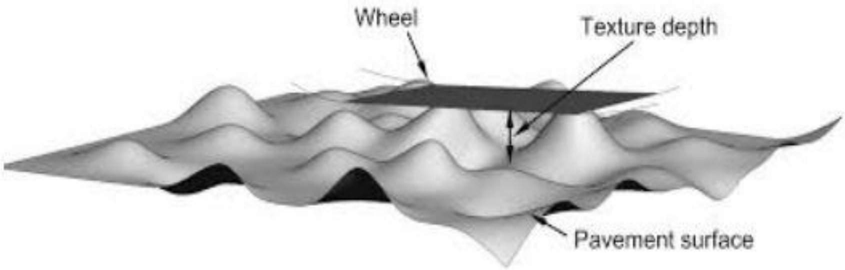

Fig. 5.6.1 Texture Depth and Wheel contact

- Whereas in the rigid pavement there are slabs made of concrete either reinforced or without reinforcement, so firstly there are formation of many stresses due to the various climatic factors and changes accordingly too. The friction in these pavements is provided by the formation of textures on its surface. It is seen that due to the repetition of loads these textures tends to get polished and the friction value decreases which not only increases the sliding phenomenon in the rolling tire but also increases the dissipation of energy in the form of heat which causes the wearing of the tire. In the older tires or tires with low inflation pressure tends to get burst as they are not able sustain such high amount of energy.
- This was one aspect where textures play a role in the wearing of the tires. The second aspect of it is if the textures width is increased about > 500 mm, the tires will take a point contact with two ends of the texture wavelength and will experience much high pressure due to less area of contact. It will give better friction but due to continuous direct impact the tires will experience tremendous high stresses and hence will increase the kinetic energy of the enclosed gas molecules. The cross ply tires won't be able to bear such high energy due less flexibility of the sidewall and hence will burn out whereas in radial tires this will be limited to a certain value and limit due to the flexible nature of the sidewalls of the radial tires.

With the tests conducted and some basic concepts of science we are seen that there are many different types of energy formation in the rigid pavement which hampers the quality of the tires. For a smaller length journey it has a lesser effect as compared to the long journey on the rigid pavement. The texture do play a major role in the heating up of the tires hence merely increasing the texture depth would increase the braking efficiency of the pavement in wet conditions but would decrease the life of the tires hence in some cases leading to major accidents due to wearing of the tires.

CHAPTER 6

CONCLUSION

In the present world the construction of the rigid pavement is gaining popularly and is under greater importance for research since it is in its new phase and requires for improvement. This paper is not concerned with any designing aspects of the rigid pavement. A lot has not been said about one aspect related to the rigid pavements and that is the energy dissipation in rolling tires because of the texture on the pavement surface.

It is the first step towards the analysis of energy dissipation into the tires and therefore has involved many assumptions in its analysis. It is seen from the tests that inflation pressure and the age of the tires play an important role in the dissipation of energy. For a tire with low inflation pressure, it has shown greater increase in the kinetic energy of the enclosed gas molecules. From the frictional analysis it is also been proved that the contribution of the friction is limited in preventing the sliding phenomenon when a fully fit and with proper inflation pressure rolls on the surface. Though the correct value of the contribution of the friction could not be determined but it is approximated to be about 1% of the increase in the kinetic energy. The friction’s major part is lost in the surroundings or is observed as heat in other metal parts near the wheel like axle etc. This gives the first initial requirement for further study or research in this respect. Another aspect that has been taken into consideration is the behaviour of the rolling tires on the rigid pavement and on the flexible pavement. It is also concluded that the tires experiences high direct impact pressure on the pavement with textures greater than the megatexture and increases the pressure flow on the surface of the tires. It has also been concluded that based on the increase in the kinetic energy and the maximum pressure of the tires, an optimum texture depth of < 1.8-1.9 mm should be adopted as the increase in the depth of the texture is increasing the spacing of two texture depths and if the spacing is not increased it can be seen that the deteriorated tire won’t last for longer distance. And about the test site it has been concluded based on the data and assumption that depth <2.5mm-2.8mm is ideal for the tires considering the age of the tire to be 3 years.

From the above things it can also be said that the process of wearing of tires is quick in nature when moving on rigid pavement with high texture wavelength than the other wavelength texture when run for a longer distance. The length of the journey on such surfaces also becomes an important factor in the design. There are immense research works on the amount of stress formation in rigid pavement but in this work more focus is given on the amount of energy in the form of heat enters inside the rolling tire due to the texture and sometimes causing tyre burst phenomenon. A lot more can be done in this respect or more practical approach can be made since this paper has given a theoretical view to it with few practical calculation of the data. The work and the collection of data was hampered due to the global pandemic COVID-19 and hence more detailed practical analysis couldn’t be done.

CHAPTER 7

FUTURE SCOPE AND INVESTIGATIONS

Based on the present work and findings it is believed that better analysis can be done with more advanced technical structure and a relation could be formed though all the proper care that was required was taken.

- The relation between the texture on the pavement and the speed of the vehicle could be formed with better data collection and analysis.
- The exact percentage of the contribution of the friction in the increase in the kinetic energy could not be calculated and requires further analysis.
- There were more ideal assumptions that were used to calculate the amount of energy inside the rolling tire which can alter with the conditions in the real world.
- Due to the global pandemic the conclusion has been made in lesser number of data; hence in further studies more number of data can be used.
- A deeper study can be adopted for the calculation of energy attributed by the texture as this whole process of analysis is a complex phenomenon.

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A Review of Literature on Analysis of Energy Produced and Distributed in Rigid Pavement

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I. INTRODUCTION

This paper tries to make study of the energy produced when a tire rolls on the surface of rigid pavement and how it gets distributed into the atmosphere and some absorbed by the rolling tire. This paper will more give emphasis on the portion of energy produced because of the textures provided on the pavement; and will not include the loss of energy due to any other cause. Texture provided on the pavement is basically a series of repeating figures drawn transverse to the moving direction in order to attain a desired value of skid resistance and friction so as to avoid skidding in any condition. But in view of this there is an abrupt increase in the amount of energy being produced and this is causing the problem of tire bursting. There has not been a lot of research going on regarding this issue but research paper related to few key problems involved in this study on combining will pave the foundation for the advance research on this issue. Papers related to tire burst, interior temperature distribution of the rolling tire, tire interaction with the pavement will help in concluding my desired purpose of research.

Afzali B(2006)[9] This paper studied the effect of change in one step of production of tire on the thermal properties and temperature distribution of the rolling tire by performing a finite element modelling of heat transfer and temperature distribution of a steady state rolling tire. It provided the critical points and the maximum temperature in a rolling tire and it helps in choosing best structure and material of the tire. The tire considered is divided into various zones and it says that each zone has its own boundary conditions for heat transfer analysis and its starting assumption will be useful in making our theoretical study.

L.Tighe(2008)[1] This paper performed its study to determine the optimum surface friction and the mean texture depth for cement concrete surface and it was found that mean texture depth of about 1.8 mm provided the maximum friction on textured PCC surface. It calculated the British Pendulum Number(BPN) for measuring the skid resistance and the study evaluated the true effect of asphalt concrete surfaces and pozzolanic cement concrete surfaces on different macro texture and its corresponding surface friction. The different combinations of textures used in preparing the specimen are screed finish, burlap, corn broom and plastic turf drag, exposed aggregate.

Woodside(2011)[10] This paper has done laboratory tests to measure the dynamic vertical, transverse and longitudinal contact forces under tires with varying inflation pressure and loads. It gave a point that longitudinal contact stresses at the trailing edge of the contact patch were on the higher side when the inflation pressure was low. For further research this paper results can be useful and the effect of these forces in the design of pavement can also be incorporated for a better design.

Yuanmang Xia(2012)[4]An important paper that has developed a new wireless temperature measurement system that aims to measure the interior temperature distribution of the rolling tire. It gave a vital point with respect to the temperature distribution in a rolling tire that at the beginning the tire temperature is in equilibrium with the ambient air temperature and starts absorbing energy and there is an increase in temperature and after much time it attains an equilibrium or steady state when all the heat generated is transferred to the ambient air and road through the tire boundary. Using this technique the measurement of temperature can be possible and this will enable us in finding out the change in temperature inside the rolling tire when moved at a certain velocity and distance.

Zuraulis(2014)[11] This paper made an analysis of the impact of the road micro profile on the duration and the type tire road contact with the pavement moving at different speed. It provides a precise data on different types of irregularities relation with the contact time of moving tire with the surface. The results will allow us in quantifying other aspects of the moving vehicle like passenger comfort, suspension system, energy production and distribution.

SadokSassi(2015)[8] This paper gives a model analysis of the vehicle whose one tire is burst and provides result on the stability and geometry of the vehicle and the driver when phenomenon of tire burst occur. Since tire burst is a fatal phenomenon it relates all the changes that occur in a moving vehicle when the tire blows out. The assumptions involved in this study can be helpful in our study. It gave the point that the blast coming from the tyre blowout generates enough energy to excite the wheel structure resonances but has relatively less effect on the stability of the driver.

Grinchuk(2016)[6] This paper made a study on the heat exchange with air and gave the temperature profile of moving oversize tire. A very important paper regarding the problem which is being considered under this paper as it gave the mathematical model of heat transfer in a tire and its heat exchange with air; The mean temperature profiles are calculated by considering transition to a stationary thermal regime and the influence of the rate of energy dissipation and of effectivethermal conductivity of rubber on the temperature field is investigated ; It will help in finding out the portion of energy exchanged with air theoretically and if we get total energy produced in the system we can be able to find the energy produced by other source.

II. CONCLUSION

• Maximum temperature inside a tire increases non- linearly with the rate of energy dissipation and an increase in the thermal conductivity of the tire material reduces the maximum temperature inside the oversize tire.
• The temperature inside the tire increases sharply during the first few hours and then attain a more or less a constant value due to more intense heat exchange with air.
• The energy that comes out of the tire during bursting phenomenon effects the stability of the vehicle and brings about changes in the road tire interaction.
• During vehicle acceleration the impact of road irregularities to the motion of vehicle is observed in case of 10 mm or more and it has been observed that at speed of 80 kmph or more and irregularities of 30 mm or more, the wheel motion increases in vertical direction and the wheel does not come in contact with the road surface.
• There are no temperature gradients in rolling tire in circumferential direction.
• When the load is heavy and inflation pressure is low, the contact force is highly non uniform.
• An increase in Cross Link Density by increasing the curing time, thermal conductivity falls and it causes an increase in maximum temperature when tire rolls.
• The temperature profiles of the change in temperature going inside the rolling tire has been obtained and the critical points with respect to temperature has been concluded from the previous research works.
• The change in skid resistance value with respect to different types of macro textures is concluded in PCC and AC surfaces.

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Analysis of Energy Produced and Distributed in Rigid Pavement

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***Abstract*:- Modern time requires higher speed and lesser time of travel between origin and destination hence expressways, of rigid pavement have attained more priority than other category of pavement. They have a design module of lesser intersections, lesser obstruction hence providing higher speeds even >100 kmph. This paper has analysed the amount of energy that is contributed by the higher texture depths into the rolling tires. This paper tries to study the energy produced when the tire rolls on the surface of rigid pavement and how it gets distributed into the atmosphere and absorbed by the rubber. For the analysis, pressure and temperature of the tire had a key role in the calculation of the energy produced. The concept of kinetic theory of gases helped us in idealising the nature of the movement of gas molecules and in calculating the energy transfer to the gas molecules. The increase in the kinetic energy gave us the conclusion about the mean texture depth that can be adopted in the designing of the rigid pavement. At different ages of the tire, the relationship between change in kinetic energy and the age of tire has been summarised. For the test site it was concluded that texture depth >2.75 mm is not suitable and greater than this will lead to tire burst accidents.**

***Keywords*:- Rigid pavement, expressway, tire, tire burst, energy, energy transfer, kinetic energy**

1. INTRODUCTION

In the modern world, Transportation has reached to a new level with enhanced technology and different material for its construction. The rigid pavement design (expressways) has given higher speed but has somehow compromised in the surface friction part too and to balance this part there has been a provision of higher texture depths which has given better griping value both in dry and wet conditions. This paper tries to make study of the energy produced when a tire rolls on the surface of rigid pavement and how it gets distributed into the atmosphere and some absorbed by the rolling tire. This paper gives emphasis on the portion of energy produced because of the texture provided on the pavement; and does not include the loss of energy due to any other cause. Necessary assumption has been made to absorb the other cause of energy dissipation. Texture provided on the pavement is basically a series of repeating figures drawn transverse to the moving direction in order to attain a desired value of skid resistance and friction so as to avoid skidding in any condition. But in view of this there is an abrupt increase in the amount of energy being produced and this is causing the problem of tire bursting.

Since the approach to this research is more or less based on the theoretical approach but still some efforts has been made to give the practical relation in the research work and for this purpose the first thing that is being calculated is the inflation pressure inside the tyre and using certain formulas and certain theoretical relations related to the energy, conclusion is being made about the work done but with lots left for the coming research which is to be done in this respect. Inflation pressure of the tyre is one of basic aspect that can be calculated with utmost precision. The selection of site is also done on the requirement basis and since rigid pavement expressway was needed, therefore Yamuna Expressway connecting Greater Noida with Agra was selected. Yamuna expressway has witnessed many accidents in the past years and tire bursting has been found one of the reasons of accident. It has been seen that the texture depth of the pavement is high enough in causing tire burst hence making it necessary to study this phenomenon and suggest a suitable depth which provided will help in reducing such accidents.

1.1 GAY LUSSAC'S LAW

The first major concept used in our analysis is Gay-lussac's law which relates the pressure with the absolute temperature of a given mass of gas. When there is a rigid container filled with a gas and its temperature is increased then the pressure of the gas increases and this results in increase in the kinetic energy ass the molecules of the gas starts striking the wall of the container with a greater force. Therefore Joseph Gay-Lussac proposed a law named Gay-Lussac's Law which states that the pressure of a given mass of gas varies directly with the absolute temperature of the gas when the volume is kept constant. This concept is valid for ideal gases. The mathematical expression for the law is as follows:

$$\frac{P_1}{T_1} = \frac{P_2}{T_2}$$

1.2 KINETIC THEORY OF GASES

Since the analysis is involving the study of ideal gas therefore the kinetic theory of gases concept comes into the picture. Kinetic theory of gases is based on the molecular level of the matter. A gas is basically a collection of large number of molecules (in the order of Avogadro's number) that are in constant random motion in which at ordinary pressure and temperature the intermolecular distance between the molecules is in the factor of 10Å or more than the typical size of a molecule. Thus it is assumed that the molecules move freely in straight lines according to Newton's first Law but that's not the case. These molecules come close to each other and strike each other called as "collisions" and this collision changes their velocity.

In this theory it is considered that these collisions either with each other or with the walls are elastic meaning that the total kinetic energy and the total momentum is conserved and the velocity after the collision does not change.

Pressure exerted on the wall, P = (1/3)nm$\sum v^2$

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1.3 KINETIC INTERPRETATION OF TEMPERATURE

We know that
PV = (1/3) nVm$\sum v^2$
PV = (2/3) N$\sum v^2$ where N is the number of molecules in the gas sample
This quantity is the average translational kinetic energy of the molecules in the gas and hence E = (1/3) nVm$\sum v^2$
Therefore the final equation of the interpretation of temperature is as:
E = (3/2) k_bNT or = (3/2) k_b T
i.e the average kinetic energy of a molecule is proportional to the absolute temperature of the gas and is independent of pressure, volume or the nature of gas. The two parameters are connected by the Boltzmann constant, k_b. With this relation the kinetic energy of an ideal gas is consistent with the ideal gas equation and other gas laws equation.

1.4 LAW OF EQUIPARTITION OF ENERGY

As here in our study, the work is going on for a diatomic gas like O_2, N_2 etc. hence the translational degree of freedom for the diatomic gas is three and it also spins about its centre of mass about two axes so therefore the total degree of freedom for a diatomic gas is five. In thermal equilibrium at absolute temperature it is seen that each translational mode of motion has an energy equal to (1/2)k_BT. Hence the average kinetic energy for a monoatomic gas having three degree of freedom will be (3/2)k_bT and similarly for a diatomic gas it will be (5/2)k_bT since it has three translational motion and two rotational motion.

2. LITERATURE REVIEW

Afzali B (2006)[12] This paper studied the effect of change in one step of production of tire on the thermal properties and temperature distribution of the rolling tire by performing a finite element modelling of heat transfer and temperature distribution of a steady state rolling tire. It provided the critical points and the maximum temperature in a rolling tire and it helps in choosing best structure and material of the tire.

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3. DATA COLLECTION

Yamuna expressway also known as Taj Expressway is basically a 6 lane, extendable to 8 lanes, 165 km long access controlled expressway which connects Greater Noida with Agra in the territory of Uttar Pradesh. It is one of the India's longest six lane expressway. This expressway starts from Pari Chowk in Greater Noida and ends at Kuberpur in Agra. It is monitored and maintained by a body called Yamuna Expressway Industrial Development Authority (YEIDA).

Fig. 1 View of Yamuna Expressway

The accident data of the Yamuna Expressway, of the past three years, was made available to us. There was not much classification of the accidents by which cause they have occurred but tyre bursting was one of the many causes due to which those accidents have occurred. The number of road accidents have been on the decrement side but the number of fatal casualties increased.

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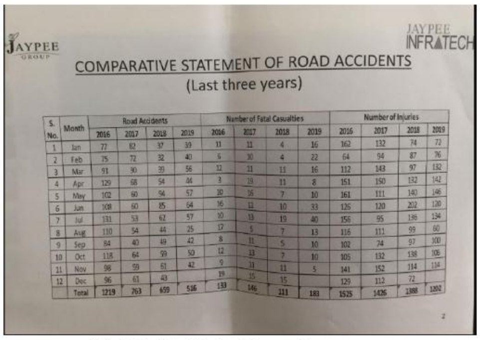

JAYPEE GROUP   JAYPEE INFRATECH

COMPARATIVE STATEMENT OF ROAD ACCIDENTS
(Last three years)

S. No.	Month	Road Accidents				Number of Fatal Casualties				Number of Injuries			
		2016	2017	2018	2019	2016	2017	2018	2019	2016	2017	2018	2019
1	Jan	77	82	37	39	11	11	4	16	162	132	74	72
2	Feb	75	72	32	40	6	10	4	22	64	94	87	76
3	Mar	91	90	39	56	12	11	11	16	112	143	97	132
4	Apr	129	68	54	44	3	19	11	8	151	150	132	142
5	May	102	60	94	57	10	16	7	10	161	111	140	146
6	Jun	108	60	85	64	16	11	10	33	126	120	202	120
7	Jul	131	53	62	57	10	13	19	40	156	95	136	134
8	Aug	110	54	44	25	17	5	7	13	116	111	99	60
9	Sep	84	40	49	42	8	11	5	10	102	74	97	100
10	Oct	118	64	99	50	12	13	7	10	105	132	138	106
11	Nov	98	59	61	42	9	11	11	5	141	152	114	114
12	Dec	96	61	43		19	15	15		129	112	72	
	Total	1219	763	659	516	133	146	111	183	1525	1426	1388	1202

2

Fig. 2 Accident Data of Yamuna Expressway

With due permission from the concerned authority some basic technical features of the expressway were obtained.

S.NO.	DESCRIPTION	
1.	Total number of lanes	6 : 3.5 m width each
2.	Permissible speed	100 kmph for LMV 60 kmph for HMV
3.	Maximum Allowable speed	120 kmph
4.	Total length	165.5 km
5.	Right of Way	100 m wide
6.	Pavement Width	15.70 m
7.	Maximum axle load design	20 tonnes
8.	Shoulder Width	5.10 m
9.	Thickness of PQC	320 mm (main carriageway)
10.	Thickness of DLC	150 mm
11.	Top Width of Embankment	47.60 m (including 6.0 m wide Median)
12.	Vehicle underpass	70
13.	Minor bridges	41
14.	Interchanges	6
15.	Box Culverts	182
16.	Main Toll Plaza	3 (26 lanes at each location)
17.	Concrete	33.2 lakh cum
18.	Cement	12.0 lakh tonnes
19.	Steel	1.30 lakh tonnes
20.	Stone Aggregate	130 lakh tonnes
21.	Bitumen	7500 tonnes
22.	Admixtures	12500 tonnes

Table 1 Features of Yamuna Expressway

In March, the first trial of the experiment was conducted from the region Etmadpur to Gautam Budhh nagar by taking two vehicles of the same class; one in the morning and the other in the afternoon. There were no stops made in between the journey and constant average speed of about 90 kmph was made. It was ensured that the tires used in this test are new and not worn out from before. Of the concerned moving vehicles the initial pressure readings of both the front and rear side (right and left both) tires were recorded with utmost accuracy that could be made on the road. The picture of the existing texture on the pavement was clicked and is shown below. In both the vehicles it was ensured that the pressure in the tires is maintained at the level as prescribed in the manual.

On completing the total length of the expressway then again the pressure of the tires is being recorded with all the precision and is noted in the sheet shown above. After analysing the sheet we could observe an increase in the pressure reading by about 2 psi in all the four tires of both the vehicles when the vehicle is loaded with the load of two persons of around 75 kg.

SHEET NO.-1

FROM- ETMADPUR TO GAUTAMBUDHH NAGAR

DATE- MARCH 2020

DAY TEMPERATURE- 24^{0}C

AVERAGE SPEED – 90 KMPH

TYRE COMPANY	TYRE MODEL	JOURNEY START TIME	JOURNEY END TIME	INITIAL TYRE PRESSURE				FINAL TYRE PRESSURE				NUMBER OF STOPS
				FRONT		REAR		FRONT		REAR		
				RIGHT	LEFT	RIGHT	LEFT	RIGHT	LEFT	RIGHT	LEFT	
MRF	FRONT- ZLX REAR- ZVTS	9:00 AM	11:00 AM	28 psi	28 psi	28 psi	28 psi	30 psi	30 psi	30 psi	30 psi	0
				34 psi	34 psi	32 psi	32 psi	36 psi	36 psi	36 psi	34 psi	0
				28 psi	28 psi	28 psi	28 psi	30 psi	30 psi	30 psi	30 psi	0
				27 psi	28 psi	28 psi	26 psi	28 psi	30 psi	29 psi	31 psi	0
				30 psi	30 psi	30 psi	32 psi	34 psi	34 psi	32 psi	36 psi	0

Fig. 3 Sheet 1: Etmadpur to Gautambudhh Nagar

Another trial was made on the next day but this time peak temperature was chosen so as to have the effect of high temperature on the test results also. This time the journey was made from the Gautam Budhh Nagar area to Etmadpur region. The loading conditions was kept the same and again the travel speed was maintained at 90 kmph. The concerned initial pressure reading was again taken with utmost precision. There was no stop in between the journey and the journey was completed in about the same time that was taken in the first test trial.

SHEET NO.-2

FROM- GAUTAMBUDHH NAGAR TO ETMADPUR

DATE- MARCH 2020

DAY TEMPERATURE- 32^{0}C

AVERAGE SPEED – 90 KMPH

TYRE COMPANY	TYRE MODEL	JOURNEY START TIME	JOURNEY END TIME	INITIAL TYRE PRESSURE				FINAL TYRE PRESSURE				NUMBER OF STOPS
				FRONT		REAR		FRONT		REAR		
				RIGHT	LEFT	RIGHT	LEFT	RIGHT	LEFT	RIGHT	LEFT	
MRF	FRONT- ZLX REAR- ZVTS	12:15 PM	3:00 PM	26 psi	26 psi	28 psi	26 psi	32 psi	30 psi	30 psi	30 psi	0
				32 psi	34 psi	32 psi	32 psi	34 psi	36 psi	36 psi	34 psi	0
				28 psi	28 psi	28 psi	28 psi	30 psi	30 psi	30 psi	30 psi	0
				28 psi	28 psi	28 psi	26 psi	32 psi	30 psi	29 psi	31 psi	0
				30 psi	28 psi	30 psi	30 psi	34 psi	30 psi	32 psi	36 psi	0

Fig. 4 Sheet 2: Gautambudhh Nagar to Etmadpur

From the above trial test we observed a significant increase in the pressure of the tires. The pressure in the front side tyres of the vehicle were kept 2 psi less than that of the

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prescribed value in the manual and those tires showed an increase of about 5-6 psi pressure value while the rear side tires which were filled with designated pressure value showed an increase of about 2-4 psi.

Fig. 5 Collection of Data

4. DATA ANALYSIS

After the collection of data, the calculation of the energy and other various aspects were calculated based on the perspective of the gas filled inside the tire and not from the perspective of the tire road contact since it required high and advanced technology for the calculation. Assumptions have been taken of the various laws and concept that are used for the calculation purpose. The one major assumption that has been taken is that the gas filled inside the tire is behaving as an ideal gas and undergoes perfectly elastic collision.

From the above collected data of the initial and final pressure, average three values were selected and the final temperature were calculated using Gay Lussac's Law. The standard initial temperature was taken to be 24°C. The change in kinetic energy was calculated and is tabulated below.

S. N O.	INITIAL PRESSU RE, P_1	FINAL PRESSU RE, P_2	FINAL TEMPERA TURE, T_2	FINAL KINETIC ENERGY, $K.E_{1,2,3}$	$\Delta K.E = K.E_{1,2,3} - K.E_{stan}$
1.	28 psi	30 psi	318.375 K	16.93 kJ	1.13 kJ
2.	26 psi	32 psi	365.72 K	19.45 kJ	3.65 kJ
3.	26 psi	30 psi	342.86 K	18.23 kJ	2.43 kJ

Table 2 Containing final temperature T_2 and change in Kinetic Energy $\Delta K.E$

Every tire has its maximum pressure that it can withstand based on its manufacturing and constituent materials and it decreases with the years and the kms it rolls on the pavement surface. Hence it becomes a major part in the provision of design of the rigid pavement since friction remaining constant in every situation, the capacity of the rolling tires will get reduced with increase in age and this deterioration level will prove fatal for the vehicle. Based on the data collected we can summarise the different situations of the tire at subsequent 1 year of interval and its decrease in the holding maximum pressure.

Case I: when the maximum pressure = 50 psi = 3.4 atm and initial pressure = 28 psi =1.904 atm

For t = 0 it means that the tire is new and can sustain maximum 50 psi pressure; for this condition the kinetic energy of the gas is calculated and at 1 year interval for different pressure conditions kinetic energies are calculated.

Age of tire, t (in years)	P_1 (in atm)	T_1 (in K)	P_2 (in atm) (in psi)	T_2 (in K)	$K.E_1$ (in kJ)	$K.E_2$ (in kJ)	$\Delta K.E = K.E_2 - K.E_1$
0	1.904	297.15	3.40 (50)	530.625	15.80	28.22	12.42
1	1.904	297.15	3.264(48)	509.40	15.80	27.09	11.29
2	1.904	297.15	3.128(46)	488.175	15.80	25.96	10.16
3	1.904	297.15	2.992(44)	466.95	15.80	24.83	9.03
4	1.904	297.15	2.856(42)	445.725	15.80	23.70	7.90
5	1.904	297.15	2.72(40)	424.50	15.80	22.57	6.77

Table 3 Increase in kinetic energy at different age of tires (maximum pressure=50 psi)

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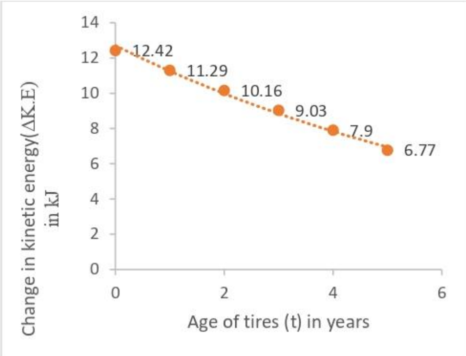

Fig. 6 Graph between age of tires and change in kinetic energy (maximum pressure =50 psi)

From the above graph it is estimated that with coming time the capacity of the tires to bear the kinetic energy decreases, not in a constant manner, and therefore if we limit the friction contribution in this energy we can come to the conclusion about the amount of texture that should be provided and of which particular depth.

Case II: when the initial pressure = 28 psi and the maximum pressure = 51 psi=3.468 atm

Age of tire, t (in years)	P_1 (in atm)	T_1 (in K)	P_2 (in atm) (in psi)	T_2 (in K)	$K.E_1$ (in kJ)	$K.E_2$ (in kJ)	$\Delta K.E = K.E_2 - K.E_1$
0	1.904	297.15	3.468(51)	541.23	15.80	28.78	12.98
1	1.904	297.15	3.332(49)	520.01	15.80	27.65	11.85
2	1.904	297.15	3.196(47)	498.78	15.80	26.52	10.72
3	1.904	297.15	3.06(45)	477.56	15.80	25.39	9.59
4	1.904	297.15	2.924(43)	456.33	15.80	24.27	8.47
5	1.904	297.15	2.788(41)	435.11	15.80	23.14	7.34

Table 4 Increase in kinetic energy at different age of tires (maximum pressure=51 psi)

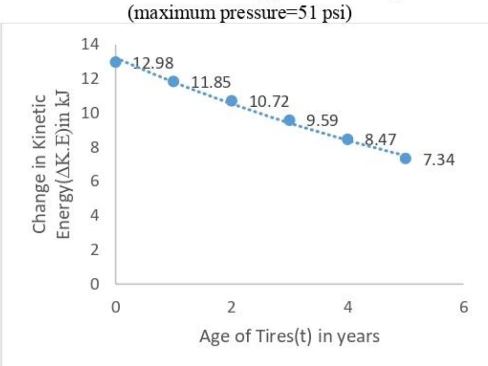

Fig. 7 Graph between age of tires and change in kinetic energy (maximum pressure= 51 psi)

Case III: when the maximum pressure = 51 psi and the initial pressure = 28 psi. In this case we assume that the reduction in the maximum pressure is not constant.

Age of tire, t (in years)	P_1 (in atm)	T_1 (in K)	P_2 (in atm) (in psi)	T_2 (in K)	$K.E_1$ (in kJ)	$K.E_2$ (in kJ)	$\Delta K.E = K.E_2 - K.E_1$
0	1.904	297.15	3.468(51)	541.23	15.80	28.78	12.98
1	1.904	297.15	3.40(50)	530.625	15.80	28.22	12.42
2	1.904	297.15	3.196(47)	498.78	15.80	26.52	10.72
3	1.904	297.15	2.856(42)	445.725	15.80	23.70	7.90
4	1.904	297.15	2.856(42)	445.725	15.80	23.70	7.90

Table 5 Increase in kinetic energy at different age of tires (maximum pressure=51 psi)

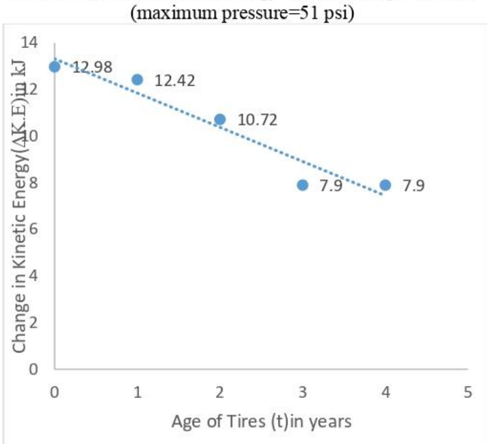

Fig. 8 Graph between age of tires and change in kinetic energy (maximum pressure= 51 psi)

Case IV: when the normal pressure = 30 psi and the maximum pressure of the tire= 44 psi =2.992 atm

Age of tire, t (in years)	P_1 (in atm)	T_1 (in K)	P_2 (in atm) (in psi)	T_2 (in K)	$K.E_1$ (in kJ)	$K.E_2$ (in kJ)	$\Delta K.E = K.E_2 - K.E_1$
0	2.04(30)	297.15	2.992(44)	435.82	15.80	23.17	7.37
1	2.04	297.15	2.856(42)	416.01	15.80	22.12	6.32
2	2.04	297.15	2.720(40)	396.20	15.80	21.07	5.27
3	2.04	297.15	2.584(38)	376.39	15.80	20.01	4.21
4	2.04	297.15	2.448(36)	356.58	15.80	18.52	2.72

Table 6 Increase in kinetic energy at different age of tires (maximum pressure=44 psi)

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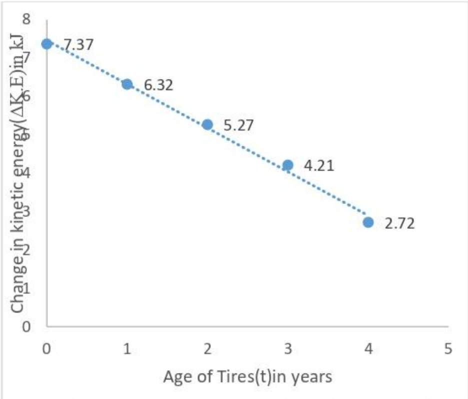

Fig. 9 Graph between age of tires and change in kinetic energy (maximum pressure =44 psi)

Case V: when the normal pressure = 30 psi and the maximum pressure of the tire= 44 psi =2.992 atm

Age of tire, t (in years)	P_1 (in atm)	T_1 (in K)	P_2 (in atm) (in psi)	T_2 (in K)	$K.E_1$ (in kJ)	$K.E_2$ (in kJ)	$\Delta K.E = K.E_2 - K.E_1$
0	2.04	297.15	2.992(44)	435.82	15.80	23.17	7.37
1	2.04	297.15	2.924(43)	425.91	15.80	22.65	6.85
2	2.04	297.15	2.788(41)	406.10	15.80	21.59	5.79
3	2.04	297.15	2.652(39)	386.29	15.80	20.54	4.74
4	2.04	297.15	2.516(37)	366.48	15.80	19.49	3.69

Table 7 Increase in kinetic energy at different age of tires (maximum pressure=44 psi)

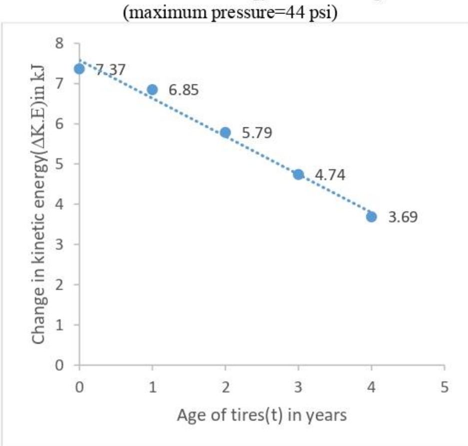

Fig. 10 Graph between age of tires and change in kinetic energy (maximum pressure =44 psi)

Case VI: when the normal pressure = 30 psi and the maximum pressure of the tire = 44 psi. In this case the deterioration is not taken as constant and accordingly graph is plotted.

Age of tire, t (in years)	P_1 (in atm)	T_1 (in K)	P_2 (in atm) (in psi)	T_2 (in K)	$K.E_1$ (in kJ)	$K.E_2$ (in kJ)	$\Delta K.E = K.E_2 - K.E_1$
0	2.04	297.15	2.992(44)	435.82	15.80	23.17	7.37
1	2.04	297.15	2.788(41)	406.10	15.80	21.59	5.79
2	2.04	297.15	2.788(41)	406.10	15.80	21.59	5.79
3	2.04	297.15	2.72(40)	396.20	15.80	21.07	5.27
4	2.04	297.15	2.516(37)	366.48	15.80	19.49	3.69

Table 8 Increase in kinetic energy at different age of tires (maximum pressure=44 psi)

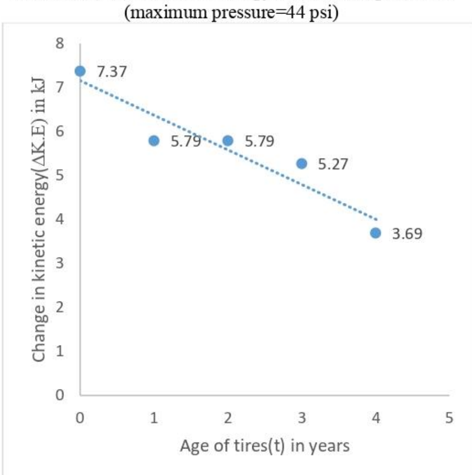

Fig. 11 Graph between age of tires and change in kinetic energy (maximum pressure =44 psi)

Case VII: when the normal pressure = 33 psi and the maximum pressure of the tires =61 psi

Age of tire, t (in years)	P_1 (in atm)	T_1 (in K)	P_2 (in atm) (in psi)	T_2 (in K)	$K.E_1$ (in kJ)	$K.E_2$ (in kJ)	$\Delta K.E = K.E_2 - K.E_1$
0	2.244(33)	297.15	4.148(61)	549.27	15.80	29.21	13.41
1	2.244	297.15	4.012(59)	531.26	15.80	28.25	12.45
2	2.244	297.15	3.876(57)	513.25	15.80	27.29	11.49
3	2.244	297.15	3.74(55)	495.25	15.80	26.34	10.54
4	2.244	297.15	3.604(53)	477.24	15.80	25.38	9.58

Table 9 Increase in kinetic energy at different age of tires (maximum pressure=61 psi)

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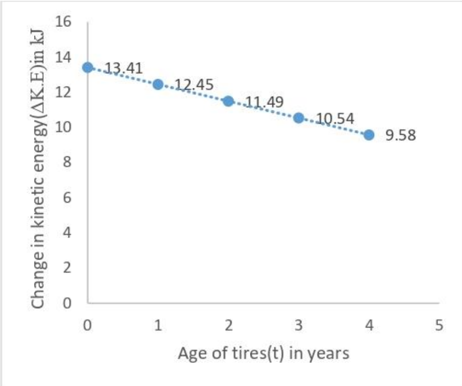

Fig. 12 Graph between age of tires and change in kinetic energy (maximum pressure =61 psi)

Case VIII: when the normal pressure = 33 psi and the maximum pressure of the tires= 60 psi

Age of tire, t (in years)	P_1 (in atm)	T_1 (in K)	P_2 (in atm) (in psi)	T_2 (in K)	$K.E_1$ (in kJ)	$K.E_2$ (in kJ)	$\Delta K.E = K.E_2 - K.E_1$
0	2.244	297.15	4.08(60)	540.27	15.80	28.73	12.93
1	2.244	297.15	3.944(58)	522.26	15.80	27.77	11.97
2	2.244	297.15	3.808(56)	504.25	15.80	26.81	11.01
3	2.244	297.15	3.672(54)	486.24	15.80	25.86	10.06
4	2.244	297.15	3.536(52)	468.23	15.80	24.90	9.10

Table 10 Increase in kinetic energy at different age of tires (maximum pressure=60 psi)

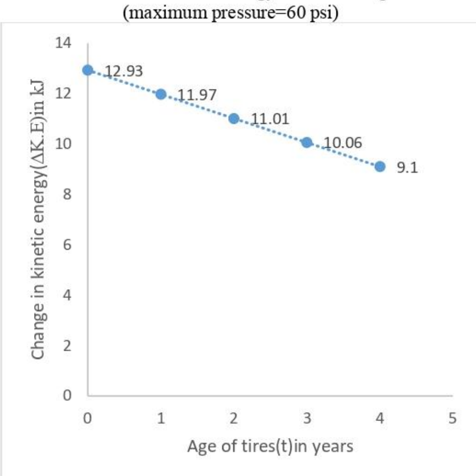

Fig. 13 Graph between age of tires and change in kinetic energy (maximum pressure =60 psi)

Case IX: when the normal pressure = 33 psi and the maximum pressure of the tires = 61 psi. And the rate of deterioration is not constant.

Age of tire, t (in years)	P_1 (in atm)	T_1 (in K)	P_2 (in atm) (in psi)	T_2 (in K)	$K.E_1$ (in kJ)	$K.E_2$ (in kJ)	$\Delta K.E = K.E_2 - K.E_1$
0	2.244	297.15	4.148(61)	549.27	15.80	29.21	13.41
1	2.244	297.15	4.012(59)	531.26	15.80	28.25	12.45
2	2.244	297.15	3.74(55)	495.25	15.80	26.34	10.54
3	2.244	297.15	3.672(54)	486.24	15.80	25.86	10.06
4	2.244	297.15	3.468(51)	459.23	15.80	24.42	8.62

Table 11 Increase in kinetic energy at different age of tires (maximum pressure=61 psi)

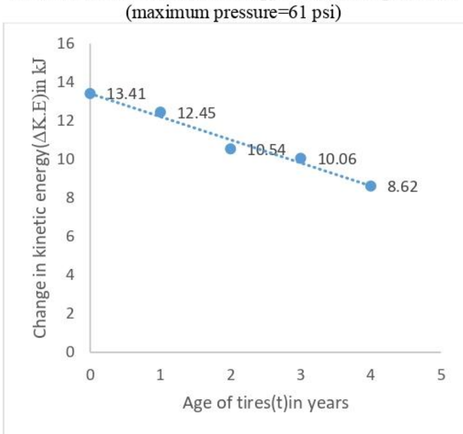

Fig. 14 Graph between age of tires and change in kinetic energy (maximum pressure =61 psi)

Case X: when the normal pressure = 40 psi and the maximum pressure of the tires = 65 psi

Age of tire, t (in years)	P_1 (in atm)	T_1 (in K)	P_2 (in atm) (in psi)	T_2 (in K)	$K.E_1$ (in kJ)	$K.E_2$ (in kJ)	$\Delta K.E = K.E_2 - K.E_1$
0	2.72	297.15	4.42(65)	482.86	15.80	25.68	9.88
1	2.72	297.15	4.284(63)	468.01	15.80	24.89	9.09
2	2.72	297.15	4.148(61)	453.15	15.80	24.10	8.30
3	2.72	297.15	4.012(59)	438.29	15.80	23.31	7.51
4	2.72	297.15	3.876(57)	423.43	15.80	22.52	6.72

Table 12 Increase in kinetic energy at different age of tires (maximum pressure=65 psi)

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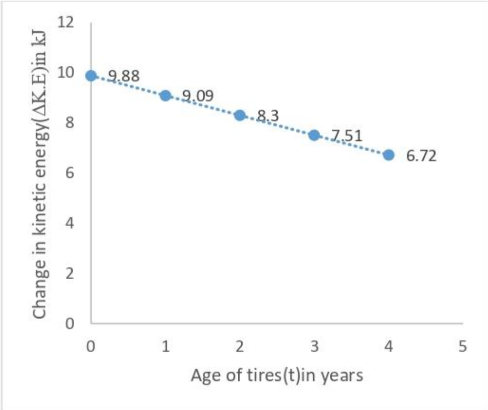

Fig. 15 Graph between age of tires and change in kinetic energy (maximum pressure =65 psi)

<u>Case XI</u>: when the normal pressure = 40 psi and the maximum pressure of the tires = 66 psi

Age of tire, t (in years)	P_1 (in atm)	T_1 (in K)	P_2 (in atm) (in psi)	T_2 (in K)	$K.E_1$ (in kJ)	$K.E_2$ (in kJ)	$\Delta K.E = K.E_2 - K.E_1$
0	2.72	297.15	4.488(66)	490.29	15.80	26.07	10.27
1	2.72	297.15	4.352(64)	475.44	15.80	25.28	9.48
2	2.72	297.15	4.216(62)	460.58	15.80	24.49	8.69
3	2.72	297.15	4.08(60)	445.72	15.80	23.70	7.90
4	2.72	297.15	3.944(58)	430.86	15.80	22.91	7.11

Table 13 Increase in kinetic energy at different age of tires (maximum pressure=66 psi)

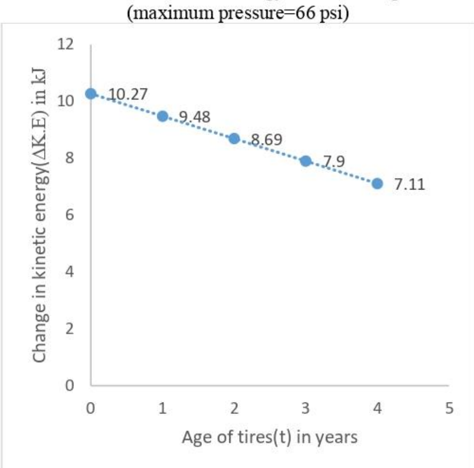

Fig. 16 Graph between age of tires and change in kinetic energy (maximum pressure =66 psi)

From the above analysis of different cases of nominal and maximum pressure of different tires we can obtain a range of texture depths that can be constructed on the pavement considering the worst case involved in the tires.

We take the weight of the un-laden vehicle= 870 kg

Weight on single wheel (considering equal distribution of weight on four wheels) = 870/4 = 217.5 kg

As we know that force * displacement = work done

The texture depths are considered as a vertical distance and as soon as the rubber tires rolls over it tends to deflect a small distance x, because of its weight so for different deflection different energies for different depth of deflection can be obtained and has been tabulated below.

Texture Depth in mm	Work done in J
2.0	0.435
2.2	0.478
2.5	0.543
2.75	0.598
2.8	0.609
3.0	0.652
3.5	0.761
3.75	0.815
4.0	0.875

Table 14 Work done by single different texture depths

Taking average life of tires as 3 years and considering that the increase in kinetic energy is 1% because of friction and rest by the texture depth we get that for tire with 28 psi nominal pressure 10.16 kJ as minimum energy to reach to the case of maximum holding pressure, for 30 psi 5.27 kJ, for 33 psi 11.01 kJ and for 40 psi 8.30 kJ. But since all these calculations are the cases involving the optimum conditions which is not the case in the present situation. The texture depth of about <1.8 mm is optimum for every situation but the test site involved had more depth so considering the basic number of texture depth as 150 we can give the conclusion of having optimum texture depth that is required for this pavement.

Going by the same methods of analysis for different texture depths starting from 4.0 mm we get the following calculations for different depths:

For 4.0 mm depth: taking number of texture depths as 150 per km of the pavement, we get the energy contributed by all texture depth for 1 km as =150*0.87 J

Similarly for 150 km length = 150*150*087 =19.575 kJ

Since the tire had initial energy = 15.80 kJ for 24°C

Therefore the total energy attributed by texture will be 15.80 + 19.575 = 35.37 kJ

35.37*1000=20.5*1.38*2.56*6.022*T

T=665.02 K

From Gay –Lussac's law,

$$\frac{P_1}{T_1} = \frac{P_2}{T_2}$$

For P_1= 30 psi T_1=297.15 K, T_2=665.02 K

We get P_2 =67 psi

Similarly for other depths 3.75 mm, 3.5 mm, 3.0 mm, 2.8 mm, 2.75 mm, 2.5 mm, 2.2 mm different values of final pressure has been calculated and tabulated below:

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Texture Depth (in mm)	Final pressure P_2 (in psi)
4.0	67
3.75	65
3.5	62
3.0	58
2.8	56
2.75	54
2.5	53
2.2	50

Table 15 Maximum pressure build up for different texture depths

5. CONCLUSION

- When the external force does not passes through the centre of mass of the body then it produces angular acceleration along with the linear acceleration resulting in the increase in angular velocity of the body. This process makes the body to slide in the backward direction and here comes the friction which acts in the direction of the force to produce anticlockwise torque to counter act the sliding process hence in helping the body to rotate without sliding with acceleration. It is seen from the concept of rolling that work done by friction is zero and hence here in our study it is concluded that the work done by friction between the rubber tire and the pavement surface is not completely zero but is very small in contributing the energy inside the tire to the gas filled with respect to other sources of energy. We here conclude that the major dissipation of energy in the form of heat is done to the surroundings and less inside the tire since the materials of the tire with high cross link density decreases the conductivity of the tread material as mentioned in the study done in 2006 and it helps the tires to sustain a high temperature in the critical points.
- Whereas in the rigid pavement there are slabs made of concrete either reinforced or without reinforcement, so firstly there are formation of many stresses due to the various climatic factors and changes accordingly too. The friction in these pavements is provided by the formation of textures on its surface. It is seen that due to the repetition of loads these textures tends to get polished and the friction value decreases which not only increases the sliding phenomenon in the rolling tire but also increases the dissipation of energy in the form of heat which causes the wearing of the tire. In the older tires or tires with low inflation pressure tends to get burst as they are not able sustain such high amount of energy.
- This was one aspect where textures play a role in the wearing of the tires. The second aspect of it is if the textures width is increased about > 500 mm, the tires will take a point contact with two ends of the texture wavelength and will experience much high pressure due to less area of contact. It will give better friction but due to continuous direct impact the tires will experience tremendous high stresses and hence will increase the kinetic energy of the enclosed gas molecules. The cross ply tires won't be able to bear such high energy due less flexibility of the sidewall and hence will burn out whereas in radial tires this will be limited to a certain value and limit due to the flexible nature of the sidewalls of the radial tires.
- We can make a conclusion about the pavement test site that considering the final age of the tires to be 3 years, in this pavement texture depth > 3.5 mm will lead to the bursting of the tires if it satisfies every condition of it so for safety of most vehicle tires depth < 2.5-2.8 mm can be considered the ideal texture depth. More than this can lead to the frequent degradation of the newer tires and bursting of the old tires if not properly handled leading to major accidents.

6. FUTURE SCOPE

Based on the present work and findings it is believed that better analysis can be done with more advanced technical structure and a relation could be formed though all the proper care that was required was taken.

- The relation between the texture on the pavement and the speed of the vehicle could be formed with better data collection and analysis.
- The exact percentage of the contribution of the friction in the increase in the kinetic energy could not be calculated and requires further analysis.
- There were more ideal assumptions that were used to calculate the amount of energy inside the rolling tire which can alter with the conditions in the real world.
- A deeper study can be adopted for the calculation of energy attributed by the texture as this whole process of analysis is a complex phenomenon.

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