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Effect of Pavement Conditions on Rolling Resistance

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ABSTRACT: *Rolling resistance is the force acting on a vehicle over a full journey. It is generated by the hysteresis of tyre and pavement. Rolling resistance, sometimes called* ***rolling friction*** *or* ***rolling drag****, is the force resisting the motion when a body (such as a ball, tire, or wheel) rolls on a surface. It is mainly caused by non-elastic effects; that is, not all the energy needed for deformation (or movement) of the wheel, roadbed, etc. is recovered when the pressure is removed. A hysteresis phenomenon can be observed when viscoelastic materials undergo a load-then-unload process. A typical hysteresis curve of viscoelastic material can be found. The shadow area enclosed by the hysteresis loop represents energy loss. A characteristic of a deformable material such that the energy of deformation is greater than the energy of recovery. The rubber compound in a tire exhibits hysteresis. As the tire rotates under the weight of the vehicle, it experiences repeated cycles of deformation and recovery, and it dissipates the hysteresis energy loss as heat. Hysteresis is the main cause of energy loss associated with rolling resistance and is attributed to the viscoelastic characteristics of the rubber. Materials that have a large hysteresis effect, such as rubber, which bounce back slowly, exhibit more rolling resistance than materials with a small hysteresis effect that bounce back more quickly and more completely, such as steel or silica. Low rolling resistance tires typically incorporate silica in place of carbon black in their tread compounds to reduce low-frequency hysteresis without compromising traction. Note that railroads also have hysteresis in the roadbed structure. Like the fuel consumption, rolling resistance also has a significant relationship with velocity. experiment has shown that, for a 32-tonn goods vehicle, rolling resistance contributes about 70% of total drag when driven at 50km/h and about 37% at 100km/h. An important issue which should not be overlooked is that rolling resistance is affected by the characteristics of the pavement surface. Rolling resistance varies between different pavement surfaces. Hard and smooth surfaces produce lower rolling resistance than soft and rough surfaces. Rolling resistance is affected by both tyre and ambient temperature.*

KYE WORDS: *Literature Study, Primary Causes Of Rolling Resistance, Rolling Resistance Coefficent, Factor Influencing Rolling Resistance, Minor Factors Under Considerasion.*

I. INTODUCTION

Rolling resistance is the force acting on a vehicle over a full journey. It is generated by the hysteresis of tyre and pavement. Rolling resistance, sometimes called **rolling friction** or **rolling drag**, is the force resisting the motion when a body (such as a ball, tire, or wheel) rolls on a surface. It is mainly caused by non-elastic effects; that is, not all the energy needed for deformation (or movement) of the wheel, roadbed, etc. is recovered when the pressure is removed. Two forms of this are hysteresis losses (see below), and permanent (plastic) deformation of the object or the surface (e.g. soil). Another cause of rolling resistance lies in the slippage between the wheel and the surface, which dissipates energy. Note that only the last of these effects involves friction, therefore the name "rolling friction" is to an extent a misnomer. In the broad sense, specific "rolling resistance" (for vehicles) is the force per unit vehicle weight required to move the vehicle on level ground at a constant slow speed where aerodynamic drag (air resistance) is insignificant and also where there are no traction (motor) forces or brakes applied. In other words the vehicle would be coasting if it were not for the force to maintain constant speed. An example of such usage for railroads is This broad sense includes wheel bearing resistance, the energy dissipated by vibration and oscillation of both the roadbed and the vehicle, and sliding of the wheel on the roadbed surface (pavement or a rail).

II. LITERATURE STUDY :-

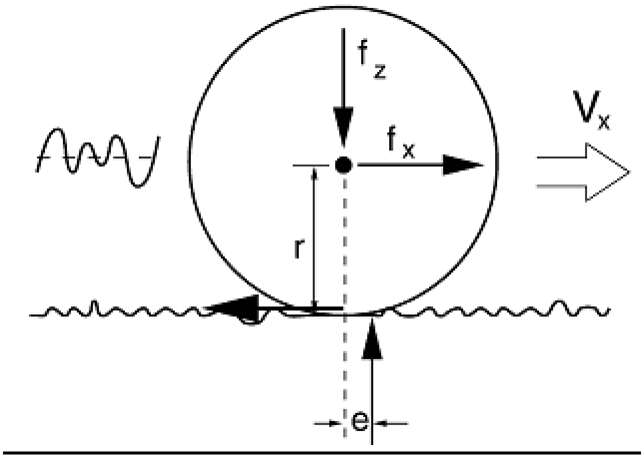


Figure 1 Tyre Rolling Resistance (Miege & Popov, 2005)

a single tyre rolling on a pavement surface with a constant velocity Vx. The radius of the tyre is r. fz is a vertical load generated by the weight of a vehicle. fx is a drag force generated by the engine to push the tyre forward. As can be shown, the sequence under the drag force fx ends up as a rotation of the tyre, and this rotation pushes the tread into a tyre/pavement interface, which has been named as the contact zone. Tread and pavement compress each other into a contact zone. The deformation is found to occur in both tyre and pavement. Meanwhile, the rotation pushes another part of the tread out of the trailing edge of the contact zone. Then, both pavement and tyre are decompressed after the tread goes out of the contact zone. The stress applied on the contact zone is uneven. Normally, the front edge experiences a bigger pressure compared to the trailing edge. Due to the uneven distribution of stresses on the contact zone, the counterforce fc, which is generated by the pavement, is not in the centre of the contact zone, but, shifts forward by a short distance e. When multiplied by the distance e of the counterforce fc it represents a resistance moment, which has been named as the rolling resistance moment. To keep the balance of the moment, another moment needs to act on the tyre and it is a product of the tyre radius r and a horizontal force fr. The horizontal force fr is the rolling resistance of the tyre (Wong, 2001).

A hysteresis phenomenon can be observed when viscoelastic materials undergo a load-then-unload process. A typical hysteresis curve of viscoelastic material can be found in Figure 2 The shadow area enclosed by the hysteresis loop represents energy loss. The dissipated energy can be calculated by using the following equation:

$E_h = \int \sigma \, d\xi$ where E_h = the dissipated energy, σ = stress, ξ = strain.

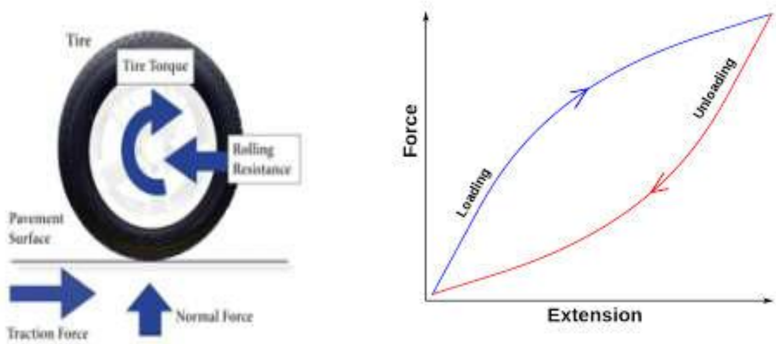


Figure 2 Rolling resistance & Hysteresis Loop

Rubber compounds of a tyre, at a regular temperature, display viscoelastic characteristics (Nokian Tyres plc., 1999), i.e. the hysteresis phenomena can be observed when a rubber compound undergoes repeated strain. A rolling tyre deforms when it contacts the pavement surface and recovers when it leaves the contact area. Therefore, rubber compounds of the tyre rapidly repeat the process of straining when the tyre is rolling on pavement. This process consumes energy which ends up as heat. Rolling resistance is not only caused by the deformation of the tyre. Bendtsen (2004) summarized three main mechanisms influencing rolling

resistance:

[1] The macro deformation of tyre

[2] The micro deformation in the contact area between tyre and pavement

[3] The slippage friction in the contact area between tyre and pavement\Sandberg (1997) also indicated that road surface texture needs to be considered in the rolling resistance calculation or simulation. Benbow et al (2007) stated that stiffness, texture and temperature have a quantifiable influence on rolling resistance.

PRIMARY CAUSES OF ROLLING RESISTANCE : A characteristic of a deformable material such that the energy of deformation is greater than the energy of recovery. The rubber compound in a tire exhibits hysteresis. As the tire rotates under the weight of the vehicle, it experiences repeated cycles of deformation and recovery, and it dissipates the hysteresis energy loss as heat. Hysteresis is the main cause of energy loss associated with rolling resistance and is attributed to the viscoelastic characteristics of the rubber.

-- National Academy of Sciences

This main principle is illustrated in the figure of the rolling cylinders. If two equal cylinders are pressed together then the contact surface is flat. In the absence of surface friction, contact stresses are normal (i.e. perpendicular) to the contact surface. Consider a particle that enters the contact area at the right side, travels through the contact patch and leaves at the left side. Initially its vertical deformation is increasing, which is resisted by the hysteresis effect. Therefore an additional pressure is generated to avoid interpenetration of the two surfaces. Later its vertical deformation is decreasing. This is again resisted by the hysteresis effect. In this case this decreases the pressure that is needed to keep the two bodies separate.

The resulting pressure distribution is asymmetrical and is shifted to the right. The line of action of the (aggregate) vertical no longer passes through the centers of the cylinders. This means that a moment occurs that tends to retard the rolling motion.

Materials that have a large hysteresis effect, such as rubber, which bounce back slowly, exhibit more rolling resistance than materials with a small hysteresis effect that bounce back more quickly and more completely, such as steel or silica. Low rolling resistance tires typically incorporate silica in place of carbon black in their tread compounds to reduce low-frequency hysteresis without compromising traction. Note that railroads also have hysteresis in the roadbed structure.

III. ROLLING RESISTANCE COEFFICENT:-

The "rolling resistance coefficient", is defined by the following equation:

$$F = C_{rr} N$$

Where

F is the rolling resistance force

C_{rr} is the dimensionless **rolling resistance coefficient** or **coefficient of rolling friction** (**CRF**), and

N is the normal force, the force perpendicular to the surface on which the wheel is rolling.

Table1 : Rolling resistance coefficient due to effects of pavement surface

Road surface	Rolling resistance coefficient
Car tyre	
Concrete, asphalt	0.013
Rolled gravel	0.02
Tarmacadam	0.025
Unpaved Road	0.05
Field	0.1-0.35
Truck tyres	
Concrete, asphalt	0.006-0.01

IV. FACTORS INFLUENCING ROLLING RESISTANCE

Vehicle Velocity

Like the fuel consumption, rolling resistance also has a significant relationship with velocity. experiment has shown that, for a 32-tonn goods vehicle, rolling resistance contributes about 70% of total drag when driven at 50km/h and about 37% at 100km/h, aerodynamic drag contributing the remainder (Gyenes & Mitchell, 1994). The results from the experiment indicate that the main factor determining vehicle fuel consumption is speed. Ejsmont (1990) stated that the relationship between rolling resistance and velocity could be described as

$$F_r = C_1 + C_2 V$$

Where, C_1,C_2 = Constants.

V = Velocity of vehicle.

Temperature : Rolling resistance is affected by both tyre and ambient temperature. The temperature of tyre will be presented first then followed up by ambient temperature. Descornet (1990) measured rolling resistance by using a “quarter-car”trailer which had been designed and tested at the Belgian Road Research Centre. A mutual dependency between RRC and temperature can be found, i.e. RRC values reduced if the tyre had a higher temperature, as shown in Figure. This is logical since a warmed tyre becomes soft and thus, less energy is needed to deform the tyre, which means less energy is consumed in the rolling process. There would also be reduced stress concentration at tyre-pavement contacts and therefore less pavement deformation.

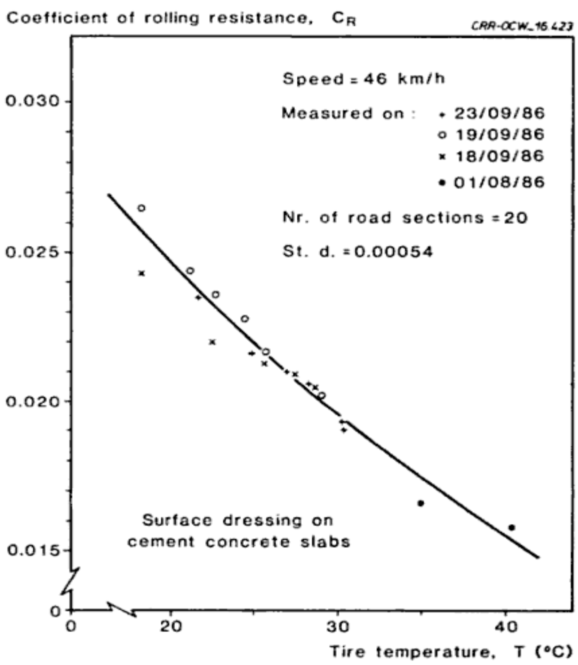
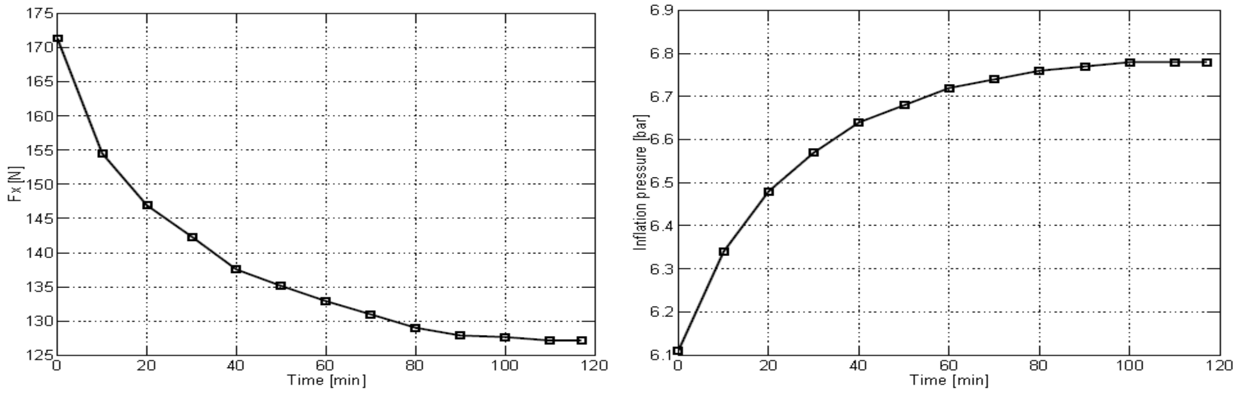


Figure 3 Rolling resistance coefficent Vs Tyre temperature (Descornet, 1990)



(a) rolling loss (b) inflation pressure

Figure 4 Measurement during tyre warm-up (Popov,Cole,Cebon,Winkler, 2002)

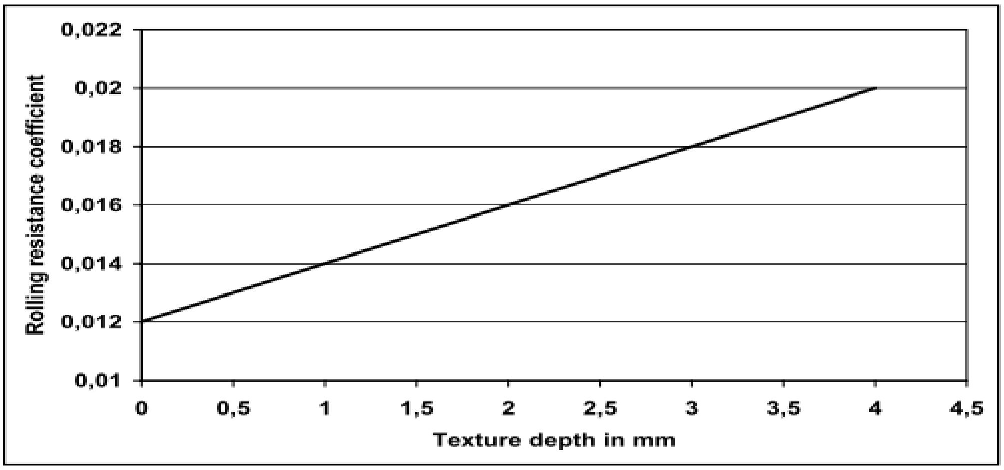


Figure 5 Rolling resistance coefficent Vs Pavement surface condition (Descornet, 1990)

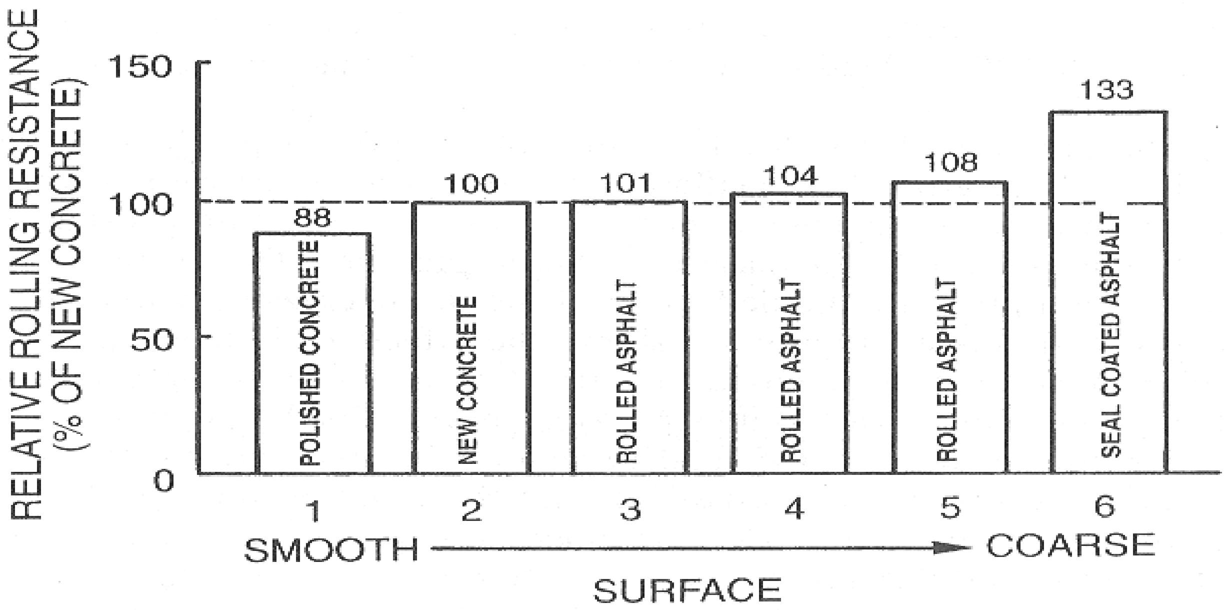


Figure 6 Pavement surface influence on rolling resistance (DeRaad, 1977)

Pavement Surface : An important issue which should not be overlooked is that rolling resistance is affected by the characteristics of the pavement surface. Rolling resistance varies between different pavement surfaces. Hard and smooth surfaces produce lower rolling resistance than soft and rough surfaces. The materials and surface characteristics also affect the rolling resistance (DeRaad, 1977). Figure shows a comparison of relative rolling resistance over a range of pavement surface types. The rolling resistance generated by a new concrete pavement has been defined as a standard value; 100%. The polished concrete pavement achieves the lowest rolling resistance; 88% of new concrete. The polished asphalt is a little higher than the standard, at 101%. The rolled asphalt pavements, number 4 and number 5, are 104% and 108%. The seal coated asphalt has the highest value, 133%. (Shown in above Fig.). Since the frictional characteristics of a pavement surface are influenced by pavement texture (Thom, 2008), pavement texture influences rolling resistance as well. Descornet (1990) stated a linear relationship between rolling resistance coefficient and texture depth by measuring a reference tyre of a trailer, as shown in Figure 2-13. The results show that the rolling

resistance coefficient increases by 0.002 as the depth of pavement texture increases by 1mm.

At Mairepav'03 Symposium in July 2003 in Portugal, A. Woodside, University of Ulster, Northern Ireland, presented a paper about rolling resistance of surface materials affected by surface type, tyre load and inflation pressure

Tyre characteristics	**Tyre Operating Conditions**	**Environmental Conditions**	**Road Surface Characteristics**
<u>**Construction:**</u> - cross ply - bias-belted - radial <u>***Tread:***</u> - compound - pattern - depth - fragmentation	Inflation pressure Load Speed Slip angle Camber angle Driving/braking force Wheel/axle configuration	Temperature Water Snow Ice	Micro-texture Macro-texture Mega-texture Unevenness

Table 2 - Factors affecting rolling resistance Based on Woodside paper Mairepav'03

OTHER MINOR FACTORS UNDER CONSIDERASION: Several factors affect the magnitude of rolling resistance a tire generates: (http://en.wikipedia.org/wiki/Rolling_resistance)

- Wheel radius, forward speed, surface adhesion, and relative micro-sliding.
- Material - different fillers and polymers in tire composition can improve traction while reducing hysteresis. The replacement of some carbon black with higher-priced silica–silage is one common way of reducing rolling resistance.
- Dimensions - rolling resistance in tires is related to the flex of sidewalls and the contact area of the tire For example, at the same pressure, wider bicycle tires flex less in sidewalls as they roll and thus have lower rolling resistance (although higher air resistance)

- Extent of inflation - Lower pressure in tires results in more flexing of sidewalls and higher rolling resistance. This energy conversion in the sidewalls increases resistance and can also lead to overheating and may have played a part in the infamous Ford Explorer rollover accidents.
- Over inflating tires (such a bicycle tires) may not lower the overall rolling resistance as the tire may skip and hop over the road surface. Traction is sacrificed, and overall rolling friction may not be reduced as the wheel rotational speed changes and slippage increases.
- Sidewall deflection is not a direct measurement of rolling friction. A high quality tire with a high quality (and supple) casing will allow for more flex per energy loss than a cheap tire with a stiff sidewall. Again, on a bicycle, a quality tire with a supple casing will still roll easier than a cheap tire with a stiff casing. Similarly, as noted by Goodyear truck tires, a tire with a "fuel saving" casing will benefit the fuel economy through many tread lives, while a tire with a "fuel saving" tread design will only benefit until the tread wears down.
- In tires, tread thickness and shape has much to do with rolling resistance. The thicker and more contoured the tread, the higher the rolling resistance. Thus, the "fastest" bicycle tires have very little tread and heavy duty trucks get the best fuel economy as the tire tread wears out.
- Diameter effects seem to be negligible provided the pavement is hard and the range of diameters is limited.
- Virtually all world speed records have been set on relatively narrow wheels, probably because of their aerodynamic advantage at high speed, which is much less important at normal speeds.
- Temperature: with both solid and pneumatic tires, rolling resistance has been found to decrease as temperature increases (within a range of temperatures: i.e. there is an upper limit to this effect). For a rise in temperature from 30°C to 70°C the rolling resistance decreased by 20-25%.

V. CONCLUSION:-

The rolling resistance depends both on how the tyre is designed (tyre factors) and on different characteristics in the road pavement. Many different **tyre factors** influence the rolling resistance:

- Different shape of the tyre gives different rolling resistance at higher speeds.
- Higher air pressure in the tyre reduces rolling resistance.
- Higher vehicle load gives higher rolling resistance.
- The tyre manufacturers can change the composition of the tyres to achieve a lower rolling resistance.
- A higher ambient temperature reduces rolling resistance.

The type of road pavement and its surface also influence the rolling resistance. Different **surface characteristics** (pavement texture) provides a major contribution to the rolling resistance as does the **structural behaviour** as both bearing capacity and viscoelastic behaviour can influence the rolling resistance. . A hysteresis phenomenon can be observed when viscoelastic materials undergo a load-then-unload process. A typical hysteresis curve of viscoelastic material can be found. The shadow area enclosed by the hysteresis loop represents energy loss. A characteristic of a deformable material such that the energy of deformation is greater than the energy of recovery. The rubber compound in a tire exhibits hysteresis. As the tire rotates under the weight of the vehicle, it experiences repeated cycles of deformation and recovery, and it dissipates the hysteresis energy loss as heat. Hysteresis is the main cause of energy loss associated with rolling resistance and is attributed to the viscoelastic characteristics of the rubber. Materials that have a large hysteresis effect, such as rubber, which bounce back slowly, exhibit more rolling resistance than materials with a small hysteresis effect that bounce back more quickly and more completely, such as steel or silica. Low rolling resistance tires typically incorporate silica in place of carbon black in their tread compounds to reduce low-frequency hysteresis without compromising traction. Note that railroads also have hysteresis in the roadbed structure. Like the fuel consumption, rolling resistance also has a significant relationship with velocity

REFERENCES

[1] 1.Environmental Impacts and Fuel Efficiency of Road Pavements; Industry report March 2004; PREPARED BY - JOINT
[2] EAPA/EUROBITUME TASK GROUP FUEL EFFICIENCY; eurobitume ;EAPA.
[3] 2.THE INFLUENCE OF PAVEMENT STIFFNESS ON VEHICLE FUELCONSUMPTION – Tao Lu; The University of
[4] Nottingham, September 2010.
[5] 3.Synthesis of the Effects of Pavement Properties on Tire Rolling Resistance NCAT, AUBURN UNIVERSITY, RESEARCH
[6] SYNOPSIS–NCAT REPORT 11-05.
[7] 4.A1 Paper Plc. (2006). Small Fleet Performance Management Tool (SFPMT) helps A1 Paper improve efficient. Department
[8] for Transport.
[9] 5.Ang-Olson, J., & Schroeer, W. (2002). Energy efficiency strategies for freight trucking: Potential impact on fuel use and
[10] greenhouse gas emissions. Transportation Research Record (1815), 11-18.
[11] 6.Bang, J. R. (1990). Reduction in Automobile Fuel Consumption. OECD/IEA Informal Expert Panel on Low Consumption

[12] Low Emission Automobile, Proceedings of an Expert Panel, Rome , 14-15.
[13] 7.Bamberger, R. (2005). Automobile and Light Truck Fuel Economy: The CAFE Standards. CRS Issue Brief for Congress.
[14] 8.Benbow, E., Iaquinta, J., Lodge, R., & Wright, A. (2007). Investigation of the Effects of Pavement Stiffness of Fuel
[15] Consumption. TRL Limited.
[16] 9. http://en.wikipedia.org/wiki/Rolling_resistance
[17] 10.FUEL CONSUMPTION & ENERGY DISSIPATION THROUGH ROAD PAVEMENT CHARACTERISTIC- Dipanjan Mukherjee; ISRJ,June,14