THE EFFECT OF ROAD SURFACING CONDITION ON TYRE LIFE.

WJvdM Steyn and M Haw*

CSIR Transportek, PO Box 395, Pretoria, 0001
*Bridgestone SA (Pty) Ltd.

ABSTRACT:

Road engineers usually maintain roads with the objective of supplying a road surface with a certain serviceability standard. This serviceability standard typically include aspects such as the allowable rutting, skid resistance and riding quality of the road. While the road is performing within the set requirements for functional and structural performance, the road is deemed to be in a serviceable condition. Once these parameters are exceeded the road will be maintained using an option ranging from simple patching of potholes and sealing of cracks to a reseal of the road or even recycling and rehabilitation of the failed sections of the road.

These maintenance actions affect the surfacing of the road and therefore the experience of the tyre in contact with the road surface. Tyres are typically designed to operate under specific conditions that include the applied vehicular load, tyre inflation pressure, temperature, allowable tyre deflection etc. It is generally assumed that as long as the road surface is relatively even and the vehicle not overloaded, the tyres will not be overstressed using the road.

Tyre engineers conduct route studies on routes to determine the stresses and strains that a tyre will experience when travelling along the specific route. The route studies include an evaluation of concepts such as the rutting on the road, but also focus on factors causing undue stresses and strains on a tyre using the road. These include the excess heat build-up as a tyre has to traverse uneven surfaces and potholes, the stresses caused by varying surface textures due to differences in road surface type and patches in specific wheel lanes, and the subsequent reduction in tyre life due to use on a specific route.

In this paper some of the aspects typically investigated in such a route study are highlighted, and the typical factors affecting the tyre life discussed. The paper is partly based on experiences with various routes in the country, and it aims to highlight to road engineers and roads authorities the major role that they can play in potentially extending the lives of tyres using their roads, and ultimately in the national economy through lower transport costs and improved safety conditions.

1. INTRODUCTION

It is common knowledge that the only contact between vehicles on roads and the road surfaces are through the tyre contact areas. The intricacies and details of these contact patches are internationally the topic of much research and investigations. In the roads area most of this research focus on the shape and distribution of the stresses between the tyre and the road surface, and on the way these stresses affect the road surfacing and structure. The tyre industry is concerned with the ways that these stresses and strains affect the tyres operating on the various roads. However, not much concern is normally left for the effect of the one party on the other, i.e. the stresses and strains imparted by the road surface on the tyre.

The tyre industry often perform route surveys for clients and prospective clients where they investigate a specific route in order to advice their clients on appropriate tyre choices as well as operational choices and issues in order to make cost-effective use of their investment in tyres. Using information from typical route studies as background, this paper focuses on the effect that various road surfacing features have on the tyre.

The objective of the paper is to highlight to road engineers the effect that their decisions regarding maintenance and rehabilitation (or the lack thereof) of road surfacings may have on the tyre life of road users. Through a better understanding of these tyre-road interaction phenomena, it is anticipated that better informed decisions can be made that should ultimately affect the economy of the country through more cost-effective transport on roads. Various concepts around tyres and road surfacings are addressed in the paper. These concepts are not discussed in detail, as the focus and message of the paper falls on the basic understanding of the tyre-road surfacing interaction phenomenon. More details regarding these concepts can be found in various references that are not cited in this paper. The paper starts with some background on tyres and road surfacings and their interaction, followed by a discussion on typical route study findings. Finally, the potential effects on the economy are briefly highlighted.

2. BACKGROUND ON ROAD SURFACINGS AND TYRES

2.1 Road surfacings

Various types of road surfacings exist. These include various types of seals, asphalt and concrete surfacings. Each of these types of surfacings develops different levels of friction between a tyre and the road surfacing. In simple terms, this friction causes the tyre to develop a contact stress between itself and the road surface, enabling the tyre to roll forward. The friction developed depend on various parameters, including tyre type, tyre material, tyre operating conditions (load and inflation pressure), surface type, surface texture and surface operating conditions (dry / wet conditions, temperature etc).

For the purposes of this paper the focus is on the surface integrity and surface texture of the road. The road surface integrity is defined as the smoothness (i.e. lack of undue unevenness and potholes or similar disruptions in surface integrity) of the road surface. The surface texture can be split into the micro texture and the macro texture. Macro texture is defined by the size, distribution and configuration of the aggregate particles in the surfacing and is normally characterised by wavelengths of between 10^0 and 10^1 mm, while the micro texture is characterised by the degree of surface roughness of the individual aggregate particles (wavelengths between 10^{-3} mm and 10^0 mm) (Williams, 2000).

It is important to realise that the macro and micro texture of the road changes with time. Generally, the macro texture of the road will increase with time and traffic due to the wearing away of binder while the micro texture will decrease due to polishing of aggregate particles. Seasonal changes in these two parameters can also occur (Veith, 1985). Also, surface maintenance on portions of the road surface will cause the macro and micro textures of the new surfacing to differ from that of the existing surfacing. This is especially important if the maintenance work is not performed over the full width of the road, as this will cause the different tyres on a vehicle to operate at different wear rates.

The surface integrity is affected by parameters such as the formation of potholes in the surfacing, mechanical damage to the surface and edge breaks. Ravelling of the surface also affects the surface texture and integrity. Another form of surface irregularity is the shoving of asphalt, causing depressions and ridges on the surface. All of these disruptions in the surface integrity cause the surface that the tyre needs to roll on to be uneven, and thus more flexing of the tyre body. Typical examples of the road surface irregularities highlighted are shown later in the paper.

2.2 Tyres

A tyre consists of combinations of rubber compounds and steel reinforcement. A tyre serves four basic functions on a vehicle (Gillespie, 1992) - It supports the vertical load wheel cushioning against road shocks; it develops longitudinal forces for acceleration and braking; it enables directional change of the vehicle, and it develops lateral forces for braking. When a tyre rolls on a road, several loads and stresses are imparted onto the tyre. This cause the tyre to flex, thereby causing the forces transmitted to the vehicle to be dampened to an extent. This flexing of the tyre causes heat build-up in the tyre. The amount of flexing (and thus heat build-up) is affected by factors such as the tyre load, tyre inflation pressure, tyre construction and road surface profile.

The effects of different tyre types and sizes are not discussed in this paper, as these factors lies outside the region of control of the road engineer. However, it is important to realise that the use of different types of tyres on a vehicle can also give rise to excessive tyre wear and tyre use on the vehicle.

2.3 Interaction between tyres and road

The interaction between a tyre and the road surface is a complicated combination of stresses and strains that depends on both tyre and road related factors (i.e. tyre material and type, vehicle speed, tyre inflation pressure and temperature, road surfacing condition and temperature, road camber, surfacing texture etc. (Clark, 1975). It is not simple to quantify the contact interaction for a tyre / road combination along a route, but, these interactive stresses and strains can be measured and modelled for very specific cases where the various parameters are well defined.

In simple terms, the tyre-road interaction stresses are the resultant of normal and shear stresses distributed non-uniformly over the contact patch. Tractive and lateral forces develop through shear mechanisms while a tyre rolls on a road surface. This gives rise to a friction coupling between the tyre and the road surface. The two mechanisms responsible for this friction coupling are surface adhesion between the rubber and the road surfacing and hysteresis through the deformation of the rubber as it interacts with the unevenness on the road surface. Both these mechanisms depend on a small amount of slip occurring at the tyre-road interface (Gillespie, 1992).

The coefficient of friction essentially indicates the difficulty with which the rubber of the tyre slips over the road surfacing material. This coefficient depends on tyre load, speed, temperature and road surface characteristics (Clark, 1975). Different road surfacing types thus give rise to differences in the interlock (or grip) that the tyre can develop with the road surface (Walker, 1996). This leads to the practical situation where the tyre-road friction between two similar tyres that runs on two different surfacings in the two wheeltracks (or on a dual set of tyres) differs, and thus the stresses on the tyres differ. For a vehicle that attempts to run in a straight line, this means that the tyres on the two axles (or on a dual assembly) run at different speeds, causing one tyre to slip more than the other and subsequent heat build-up in the tyre.

Tyre wear mainly originates from sliding in the rear part of the tyre-road contact patch (Clark, 1975). It is mostly affected by the micro texture of the road surface (Williams, 2000) and tyre temperature (Veith, 1985). The wear is affected by the normal pressure distribution on a tread element, which is directly affected by road surface texture (Walker, 2000). Increased tyre temperature leads to increased tyre wear, and thus, if operation of a tyre on a specific road surface cause excessive heat build-up (i.e. through excessive flexing) the wear rates of the tyre will also increase.

In order to measure the tyre-road stresses a device such as the Stress-In-Motion (SIM™) device can be used (De Beer et al, 2004). The SIM™ device is used to quantify the stresses developed between a (currently slow) moving tyre and the road surface. Typical results confirmed the complicate contact stress patterns (see Figure 1). The SIM™ device has recently also been used to quantify the contact stresses between an uneven surface (simulated edge break) and a tyre (De Beer et al, 2005). In Figure 2 the initial results of this analysis are shown. The data clearly shows that the stresses experienced by the tyre-road combination in such circumstances are highly irregular and different from 'normal' (Figure 1) operation, causing obvious additional stress / strain to both the tyre and the road. Analysis of the data in Figures 1 and 2 indicates an increase in maximum vertical contact stress from 0.85 MPa to 2.1 MPa for the same tyre and similar loading conditions – a 147 per cent increase.

Tyre designers also make use of various software analysis models in their tyre design and analyses efforts (Surendranath, 2003). Analysis of tyre response to so-called misuse situations (i.e. driving through potholes and over kerbs) form part of these analyses (Hanley & Crolla, 2001).

3. ROUTE STUDIES

Route studies (in the context of this paper) are investigations performed by tyre suppliers to evaluate the potential affect of the road condition on the tyres of the vehicles using the specific route. Typically, this may be required to evaluate the suitability of using a certain type or size of tyre on the specific route. Aspects typically evaluated during a route study include the road surfacing condition (i.e. presence of potholes and rutting), road surfacing skid resistance / friction, radii of turns and curves, road width in relation to the potential wheel tracks of the vehicle using the route, terrain undulations and any other objects that can cause excessive stresses to the tyres (i.e. exposed rail crossings, dirt on the road surface etc).

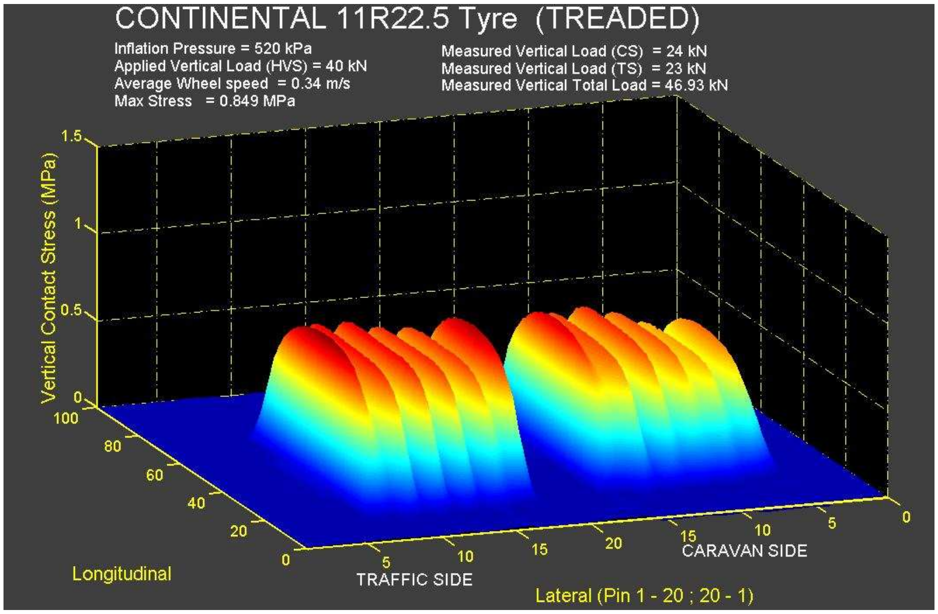

Figure 1: **Typical tyre pavement contact stress measured with the SIM^{TM}.**

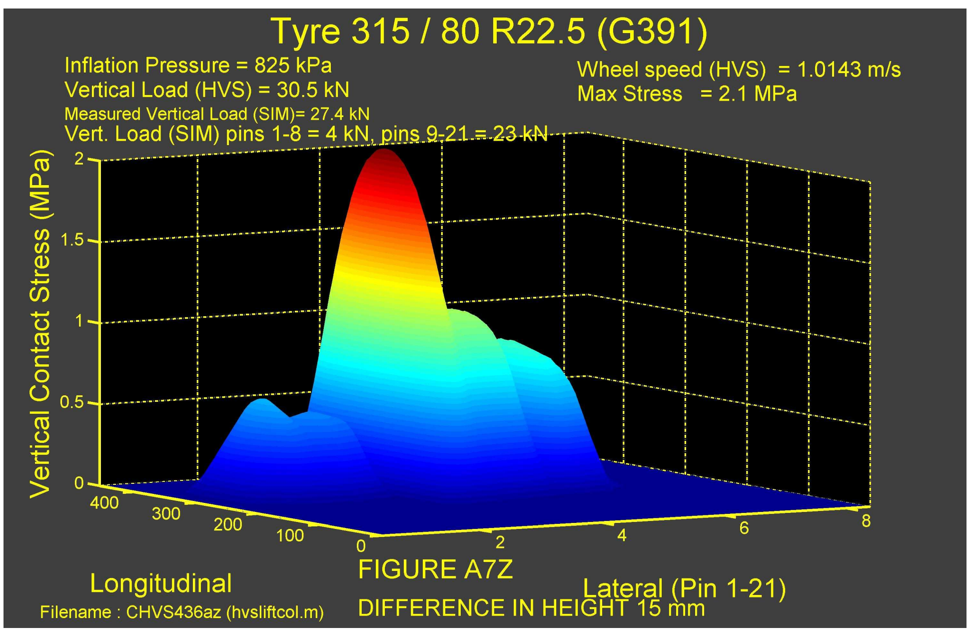

Figure 2: **Typical tyre pavement contact stress for a tyre rolling over an edge break measured with the SIM^{TM}.**

During recent route surveys conducted by Haw (2004), it was found that the following tyre related problems can be expected from operating a vehicle on these two routes:

- Heat related problems

    - Severe heat build-up;
    - Retention of heat by the tyres;
    - Belt-edge separations;
    - Tread and / or total belt separations;
    - Shoulder separations and susceptibility to damage, and
    - Body ply and related component failures.
- Impact related problems
    - Immediate fractures, and
    - Fractures caused by earlier impacts.
- Bead failure
    - Turn-up ply separation;
    - Bead heat separation;
    - Air loss through bead movement.
    - Bead deformation;
    - Cracking between the bead heel and toe, and
    - Burnt beads.
- Irregular wear
    - Increased wear rates, and
    - Tread cracks

The causes for these potential tyre problems are all directly related to road surfacing conditions. The surfacing conditions identified as the main causes were identified as (figures illustrate the problems encountered):

- Unevenness of the road surface due to rutting and shoving
    - On deep ruts the tyres are running inside the rut causing heat build-up due to undue flexing and friction (Figure 3), and
    - Swaying of the vehicle inside ruts causes exaggerated tyre flexing and heat build-up as tyres are running against the rut / shoved material.
- Surface texture difference / varying surfacing types
    - Causing differences in rolling resistance with resultant uneven tyre wear rates;
    - Rougher textured areas causes increased heat build-up in the tread area of the tyre compared to the tyre running on smoother textured areas, and
    - Where surfacing types changes abruptly, the tyre friction is increased and further tyre wear can be expected (Figure 4).
- Patches on the surfacing
    - Causing change in grip between the tyres and surfacing, between tyres on two wheel tracks and conflict across the axle – all of these lead to heat build-up and increased tyre wear.
- Changes in road camber and excessive camber
    - Causing excessive heat build-up due to excessive tyre flexing and overloading of the tyres on one side of the vehicle (Figure 5).
- Sharp corners
    - Causes differential friction changes across tyre treads and between two tyres on a dual set – causes excessive heat build-up and increased tyre wear.
- Potholes, surface imperfections and obstacles (i.e. uneven railway crossings)
    - Pothole size and depth may cause a tyre to totally pass through it and be inside the pothole by deeper than its sidewall height, causing major impact damage (Figure 6);

  - Surface unevenness and obstacles cause impact damage as the tyre runs into and out of the imperfection, and
  - Shoulder edge breaks force vehicles to run across the centreline, causing tyres to run on different cambers and surfacings, or being damaged through impact over the edge breaks (Figure 7).
- Water on the surface (i.e. inside ruts);
  - Prolonged exposure of tyre tread rubber softens the surface layers of the tyre near the rubber / water boundary (Moore, 1975). This has a negative effect on tyre wear;

Often, the type of problems listed above are more prevalent when operating a vehicle with smaller than standard tyre diameters as the tyre has to roll more often for the same distance of travel and therefore issues such as heat build-up gets exaggerated. Tyre failures are not necessarily happening while the vehicle is travelling on the specific route. Often, the damage caused by travelling on the route is initiated due to these specific problems, and only manifest much later when the total accumulated damage caused by the various problems on the surfacings on various routes exceeds the strength of the tyre. Some immediate failures may actually occur. The examples cited should be clear evidence to indicate that road surface condition can cause excessive and undue damage to tyres operating on a specific road.

5. ECONOMIC EFFECTS

It is important to state the effect of the factors discussed in this paper in terms that can be used to convince authorities of the necessity for adequate maintenance on roads, leading to even road surfaces. One way of doing this is to indicate the economic cost of ineffective road maintenance. Nordengen et al (2004) did an analysis to determine the impact of road network deterioration through calculation of the Standardised Vehicle Operating Cost (SVOC) of an ideal network and several actual network conditions. The network condition was expressed in terms of the riding quality (a factor that will reflect many of the road surface irregularities discussed in this paper).

Analyses indicated that the heavy vehicle operating costs on a road network in a deteriorated condition (similar to current South African conditions) is on average 12.8 per cent higher than what it would be on an ideal network (60 per cent of roads in a Good and Very Good condition). These SVOC values include the cost of tyres. The practical effects of unacceptable road surfacing conditions experienced by vehicle owners thus do have a direct effect on the country’s economy.

6. CONCLUSIONS

In this paper it was shown how various road surface irregularities can cause undue and excessive tyre wear and damage. The conditions leading to this tyre deterioration is directly caused by a lack of adequate maintenance of road surfacings. These conditions lead to unsafe and uneconomic operation of vehicles on the road network.

It is imperative that road owners realise that adequate and planned maintenance of road surfacings plays a vital role in the economy of the country, as well as the well-being of its population through provision of safe transport of goods and people.

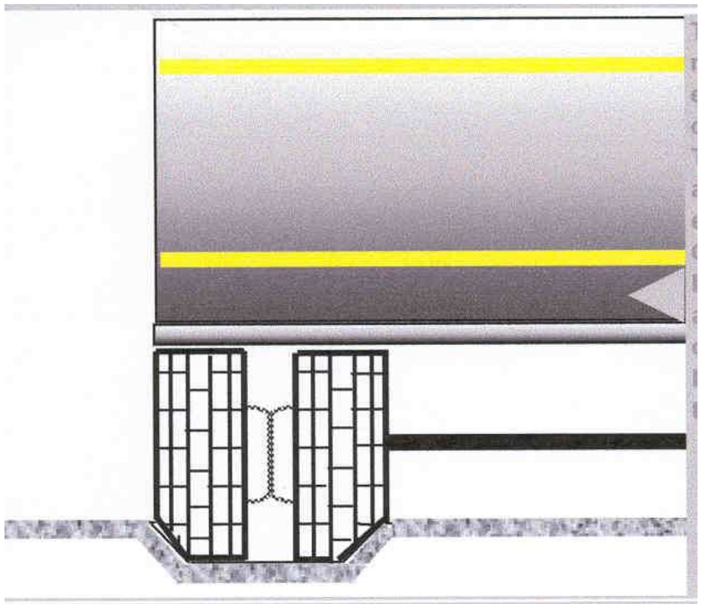

Figure 3: **Increased friction and heat build-up due to tyres running inside a rut.**

Figure 4: **Changes in the condition of the surfacing causing changes in tyre wear.**

Figure 5: **Excessive road camber causing overloading and increased tyre wear through unequal loading.**

Figure 6: **Potholes and unevenness causing tyre impact damage and heat build-up.**

Figure 7: **Edge break causing tyre impact damage and heat build-up.**

7. RECOMMENDATIONS

It is recommended that road owners take cognisance of the effects that the lack of adequate and sufficient maintenance has on other parties such as vehicle owners, and appreciate these costs when planning maintenance of the country's road network. Further, more detailed investigation into the practical issues around tyre-road interaction and provision of tyre-friendly road surfaces should be initiated to ensure that the economy can benefit from better roads in Africa.

8. ACKNOWLEDMENTS

The permission of the Director of CSIR Transportek for publishing this paper is acknowledged, as well as the support and information from Mr Marcus Haw of Bridgestone SA.

9. REFERENCES

Clark, S.K. 1975. Mechanics of pneumatic tyres. US Department of Transportation, NHTSA, Washington, DC.

De Beer, M., Fisher, C. & Kannemeyer, L. 2004. Tyre-pavement interface contact stresses on flexible pavements – Quo vadis? 8th Conference on Asphalt Pavements for Southern Africa, Sun City, 12 to 16 September 2004.

De Beer, M. Sadzik, E.M., Fisher C. and Coetzee, C. 2005. Tyre-pavement contact stress patterns of two types of test tyres used on the Gautrans Heavy Vehicle Simulator (HVS Mk IV^{+}) measured with the Stress-In-Motion (SIM) system. Paper to be presented at South African Transport Conference 2005, Pretoria, South Africa.

Gillespie, T.D. 1992. Fundamentals of vehicle dynamics. Society of Automotive Engineers, USA

Hanley, R. & Crolla, D. 2001. Tire modelling for misuse situations. Tire Technology International 2001, UK & International Press, Surrey, United Kingdom

Haw, M. 2004. Personal communication on client confidential route studies.

Moore, D.F. 1975. The friction of pneumatic tyres. Elsevier Scientific Publishing Company, Amsterdam.

Nordengen, P.A. 2004. Analysis of the impact of a deterioration of the road network on the operating costs of heavy vehicles. Eighth Road Pavement Forum, November 2004, Pretoria, South Africa.

Surendranath, H. 2003. Assessment using finite element analysis. Tire Technology International 2003, UK & International Press, Surrey, United Kingdom

Veith, A.G. 1985. The most complex tire-road interaction: Tire wear. The tire road interface, ASTM Special Technical Publication 929, American Association for Testing and Materials, Philadelphia, USA

Williams, A.R. 2000. Better road transport. Tire Technology International 2000, UK & International Press, Surrey, United Kingdom

CV of presenter

Dr Wynand Steyn is a pavement engineer with a research interest in vehicle-pavement interaction and accelerated pavement testing. He has spent the last 15 years with CSIR in various positions, and enjoys the development of new technologies and research challenges.