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Review on Effect of Pavement Characteristics on Fuel Consumption

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Abstract: ***Effect of pavement on vehicle fuel consumption in the literature represents the interest of the engineering community in making pavements, more fuel efficient through which sustainability could be maintained in the environment. The literature reviewed in this article covered the effect of pavement characteristics such as Smoothness, Texture, and type of pavement on rolling resistance. Methods used by the authors in the previous studies includes literature review, Field experiments, Lab experiments and modeling and the scopes of the studies extended from smoothness and texture to pavement characteristics. Existing literature establish a relationship between pavement properties and fuel economy. Smoothness and texture affect the rolling resistance most, the effect of smoothness is positive and that of texture is negative. But in most of the studies the effect of structural property such as stiffness or pavement type does not provide a significant difference in fuel consumption between flexible and rigid pavement and require more rigorous work in the area.***

Keywords: Texture; Smoothness; Pavement; Fuel Economy; Rolling Resistance; Sustainability.

I. INTRODUCTION

On the basis of study conducted by Nielsen (2014), data released by press information bureau of India, Ministry of Petroleum & Natural Gas revealed that 70% of Diesel and 99.6% of the total petrol consumed in India by transport sector only. It has been the major challenge for the auto industry to satisfy customer demand as well as to maintain sustainability by taking care of carbon emissions and reducing fuel consumption side by side, these are directly related to the fuel economy i.e. less fuel consumption lesser will be the carbon emissions. It is not simple as it looks like, according to the movement of vehicle is affected by various factors such as rolling resistance, inertial forces, internal friction force, aerodynamic forces, gravity forces on slopes, Köppen (2009). All these forces need to be studied, so that overall fuel economy could be increased in an efficient way. This literature review is mainly focused on rolling resistance as a factor affecting fuel consumption on a different type of pavements. According to Schuring (1977), rolling resistance is "the mechanical energy converted into heat by a tire moving for a unit distance of roadway". Free body diagram is shown in Figure 1 which represents, F (Force applied to axle), R (Reaction force), W (Vertical load), and r (radius of wheel).

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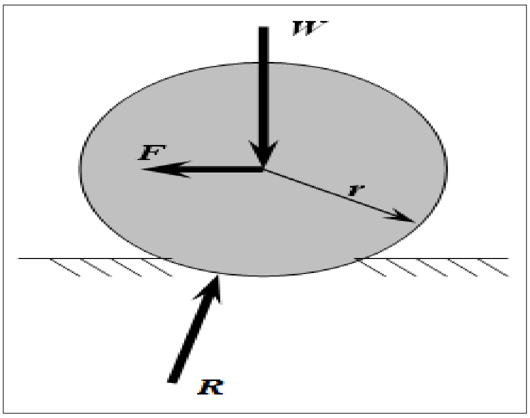

Figure 1: Free Body Diagram of Rolling Resistance (Source: Wikimedia)

National Research Council (2006) defined rolling resistance by following equation;

$F = C_{rr} N$

Where

F = Rolling resistance force

C_{rr} = Coefficient of rolling resistance

N = Normal force

There is an energy loss due to friction between tire and pavement, rotation of tires, aerodynamics,

Drag, temperature change, speed and inflation pressure and rolling resistance. Beauving et al. (2004) from the Figure 2, given by Michelin (2003), illustrate that for a vehicle running at a speed of 28 m/sec, air drags (F_d) consume three-fifth, rolling resistance (F_{RR}) consume one-fourth and internal friction (F_v) consume almost one-sixth of the total energy generated by engine of a vehicle to move in forward direction on horizontal surface.

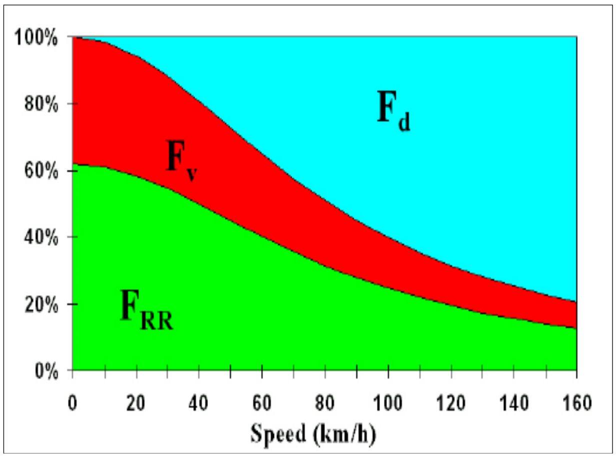

Figure 2: Energy consumption (%) due to rolling resistance (F_{RR}), air drags (F_d) and internal friction (F_v) at a constant speed. Michelin (2003)

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It shows that, as the speed of the vehicle increases air drag will be the most dominating factor in energy consumption but apart from vehicle properties pavement properties also affects rolling resistance such as texture, roughness and stiffness of the pavement. Figure 3 shows different types of texture in pavement. OECD (1989) found that texture induces vibration and smoothness, both affects fuel consumption of the vehicle. Schmidt (2010) illustrates that when tires came in contact with the pavement, stiffness or deflection affects rolling resistance and then affects fuel consumption. Van Dam et al. (2015) measured roughness is measured by International Roughness Index (IRI) and has a great impact on fuel economy. According to Federal Highway Administration (FHWA) report, 10% reduction in IRI value results in 4.5% of fuel saving.

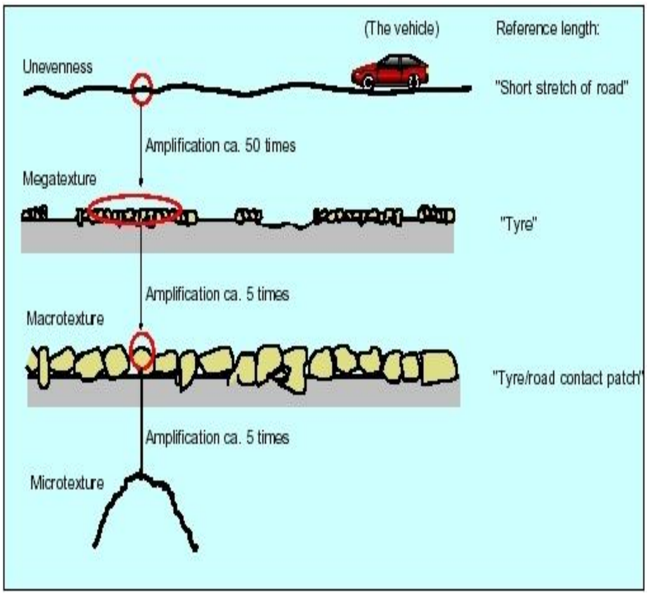

Figure 3: Different Textures and Unevenness in Pavements. Sandberg (1990)

II. OBJECTIVE

The main objective of this review is to find out the answer of two questions, how different pavement factors affect rolling resistance? And what is the difference in fuel consumption among different types of pavement such as flexible and rigid. It is being done by reviewing available literature on effect of pavement properties such as stiffness, texture, and smoothness on fuel consumption of the vehicles on different pavements for different categories of vehicles i.e. heavy and light. It covers various methods used by the authors such as lab experiments, field experiments, literature review and modeling.

III. LITERATURE REVIEW

Deraad (1978) identified major factors such as design, load, speed, inflation pressure, steer, temperature of the tire respectively and surface type and aggregates used these all contributes to tire rolling resistance. The main focus of the study was to assess, how surface texture affects rolling resistance. It was found that rolling resistance was reduced by 8% on newly constructed concrete surface in contrast to highly textured asphalt pavement, which means that higher texture leads to higher rolling resistance but also suggested that there is a need of safety considerations during wet conditions. The limitation in this study was that only two concrete surface were used with smooth macrotexture and asphalt surface used which has medium macrotexture and also speed of the vehicles used were not as per standard of the highway. Zaniewski et al. (1982) found that for test truck fuel consumption increased by 20% when changing from asphalt concrete to plain cement concrete but again Zaniewski (1989) reported opposite results to the study in 1982 by same author that there is no significant difference i.e. only 1% in fuel consumption between asphalt concrete and plain concrete both the statements were contradictory to one another, major limitations were no characterization of pavement structure and the roads used were in good condition. Bester (1984) used experimental cost down method and found that difference in type of pavement has very small effect on rolling resistance as compare to surface treatment, it means that surface texture plays major role and more the smoothness less will be rolling resistance, some of the limitations were no characterization of pavement or material and no statistical analysis was done. Lu (1985) found that 10% more energy is required to move vehicle forward on rough roads as compare to smoother roads also realized that high speed and roughness affects rolling resistance but slow speed does not affect the same but the model used in this study was not validated by field study. Du Plessis et al. (1990) studied 77 observations on 26 different sections of roads and revealed that increasing tire temperature, decreasing roughness and decreasing texture all results in decreasing rolling resistance conclude that road surface characteristics affect rolling resistance up to 7% but no statistical analysis was done. Sandberg (1990) in vehicle fuel economy study the test was conducted at vehicle speed of 14 m/sec, 17 m/sec, and 19 m/sec and concluded that there may be difference of up to 11% in fuel consumption from smoother to rougher roads and texture could affect fuel consumption by 7%. It was observed that mega-texture was more influential than macrotexture i.e. macrotexture was only effective at speed of 17 m/sec as shown in Figure 4.

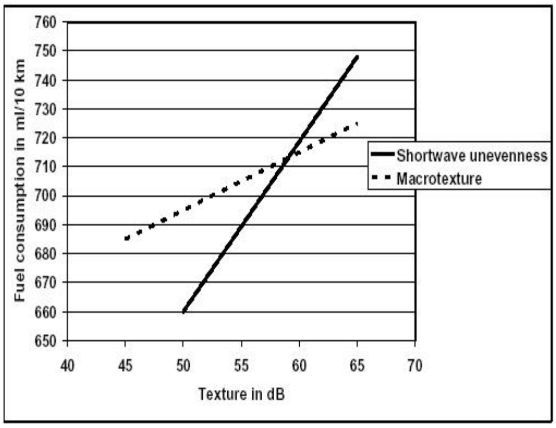

Figure 4: Fuel Consumption Versus Texture at 17m/sec. Sandberg (1990)

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Sandberg et al. (2011) demonstrates that road surface quality i.e. megatexture and roughness had significant impact on fuel economy and suggested that stiffness cannot be excluded in factors affecting rolling resistance in the modeling. Limitations were that concrete was not tested and standard texture measurement unit were not used in 1990 and pavement structure was not assessed in 2011. Laganier and Lucas (1990) conducted three phase research and in all the phases fuel consumption was affected by surface texture and smoothness and can make difference up to 10% in fuel consumption also concluded that both smoothness and texture are equally important but the methods and units used in study for texture measurement are not in use now a days. Descornet (1990) measured the effect of megatexture and macrotexture on rolling resistance as shown in Figure 5 and concluded that megatexture and macrotexture can influence rolling resistance by almost 47% also it was found that there is a linear relation between rolling resistance and fuel consumption as show in Figure 6 and found that reducing rolling resistance can save fuel up to 9%, relation between in this study no statistical analysis was present.

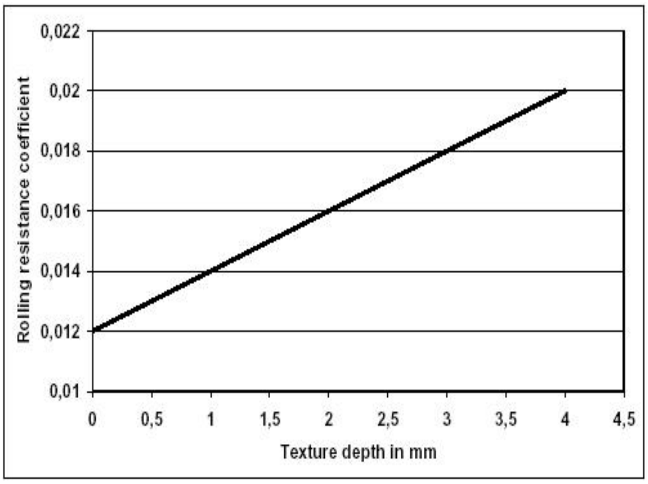

Figure 5: Texture Versus Rolling Resistance. Descornet (1990)

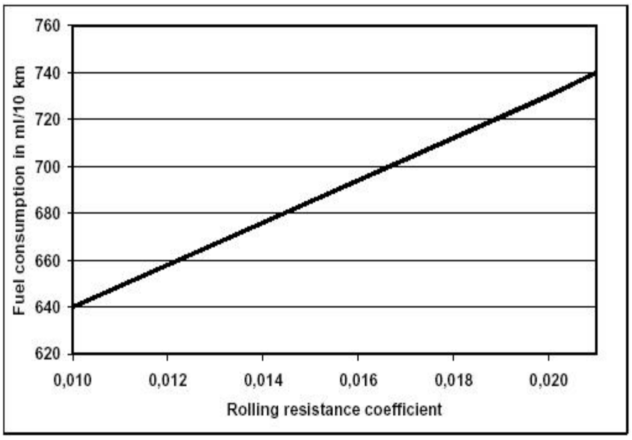

Figure 6: Rolling Resistance Versus Fuel Consumption. Descornet (1990)

Delanne (1994) assessed the effect of macrotexture and smoothness on vehicle fuel economy and found that fuel consumption increases exponentially with increasing texture and unevenness. It was measured that 1.55 mm increase in texture leads to 50% increase in rolling resistance. Reduction in smoothness or increase in roughness can increase up to 6% fuel consumption and increase in macrotexture can increase up to 5% of fuel consumption as shown in Figure 7 but no statistical analysis was done in this study. Cenek (1994) used study torque method of measuring rolling resistance, torque, wind speed, direction of wind and suspension losses were measured and found that 1 mm increase in texture and with smoothness of 1 m/km could increase rolling resistance by 44% and 2 mm increase in texture could be disastrous because of non-linear equation, in this study characterization of pavement was not done by the author. De-Graaff (1999) used fully fueled and instrumented passenger car running at 25 m/sec speed and observed that there is no statistical difference between porous and dense graded mixtures in terms of fuel consumption; also there were no significant difference after considering texture as a factor. Sime (2000) found that different textures may influence fuel consumption up to 10% for heavy vehicle but difference in fuel consumption is not statically significant for passenger car. Author also suggests that both heavy vehicles and passenger cars together can significantly increase fuel economy. Taylor et al. (2000) assess the influence of various factors such as structure of the pavement, speed of the vehicle,

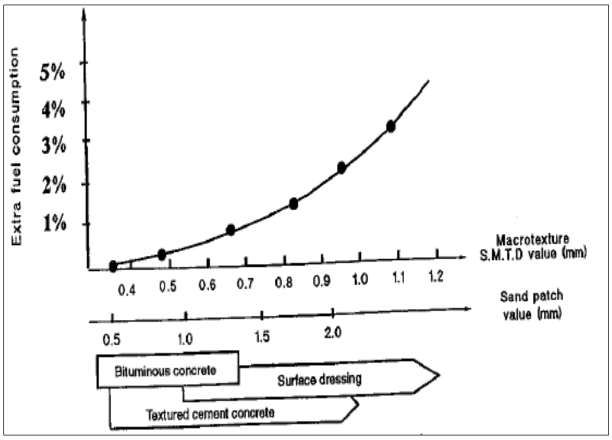

Figure 7: Macrotexture Versus Fuel Consumption. Delanne (1994)

Load of the vehicle, and circumstantial temperature, on vehicle fuel economy and found that 11% more fuel consumption by heavy loaded semi-trailer on asphalt pavement as compared to concrete but additional analysis by Taylor et al. (2002) corrected its result and suggested that there is extra fuel consumption of 4.1%-4.9% on bituminous pavement as compared to concrete but the study was limited to less accurate roughness measurement and short test sections. Lindahl and Goos (2002) claimed that the asphalt pavement section used by Taylor et al. (2000) in Phase-II study was in worst condition and produced biased results in favor of concrete pavement. Starling (2001) found in national center for asphalt research report that rough roads adds up to 10% in fuel bills. In a report by NPC (2002), it has been cited that there is impractically more dissipation energy occurs on asphalt pavement in contrast to concrete pavement and concluded that there is 0.05% more fuel consumption for vehicle

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on asphalt pavement as compare to concrete due to energy dissipation and shows contradictory results to report by Taylor et al. (2002) but the results by National Research Council of Canada (NRC) were limited to summer and spring season and not for winter. Mckeown (2002) stated that increasing pavement surface deflection from 60 micron to 98 micron can lead to 28% more fuel consumption. Jackson et al. (2005) through international cybernetics corporation suggested that if smoothness increased by two times than 16% fuel saving can be achieved and if increased by four times than 5.2% increase in fuel saving can be done. Heffernan (2006) after measuring fuel economy for 2 years found that rough tracks leads consume more fuel for vehicle, by increasing smoothness by 10 m/km, there will be 0.5 miles per gallon of fuel economy. Taylor and pattern (2006) found that heavy goods lorry running with 28m/sec, saves 1.8% fuel on an average on concrete pavement as compare to asphalt and also save 3.1% fuel as compare to composite(asphalt top over concrete) and at 17 m/sec save 3% as compare to asphalt and save 6% fuel as compare to composite pavement. Limitations in this study were that different grades of concrete and asphalt were not considered and parameters such as surface wear, concrete lining, friction or cross-section of pavement irregularities, potholes, ruts or bumps and chemical and physical properties were also not considered. Amos (2006) in a study initiated by Missouri Department of Transportation, difference in fuel consumption by dump truck before and after resurfacing of pavement as shown in Figure 8 and fuel consumption was recorded and smoothness of the pavement was measured by Automated Road Analyzer (ARAN) and it was observed that 53% improvement

Figure 8: Road Surface Before (Left) and After (Right) Resurfacing. Amos (2006)

In smoothness leads 2.46% less fuel consumption by dump trucks. Also driver comfort and control improved dramatically and number of breaks application was reduced in night time. Only one type of vehicle were used in the study i.e. dump trucks and analysis on statistical data was not conducted. Benbow et al. (2007) in Transport Research Laboratory as a test facility found that deflection decreased by 28 micro meters at 50000 N load and 283 K of temperature results in decreasing of rolling resistance. This suggest a decrease of 1.14% in fuel consumption on concrete pavement in contrast to asphalt pavement and this fuel consumption on a given road is proportional to road length, number of vehicles travelling and rate of fuel consumption for different vehicles. Also increase in texture by 0.44 mm will lead to 0.71% less fuel consumption. Other factor considered was temperature i.e. if temperature increase of 273 K per year will results in reduction in fuel consumption of 0.016% per year which not significant on flexible pavements. Perriot (2008) made critical review on literature that claims cement concrete pavement as more efficient in fuel economy as compare to asphalt pavement for example Abdo (2005) claimed that on rigid pavement fuel consumption gets reduced up to 15% as compare to flexible pavement, another study by Cimbéton (2007) also shows similar results to phase –III study by Taylor and pattern and shows that plain cement concrete (PCC) pavement consume 0.88% less fuel in contrast to asphalt pavements. Perriot identified some of the factors which influence rolling resistance such as Structural characteristics (energy dissipation by friction between tire and pavement, deformation of tire, shock absorbers respectively), and structural property (viscoelasticity) of the pavement. Perriot argued that energy dissipation is only because of viscoelastic nature of bituminous pavements rather than tire-pavement contacts area because greater is flexibility of bituminous mixes less dependency contact area for dissipation of energy. Author concludes that to reduce the rolling resistance, small wavelength evenness must be targeted instead of less reliable hypothesis such as nature or stiffness of the pavement. Stubstad (2009) presented a study conducted by California Department of Transportation (Caltrans) which shows that for every 5mph decrease in speed fuel saved was 6% in favor of plain cement concrete(PCC), for every 50 inch/mile decrease in International roughness index(IRI) 1.8% to 2.7% fuel was saved in favor of diamond grinded PCC and every increase of 27.57 KPa pressure in tire results in 1% to 1.7% less fuel consumption on PCC and asphalt pavements individually but if comparison in fuel consumption between PCC and asphalt pavement in terms of tire pressure is done there is no significant difference observed in the study. Pavement texture was not considered in the study. Newcomb (2009) concluded from previous studies that Smoothness plays a crucial role in vehicle fuel economy. Also it was identified that by making roads smoother, 7 billion gallon of fuel per year could be saved which is equivalent to fuel consumed by 10 million vehicles every year. Sumitsawan et al. (2009) studied urban driving cycles at non-highway speeds, observe vehicle with constant as well as accelerating speeds. Data presented shows that there is on an average 5% less fuel consumed on concrete as compare to asphalt pavement at constant speed but there is no statically significant difference for accelerating vehicle in terms of fuel consumption on both the pavements. Also it was found that at 13 m/sec, concrete had a great fuel economy with 10% level of significance but in this study pavement structure was not considered. Hultqvist (2010) after measuring fuel consumption found that on concrete section fully loaded lorry consume 6.7% less fuel and passenger car consume 1.1% less fuel as compare asphalt pavement. These results are similar results in previous studies claiming concrete pavement consume less fuel as compare to asphalt, but asphalt pavement used in this study has double the texture as compare to concrete pavement and was not in good condition. Yoshimoto (2010) found that 3.4% fuel saved by heavy goods vehicle on concrete pavement as compare to asphalt along with significant savings in fuel consumption concrete pavement provide smoother ride in contrast to asphalt pavement.

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Thom et al. (2010) use 3D finite element model as shown in Figure 9 and was analyzed and effect of structural stiffness of the pavement on fuel consumption was assessed. It was found that effect of sub-grade stiffness is secondary and upper layer stiffness is more for both asphalt and concrete pavement with factor with significance of 1.7 to 4.5. In this study it was observed that energy loss is more in summer days as compare to winter. The study predicts that the energy lost from a concrete pavement is 350MJ/m and from asphalt pavement is 900MJ/m at a moderate temperature which concludes that there is a saving in energy of 550MJ/m in concrete as compare asphalt. In this study, only pavement deflection was considered and texture and other tire properties were not an author suggested more detailed experiment on these parameters.

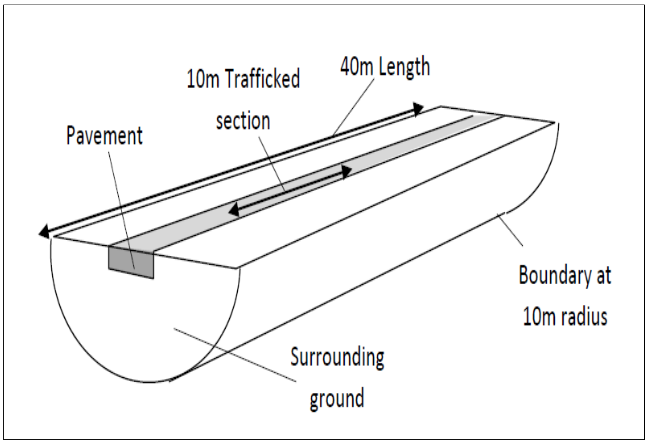

Figure 9: 3-D Finite Element Model. Thom et al. (2010)

Zaabar and Chatti (2011) used five different vehicles on five different locations to assess the effect of texture on fuel economy in relation to smooth and flat pavements. The IRI on these pavements ranged between IRI of 0.8 and 6.0 m/km for AC pavements and texture of 0.23 mm to 1.96 and for PCC pavements IRI was taken as 0.8 and 2.5 m/km and texture as 0.23 to 2.7 mm. the authors used analysis of covariance (ANCOVA) to estimate, how roughness and texture affects fuel consumption. It was concluded that for both light and heavy trucks in summer conditions at the speed of 16m/sec, the grade, IRI and texture all were statistically significant, but not at 20 m/sec and 25 m/sec speed. The result for winter season is not present in the study. Pouget et al. (2011) used finite element modeling along with a linear viscoelastic (LVE) model for enabling simulation of pavement behavior under load of 40 Ton Truck for estimation of extra fuel consumption due to dissipation of energy at the time of passing. At a speed of 28 m/sec and at temperature of 336K (summer condition) the dissipated energy was at peak which causes fuel consumption of 5.5% in excess. At 288K (mean reference temperature in France) and with same speed, 0.25% excess fuel was consumed. It was concluded that at purely elastic condition i.e. (at very low and very high temperatures) excess of fuel consumption was negligible (less than 25%). Akbarian and Ulm (2012) used mechanistic approach to prosper relation among pavement deflection and structural as well as materialistic properties of pavement. Federal Highway Administration's (FHWA) Long-Term Pavement Performance (LTPP) program was used as main source of the data and it was calibrated using wave propagation methodology. An infinite beam loaded with non-deformable tires on viscoelastic foundation was assumed. It was proposed that more deflection leads to more fuel consumption, then the model was applied to entire LTPP database and use Monte Carlo simulation and concluded that stiffer and rigid pavement can reduce fuel consumption by 4%. Major limitation was that model was not accurate to the significant validation and it was not clear that whether subgrade reaction or subgrade modulus is used. Greene et al. (2013) found that all common pavements unlike concrete deteriorate the same way. With additional complexity of Traffic volume more significant differences unfolded within the pavement. Also, the study suggests that roughness has a significant impact on fuel economy as it was recorded that, an increase in fuel consumption of 70,564 L/km over a test period (1990-2004) was there. Jiao (2013) reports that average fuel consumption gets reduced by 3.2%-4.5% for passenger car and tractor-trailer on concrete as compare to asphalt pavement due to deflection and stiffness considerations, but author was failed to explain why percentage of fuel consumption saved was more at lower temperature i.e. (290, 293, 295, 298, 299, and 300K) as compare to 302K. This may be due to wind speeds considered in the study along with temperature but it was not explained in the study.

IV. SUMMARY OF REVIEW

The literature review is summarized in Table 1, Table 2 and Table 3 as the effect of smoothness, texture and pavement type on rolling resistance respectively. Some of the studies repeated in the tables due to multiplicity of the scope in one study. Willis et al. (2015) in a review concluded that the influence of all three pavement properties i.e. texture, smoothness, and stiffness on rolling resistance are not considered together and how these properties affect the fuel economy. Willis also suggests that above three properties are independent of each other and at the time of observation of the effect of one; other two parameters cannot be controlled during modeling.

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Table1: Effect of Smoothness on Rolling Resistance

Study	Method of Study	Scope of Study	Findings of Study	Limitations
Bester, 1984	Field Test	Smoothness and Pavement Type	Smoothness had effect on rolling resistance values	Data was Limited, no characterization of pavement
Lu, 1985	lab Test and modeling	Smoothness	Smoothness and speed of vehicle together affect rolling resistance; Rougher roads consume 10% more energy of vehicle	No validation of the model, Limited pavement properties.
Laganier and Lucas, 1990	Lab Test and Field Test	Texture and smoothness	Smoothness and texture both are critical for fuel consumption	Standard measurement used for smoothness and texture are obsolete nowadays.
Sandberg 1990	Field Test	Texture and smoothness	Smoothness affects fuel consumption by more than 12%.	Texture measurements were not standard.
Du Plessis et al. 1990	Field Test	Texture and smoothness	Texture and smoothness affect fuel consumption 7%.	No statistical data, No standard measurement of smoothness
Delanne, 1994	Lab Test and Field Test	Texture and smoothness	Smoothness could affect fuel consumption by 6% and texture can affect fuel economy by 5%.	No statistical data, No standard measurement of smoothness
Cenek, 1994	Field Test	Texture and smoothness	The relationship between smoothness and texture is non-linear.	Limited study on Pavement characteristics
Amos, 2006	Field Test	Smoothness	Improvement in fuel economy by 2.46% after resurfacing for dump trucks.	No statistical data available.
Heffernan, 2006	Field Test	Smoothness	Rough tracks consume more fuel as compare to smoother one.	No consideration of Texture.
Zaabar and Chatti, 2011	Field Test	Texture, Smoothness, Pavement Type	Smoothness and texture were both significant in reducing fuel consumption at slow speeds in summer.	Data for winter season was not present.

Table2: Effect of Texture on Rolling Resistance

Study	Method of Study	Scope of Study	Findings of Study	Limitations
Deraad, 1978	Lab Test and Field Test	Texture	Rolling resistance is higher on textured surfaces	Limited speeds, limited Texture
Laganier and Lucas, 1990	Lab Test and Field Test	Texture and Smoothness	Smoothness and texture both are critical for fuel consumption	Standard measurement used for smoothness and texture are obsolete nowadays.
Sandberg 1990	Field Test	Texture and Smoothness	Smoothness affects fuel consumption by more than 12%.	Texture measurements were not standard.
Descornet, 1990	Field Test	Texture	Texture could affect fuel consumption by 9%.	No statistical data available
Du Plessis et al. 1990	Field Test	Texture and Smoothness	Texture and smoothness affect fuel consumption 7%.	No statistical data available

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Delanne, 1994	Lab Test and Field Test	Texture and Smoothness	Smoothness could affect fuel consumption by 6% and texture can affect fuel economy by 5%.	No statistical data available
Cenek, 1994	Field Test	Texture and Smoothness	The relationship between smoothness and texture is non-linear.	Limited study on Pavement characteristics
De Graaff, 1999	Field Test	Texture and Smoothness	Effects of texture can be overcome by other effects	The structural assessment was not present.
Sandberg et al. 2011	Field Test	Texture	Texture had great impact on fuel economy	The structural assessment was not present.
Zaabar and Chatti, 2011	Field Test	Texture, Smoothness, Pavement Type	Smoothness and texture were both significant in reducing fuel consumption at slow speeds in summer.	Data for winter season was not present.

Table 3: Effect of Pavement Type on Rolling Resistance

Study	Method of Study	Scope of Study	Findings of Study	Limitations
Bester, 1984	Field Test	Smoothness and Pavement Type	Smoothness had effect on rolling resistance values	Data was Limited, no characterization of pavement
Zaniewski, 1989	Field Test	Pavement type	In terms of fuel consumption, asphalt and concrete pavement shows no statistical differences.	Non-consideration of pavement characteristics, Study conducted only on good pavements.
De Graaff, 1999	Field Test	Texture and Pavement Type	Effects of texture can be overcome by other effects	The structural assessment was not present.
Taylor, G.W et al. 2000	Field Test	Pavement type	Results in favor of Concrete in terms of fuel economy.	The study was limited to summer and spring.
Taylor, G.W et al. 2002	Field Test	Pavement type	Results in favor of Concrete in terms of fuel economy.	The study was limited to summer and spring.
NPC, 2002	Modeling	Pavement type	Concrete 0.05 percent more fuel efficient	Modeled only spring and summer
Taylor and pattern, 2006	Field Test	Pavement type	Limited difference between concrete and asphalt in terms of fuel consumption	Limited study on Pavement characteristics.
Hultqvist, 2010	Field Test	Pavement type	Up to 6% by heavy lorry and 1% by passenger car savings in fuel consumption on concrete pavement	Asphalt pavement considered had double the texture than concrete.
Perriot, 2008	Literature review, Modeling	Pavement type	No significant difference in rolling resistance between Pavement types.	Verification of model not present.
Thom et al. 2010	Modeling	Pavement type	Pavement stiffness had the great impact on energy dissipation.	Texture, smoothness and contact area not considered
Sumitsawan et al. 2009	Field Test	Pavement type	Concrete more fuel efficient than asphalt at the constant speed but no significant results while accelerating.	Structural properties of pavement not considered

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Zaabar and Chatti, 2011	Field Test	Texture, Smoothness, Pavement Type	Smoothness and texture were both significant in reducing fuel consumption at slow speeds in summer.	Data for winter season was not present.
Pouget et al. 2011	Modeling	Pavement type	Dissipated energy leads to 0.25% more fuel consumption on flexible pavements.	No major limitation
Akbarian and Ulm, 2012	Modeling	Pavement type	More stiff pavements could reduce fuel consumption by 4 percent.	No validation by field test, tire deformation was not considered, Same modeling of Asphalt and concrete, Confusion on k, exaggerated results by Monte Carlo simulation.
Stubstad, 2009	Field Test	Pavement type	6% fuel economy on concrete.	Pavement structural properties and texture were not considered
Jiao, 2013	Field Test	Pavement type	Concrete consume 3.2%-4.5% less fuel.	Non- equivalent pavement structures and Texture was not considered.

V. CONCLUSION

Most of the studies reported that smoother roads tend to reduce rolling resistance and ultimately reduce fuel consumption**.** Federal Highway Administration report suggests that 10% reduction in international Roughness index leads to 4.5% saving in fuels. Caltrans suggests for every 0.8 m/km reduction of smoothness leads to 1.8%-2.7% saving in fuel. Texture has a negative effect on fuel economy**.** It has been observed by the above literature that higher texture leads to higher rolling resistance and ultimately more will be the fuel consumption. Early works established the relation between texture and speed of the vehicle but present studies deny the fact that speed of the vehicle and texture and correlated in terms of vehicle-pavement interaction. Results from the studies on the effect of pavement type and stiffness are not consistent and most of the studies suggest concrete as more effective pavement in terms of energy dissipation but at only higher temperatures and heavy loaded vehicles. At low temperature and with light vehicles more studies need to be done. Some of the studies show insignificant difference between flexible and rigid pavement in term of fuel consumption at low temperatures. Other studies suggest texture and smoothness play major role and it cannot be concluded just on the basis of stiffness that concrete is more efficient in terms of fuel economy. From the above literature review, it is concluded that rolling resistance is mostly affected by smoothness. Effect of texture becomes ineffective on properly constructed and maintained roads and no clear consent can be derived on the effect of pavement type on vehicle fuel consumption.

TERMINOLOGY

1. Stiffness: Baumgart (2000). defined the stiffness of an object as “the extent to which it resists deformation in response to an applied force”.
2. Texture: Deviations from a planar and smooth surface, affecting the vehicle/tyre interaction (Source: Wikipedia)
3. Macrotexture: the texture of the pavement having wavelengths from 0.5 mm to 50 mm. (Source: Wikipedia)
4. Megatexture: pavement wear and distress, causing noise and vibration and has wavelengths from 50 mm up to 500 mm. (Source: Wikipedia)
5. Roughness/ Smoothness/ Unevenness: Undulations in the road surface which can affect drivability. These all are components of texture.

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