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Top topography surface roughness power spectrum for pavement friction evaluation

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ABSTRACT

This article deals with the most suitable calculation procedure for top topography surface roughness power spectrum (PSD). The information top PSD provides about the roughness characteristics and its practical application in tyre-road friction studies are covered. The influence of portions of top topography used for calculations on the realization these PSDs give about surface height distributions is investigated. Results of roughness PSDs generally proved to be dependent on portions of top topography used for calculations. A high correlation with an average around 0.8 was found with friction and top 20% of PSDs, but only at a short-scale surface roughness $\lambda \le 1$ mm. Low correlation coefficients between friction and longer λ were discussed through the depth of the penetration of the rubber into each pavement.

1. Introduction

Rubber friction has long attracted the interest of many physicists, tyre experts and pavement engineers. With the recent development of the theories of rubber friction and contact mechanics [1–7], the complexity of the relation between road surface roughness and rubber friction is now more highlighted than before. Although many experimental works have addressed this connection [8–20], the multiscale nature of the pavement surface roughness and the partial contact of the tyre rubber with this roughness profile make it difficult to explore meaningful relations between friction and simple roughness indicators.

When dealing with this, the first step is to introduce roughness indicators that can fully characterize the top surface topography (tyre-road contact zone) on different length scales. Persson [2] employed the surface roughness power spectrum (PSD) for the characterization of randomly rough surfaces in multiscale and developed a theory of rubber friction for the sliding of a rubber block on a rough surface, with roughness on many different length scales. Chen and Wang [8], applying PSD to study the evolution of the surface profile of aggregates in the laboratory polishing process, reported changes in the micro-roughness as the main contribution to the loss of friction. However, Mahboob Kanafi et al. [15], employing the same roughness characterization method in a field experiment, concluded that the macro-/micro-roughness variations of road pavements occur within the full surface topography and not exclusively on the top profile; thus, observing a pattern between full-profile PSD variations and the evolution of friction still remained a challenge in actual field conditions. In the field experiment of Hartikainen et al. [13], frequency-wise correlation of pavement friction with the PSD calculated only on the top profile (a technique first introduced by Persson et al. [21]) was conducted, with the highest correlation being found at the longest length scale under investigation.

Although so far the top power spectrum appears to be the best technique to characterize the road surface profiles for tyre-road studies, the knowledge of the approperiate calculation of the top PSD and how the resulting top PSD must be interpreted in the calculations of the contact mechanics is still incomplete. In this regard, here, we dedicate the next section to a review of the characterization of the top surface topography of pavements by presenting the most suitable calculation procedure for the top PSD and illustrating the actual information it gives about the height distribution of a surface that is obtained through this top PSD. The application of this technique in the field experiments is then investigated thoroughly, using experimental data given in Section 3, inclusive of the monitoring of four road pavements during a nine-month evaluation period. In Section 4, a discussion is presented on the depth/portion of the top topography that is relevant for the top PSD calculations during tyre-road sliding contact and a rough estimate of this portion is then given for the experimental data. This is followed by sections providing the results and conclusions concerning the correlation between friction and the top PSD at each of the length scales under study, where the influence of the portion of the surface topography used in the top PSD calculations is also explored on the correlation results.

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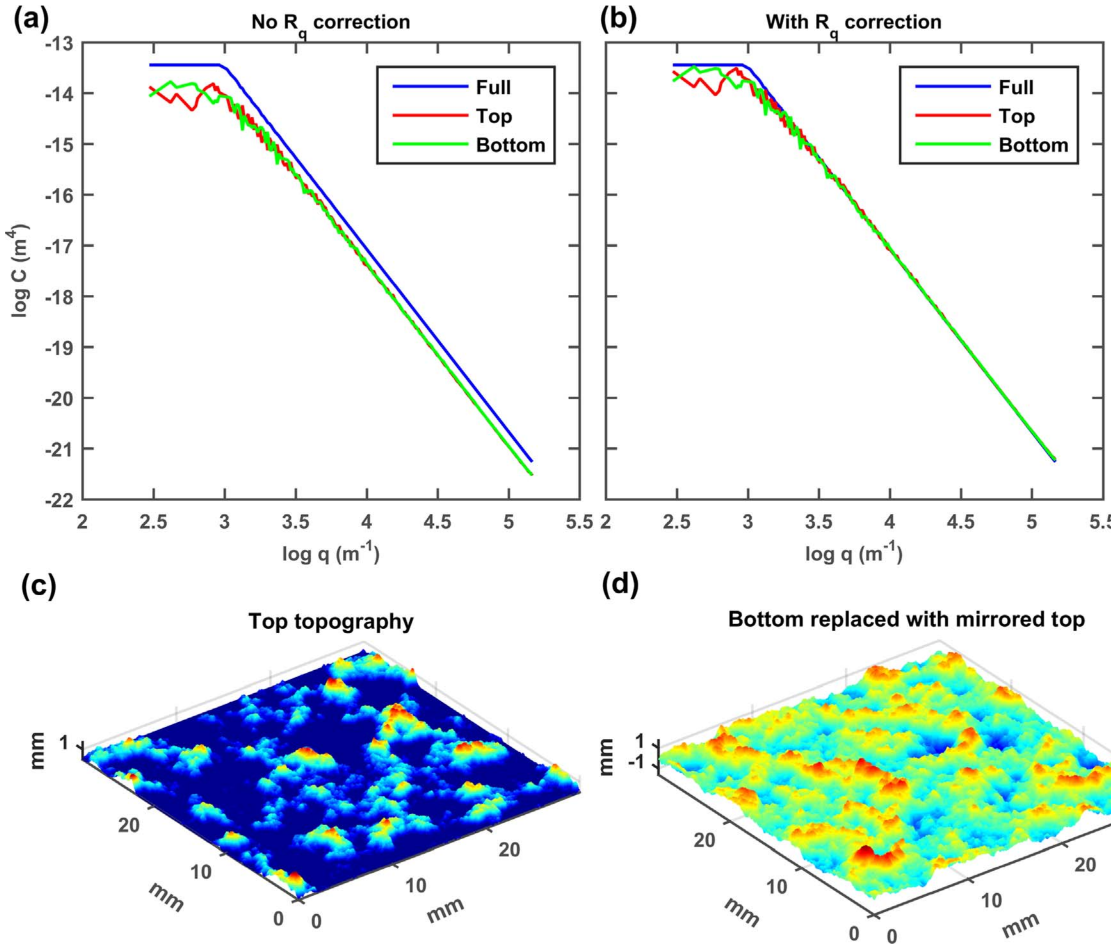

Fig. 1. Top topography analysis of a fractal surface. (a): Full, top and bottom power spectra with no correction of R_q. (b): Compensating for the reduction in R_q for top and bottom power spectrum. (c): Top topography of a fractal surface. (d): Generated artificial surface from the top topography PSD presented in (b) but with random phase, and with exactly the same statistical properties as the top topography in (c).

1.1. Top topography power spectrum

For a randomly rough surface, when the surface height distribution can be approximated with a Gaussian distribution, all the statistical properties of the surface roughness are contained in the surface roughness power spectrum C(q) where q is the roughness wavevector [21]. However, the surface characterization of asphalt pavements has, in many cases, shown non-random distribution of heights [13,15]. This skewed texture could arise from the hot mix asphalt compaction process or pavement mix types such as open-graded mixes, etc., but the magnitude of the pavement skewness also evolves through the year as a result of the change to warm seasons from cold periods and vice versa [15]. For a skewed pavement surface, any indicator of the surface roughness derived from the full surface profile overshadows the true roughness that actually contributes to the tyre/road contact. The conditions under which the tyre rubber is able to deform and make contact with the pavement surface everywhere (full contact) depend on the perpendicular pressure σ_0. At the least, a local pressure in the order of the elastic modulus of the filled rubber E ≈10 MPa (static case) is needed to satisfy the latter condition [2]. Thus, only partial contact is normally expected for typical passenger/truck tyre applications (σ_0 < 1 MPa), which only occur on top of the highest asperities. While pavement skewness escalates roughness indicators such as MPD (mean profile depth), R_q (root mean square roughness) and even the energy represented at different frequencies of the roughness PSD, the increase in the parameters has no influence on the area of real contact, leading to false conclusions when these indicators are correlated with friction data. For this reason, there is an urge towards the characterization of surface roughness only on the top topography of pavements, still representing roughness at different length scales.

Ueckermann et al. [17] used summit profile PSD in order to exclude the surface cavities of the pavement. However, as also mentioned by the same authors, this method alters the information on the low-frequency components of the surface roughness. Altering texture components is not accepted in this context as all roughness wavelengths are a priori equally important in contact mechanics [2]. The top and bottom power spectrum approach was first introduced by Persson et al. [21] for surface characterization, defined by:

$$C_T(q) = \frac{1}{(2\pi)^2} \int d^2x \langle h_T(x) h_T(0) \rangle \quad e^{-iq.x} \tag{1}$$

$$C_B(q) = \frac{1}{(2\pi)^2} \int d^2x \langle h_B(x) h_B(0) \rangle e^{-iq.x} \tag{2}$$

where $h_T(x)=h(x)$ for $h > 0$ and zero otherwise, $h_B(x)=h(x)$ for $h<0$and zero otherwise, and ⟨...⟩ stands for ensemble averaging, i.e. averaging over a collection of surfaces with the same statistical properties [21]. Although this approach was first presented by Persson et al. [21], the concept of its calculation and the realization it gives about the surface roughness components of a pavement require additional explanation. In general, the top power spectrum could be calculated for any portion of the top surface topography and not just above/below the average plane. In the work of Hartikainen et al. [13], the frequncy-wise correlation of the top power spectrum (calculated at a specific depth of height profile) with friction was studied for the first time; however, the concept of the calculation procedure is somehow not well identified.