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Characterization of pavement texture by means of height difference correlation and relation to wet skid resistance

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ABSTRACT

Driving safety is of utmost importance in the automobile industry and is acknowledged by the introduction of the tire wet grip index as part of the EU tire label. The rubber pavement interaction is determined by the viscoelastic properties of the rubber as well as by the pavement texture. Nowadays available optical surface profiling instruments allow for a detailed measurement of surface roughness covering several length scales. This enables the validation of a mathematical statistical description of pavement texture within the framework of self-affine surfaces and hence provides a holistic characterization of surface roughness covering several length scales within a few characteristic parameters.

We deduce within this article the correlation between classical surface roughness parameters and the parameter set of self-affine surfaces. These parameters allow for a detailed understanding of the relationship between pavement texture and its wet skid resistance. We present wet skid resistance measurements with the British pendulum and a linear friction tester device on different pavement textures. We demonstrate that the so-called estimated texture depth does not correlate to the surface skid resistance measured with the British pendulum. Finally, we deduce a dependency of wet skid resistance on pavement texture which is supported by current models for hysteresis friction.

1. Introduction

The quantitative evaluation of surface roughness is of major interest in various industrial applications. The study of road surface texture is of great importance in pavement engineering as it determines among other factors the noise emission from the tire-pavement interface, the frictional forces that can be transmitted between tire and pavement and the water drainage capacity (ISO 13473-1: 1997, 1997). Typically these different applications require studies of the pavement texture at specific characteristic length scales relevant for the application. The challenge in studying the relationship between the pavement wet skid resistance and its texture

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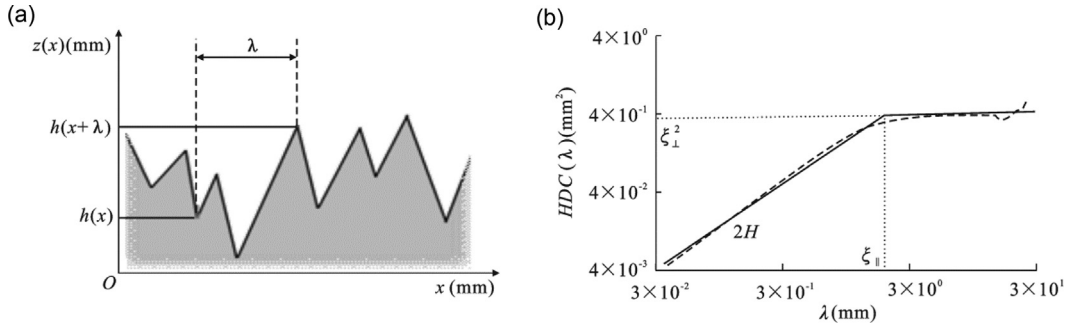

Fig. 1 – Height difference at a given λ and its relationship with $\xi_{\parallel}$, $\xi_{\perp}^2$ and H (Solid line indicates a least squares fit of Eqs. (3) and (4) to $HDC(\lambda)$). (a) Schematic height profile $z(x)$ highlighting the height difference for a given lateral length scale λ. (b) Height-difference correlation function with three characteristic parameters $\xi_{\parallel}$, $\xi_{\perp}^2$ and H.

lies in the roughness characterization for all length scales possibly from centimeter to micrometer. Another challenge lies within the measurement of wet skid resistance. As friction always depends on both contact partners which are sliding with respect to each other (in our case a piece of rubber or tire and the pavement surface), there exists not a unique friction coefficient for a given surface but it depends on the instrument that has been used for the measurement. A friction coefficient measured on a given pavement texture always depends on the rubber properties and in addition also on the measuring conditions (contact pressure, velocity and temperature). Hence, it is obvious that these conditions need to be accounted when the relationship between pavement texture and its wet skid resistance is studied.

2. Statistical description of pavement texture

Recently it has been suggested to describe the pavement texture within the framework of self-affine surfaces (Klüppel and Heinrich, 2000; Persson, 2001). In the following we will introduce the concept of self-affine surfaces and the resulting surface roughness description for this class of surfaces.

2.1. *Texture description for self-affine surfaces*

2.1.1. *Height-difference correlation function*

For a mathematically analysis of the roughness of a surface texture we can assume the height profile $z(x)$ to be self-affine, i.e. for an arbitrary scaling factor Λ the following transformation property holds true

$$x \to \Lambda x, \quad z \to \Lambda^H z \tag{1}$$

where H is the so-called Hurst exponent which is related to the fractal dimension D, $D=3-H$, $0 \le H \le 1$.

Note that for simplicity in Eq. (1) a two-dimensional notation is used. One possibility for the description of the surface roughness of a self-affine surface is to consider the height-difference correlation function

$$HDC(\lambda) = \langle (z(x+\lambda) - z(x))^2 \rangle_x \tag{2}$$

where $\langle \ldots \rangle_x$ denotes averaging over x, $HDC(\lambda)$ describes the mean square height difference of the surface with respect to the horizontal length scale λ.

Fig. 1(a) displays schematically a height profile with the height difference between two points indicated. In the case of a self-affine height profile $z(x)$, the height-difference correlation function can be written as

$$HDC(\lambda) = \left(\frac{\lambda}{\xi_{\parallel}}\right)^{2H} \xi_{\perp}^2 \quad \text{for } \lambda < \xi_{\parallel} \tag{3}$$

$$HDC(\lambda) = \xi_{\perp}^2 \quad \text{for } \lambda < \xi_{\parallel} \tag{4}$$

Here we have introduced the correlation lengths $\xi_{\parallel}$ in horizontal direction and $\xi_{\perp}$ in vertical direction. The power law in Eqs. (3) and (4) follows directly from the definition in Eq. (1) of self-affinity and can therefore be used as a criterion for the self-affinity of a given surface texture. Note that the height-difference correlation function allows for a roughness characterization covering many length scales λ and that it is uniquely determined by the three roughness parameters $H, \xi_{\parallel}$ and $\xi_{\perp}^2$. Fig. 1(b) depicts exemplarily a $HDC(\lambda)$ plot on a double logarithmic scale for a self-affine surface texture with the three roughness parameters indicated.

At small length scales $\lambda < \xi_{\parallel}$, the $HDC(\lambda)$ can be well approximated by the slope from Eq. (3). This implies that the roughness at each length scale λ is increasing in accordance to the slope $2H$ until λ approaches $\xi_{\parallel}$ and the roughness at $\xi_{\parallel}$ then reaches a saturation level $\xi_{\perp}^2$. For length scales $\lambda > \xi_{\parallel}$, the surface roughness (or height difference) is not increasing any more with increasing distance λ between two points of the height profile. Roughly speaking, $\xi_{\parallel}$ corresponds to the mean spacing of the aggregates used in an asphalt grading curve and $\xi_{\perp}$ corresponds to their mean height. We will discuss the meaning of the three parameters in more detail in the following section.

2.1.2. *Practical meaning of $\xi_{\perp}$, $\xi_{\parallel}$ and H for surface texture*

The HDC comprises several important features for the rigorous description of pavement texture. In Fig. 2(a) and (c) we present two height profiles which have been manipulated numerically. The impacts of these changes on