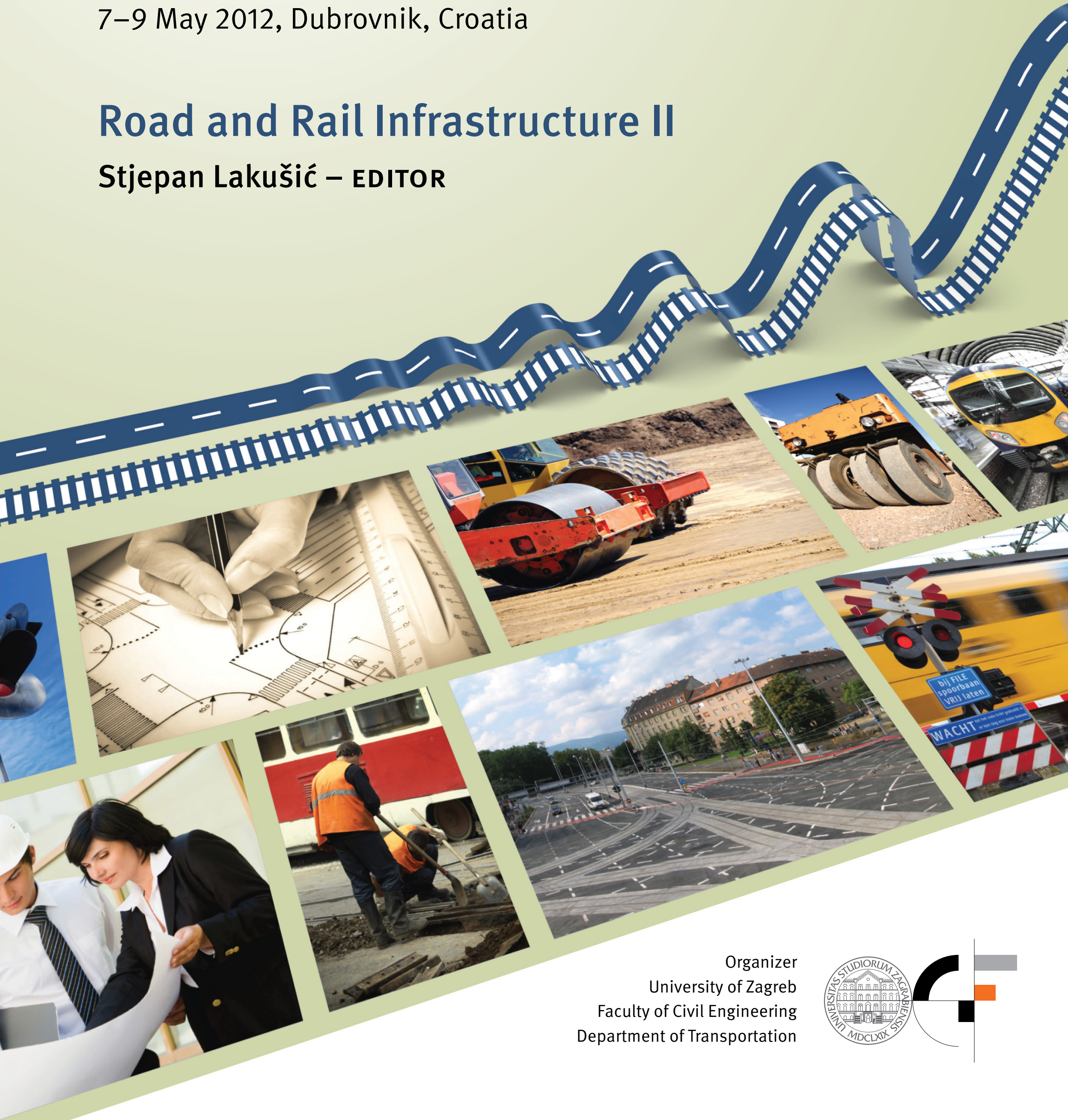
CETRA^{2012}

2nd International Conference on Road and Rail Infrastructure

7–9 May 2012, Dubrovnik, Croatia

Road and Rail Infrastructure II

Stjepan Lakušić – EDITOR



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DEPENDENCY BETWEEN ROAD SURFACE GEOMETRY AND SKID RESISTANCE

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Abstract

Safety and functionality are the basic requirements in road construction. To meet these requirements the qualitative and quantitative influence of the extrinsic and intrinsic factors of safety and functionality requires a detailed investigation. If the wearing course as the interface between road and tyre is considered exclusively, good skid resistance (drainage capability, friction) and acoustic behaviour constitute the most important surface characteristics. They are strongly influenced by the geometrical properties of the wearing course and may have contradictory needs. As an example, there is an overlapping domain in which the wavelength of the road texture influences both, the skid resistance and the acoustic characteristic of the wearing course. The long–term objective is to develop models for simulating all the single characteristics of the wearing course. For this purpose, every single characteristic has to be investigated and modelled independently. Then, the single approaches can prospectively be combined for artificial material design.

The main focus of the current research lies on investigating the skid resistance of roads. Therefore priority is on identification of the dependency between road surface geometry and the related dimensions of skid resistance, which is still not completely explored. First, geometrical parameters of measured textures will be determined to characterise isotropic asphalt surfaces. Secondly, virtual textures on various wavelength dimensions will be generated by utilisation of the multi–scale fractal structure. Then, the combination of geometry and the appearing friction build the tribological model. This model will be transferred into a contact mechanical simulation to reproduce rubber friction numerically. Results of the simulation will be the forces in related micro–contact points. From this the rubber friction coefficient and the real contact area between tyre and road can be derived. This will give the opportunity to specify the connection between various road surface geometries and the related dimensions of skid resistance.

Keywords: skid resistance, friction, texture analysis, tribology, simulation

1 Introduction

Skid resistance is the force which comes to effect when a tyre that is prevented from rotating slides along the pavement surface. The related interrelation of contact mechanic between tyre and road surface is not completely investigated.

Accidents due to pavement skid resistance deficiencies are a major concern of highway authorities. They have to ensure that drivers are able to use a road securely. For this reason monitoring and controlling skid resistance of pavements is an important component of road surface maintenance and is measured periodically. Skid resistance measurements can also be used to evaluate various types of materials and construction practices. Skid resistance can be measured by various methods but all devices have in common that they are tactile techniques where a rubber tyre or slider has to be rubbed over a wetted road surface. The results of such measuring methods are friction forces which are characterised by wide ranges of dispersion and are confined to small parts of the road surface. The mentioned measuring methods provide friction values for either single spots or for a single continuous line in the wheel track of a lane. Large parts of the road surface with potentially low skid resistance remain undetected. Furthermore, the need to wet the surface makes measurements elaborate and expensive. These disadvantages make it desirable to develop a contactless method to determine skid resistance of a road surface. To quantify skid resistance by a contactless method, dependency between surface geometry (texture) and skid resistance has to be investigated fundamentally.

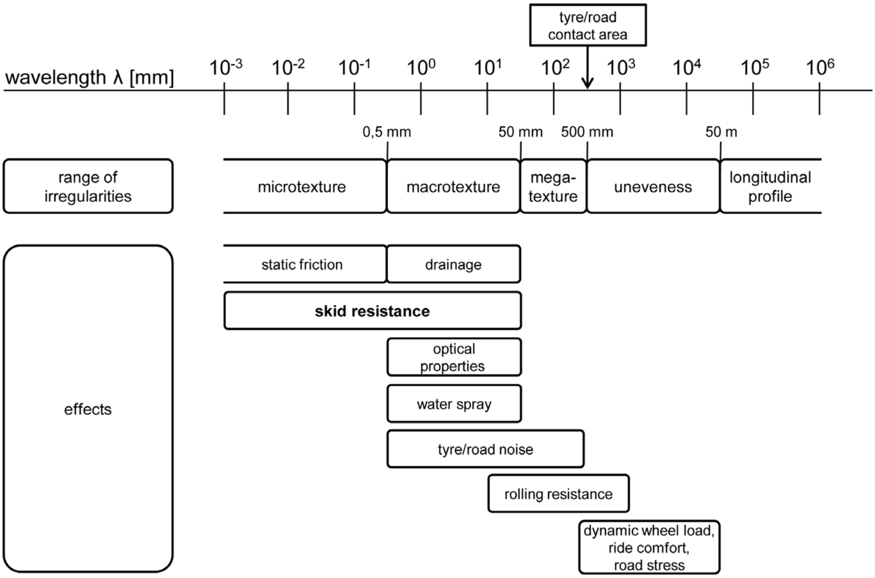

Figure 1 Wavelength spectrum of a road surface and effects on road safety [1]

Fig. 1 shows that different wavelength dimensions of a texture affect different surface characteristics. Skid resistance depends on pavement's microtexture and macrotexture. Macrotexture refers to the large–scale texture of the pavement (range of texture wavelength 0,5 mm – 50 mm) and is influenced by the aggregation of particle arrangement. It provides drainage volume and reduces the danger of hydroplaning. Microtexture refers to the fine scale texture of the pavement aggregate component (range of texture wavelength 1 μm – 0,5 mm). It controls the contact between the tyre rubber and the pavement surface. In consequence, rubber friction between tyre and road surface is primarily influenced by microtexture. [1]

Basically, rubber friction consists of two major components (Fig. 2). The first component is adhesion. It is the result of temporary molecular bonding between the two surfaces and depends on the size of contact area between the elastomer and the rigid rough surface. The true contact area depends on the surface texture, material properties and the contact pressure. It is much smaller than tyre contact patch. The second component is hysteresis what is the main cause of energy loss associated with rolling resistance. It is attributed to the viscoelastic characteristics of rubber. As the tyre rotates under the weight of the vehicle, it experiences deformation and recovery, and the hysteresis energy loss is dissipated as heat. Warmed up tyres possess a larger area of contact with the road surface. So, hysteresis indirectly influences the adhesive component of rubber friction and is supposed to be the significant friction component at higher driving velocities. [2]

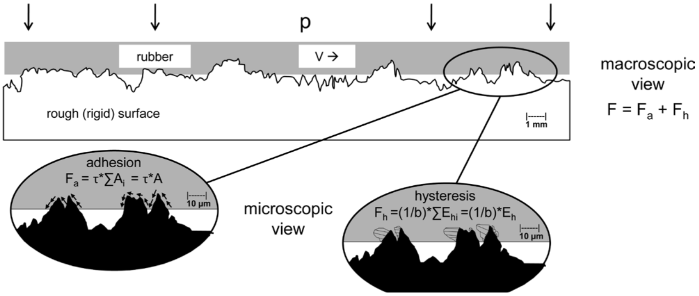

Figure 2 Friction interaction between tyre and road [2]

Main goal of this research is to identify the dependency between road surface geometry and related dimensions of skid resistance by simulating hysteresis component of friction between rubber and rough surfaces on microscale (Fig. 3). First, geometrical parameters of textures will be determined to characterise isotropic asphalt surfaces. Secondly, virtual textures on various wavelength dimensions will be generated by utilisation of the multi–scale fractal structure of technical surfaces.

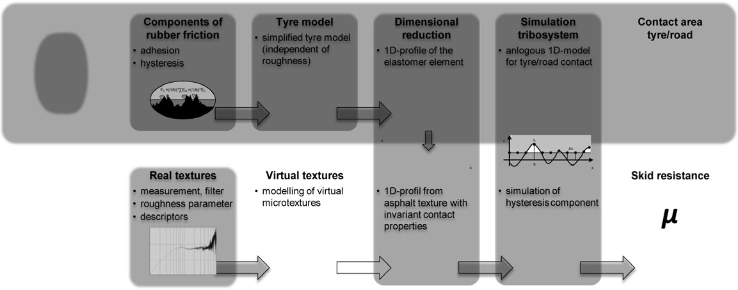

Figure 3 Overview: From asphalt texture to the skid resistance

The derived tribological model will be transferred into a contact mechanical simulation method to reproduce rubber friction virtually. Results of the simulation will be the forces in related micro–contact points, hence the rubber friction coefficient and the real contact area between tyre and road surface.

2 Texture geometry modelling

2.1 Data pre–processing

For the depiction of skid resistance, high–resolution microtexture data of asphalt surfaces are necessary, which had been derived from precise optical measurement systems. Therefore, different asphalt samples had been scanned with a structured light 3D scanner within a wide range of microscale. Results of the scans are measuring fields on asphalt samples sized 12 mm x 7,6 mm with 912.000 data points and a lateral resolution of 10 µm. As a first pre–processing step the measuring field were squared to the size 5,12 mm x 5,12 mm. Afterwards different methods were applied to interpolate missing data and eliminate noisy data and inconsistences such like outliers. As mentioned above, the frictional component of skid resistance depends on pavement's microtexture. Therefore, as a second step the asphalt texture was separated for further geometry evaluation into its long–wave (waviness) and short–wave range (roughness) (Fig. 4).

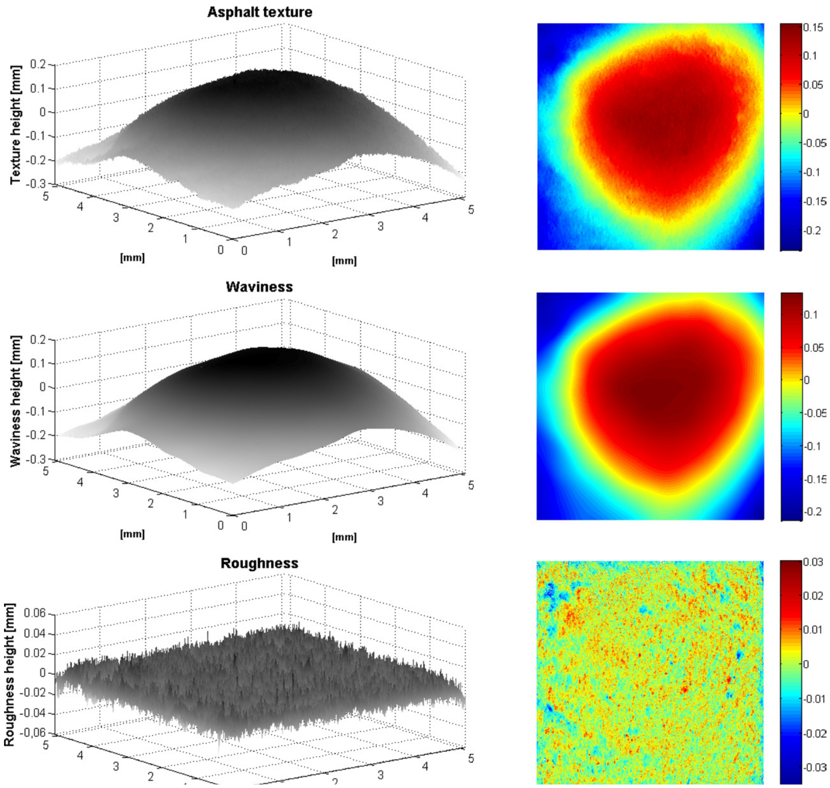

Figure 4 Separation of asphalt texture in waviness and roughness by 2D Gaussian filter

An approximation of a 2D Gaussian filter algorithm with high computational efficiency, established by [3], was implemented, which ensures both amplitude accuracy and zero phase characteristic. The filter for 3D surfaces is defined as shown in Eq. (1), whereas h(x,y) is the 2D Gaussian distribution, the constant $\beta = \ln 2/\pi$ and λ_{xc}, λ_{yc} are the cut–off wavelengths in the x and y directions. The 2D distribution is used to perform filtering using convolution methods.

$$h(x,y) = \frac{1}{\beta\lambda_{xc}\lambda_{yc}} e^{\left\{\frac{-\pi}{\beta}\left[(\lambda_{xc}^{x})^2(\lambda_{yc}^{x})^2\right]\right\}} \qquad (1)$$

2.2 Determination of texture's characteristics

For the characterisation of various asphalt surfaces including their isotropic textures, geometrical parameters are required, which will directly influence the subsequent simulation of friction. For this purpose, texture heights had been described by their statistical properties. Roughness parameters identify the small–scale variations in the height of a physical surface. These parameters can be used to characterise surface texture. For a long time these parameters were based upon 2D contact measurements, but in the last years the increasing amount of contactless 3D measurements methods led to a standardisation of the analysis of 3D texture [4]. The amplitude properties, e. g. root mean square, surface skewness or kurtosis, are described by different parameters, which give information about the statistical average properties, the shape of the height distribution histogram and about exceptional properties. Hybrid parameters reflect slope gradients and may be used for a further differentiation of the surfaces with similar amplitude properties. (Table 1)

Table 1 Calculated parameters of a high and a low grip sample

	Parameter	high grip sample	low grip sample
amplitude parameters	Sa [µm]	6,243	4,033
	Sq [µm]	8,122	5,163
	Ssk [-]	0,847	0,017
	Sku [-]	4,483	3,680
	Sz [µm]	88,004	66,239
	Sp [µm]	54,367	30,046
	Sv [µm]	-33,693	-36.193
hybrid parameters	Sdq [µm/µm]	6,373	6,389
	Sdq6 [µm/µm]	5,857	5,230
	Sdr [%]	1401,37	1477,22

The functional parameters of a surface can be derived by calculation of the Abbott Firestone Curve (Fig. 5), which is also called material ratio or bearing area ratio curve. This curve is calculated by accumulation of the height distribution histogram and the subsequent inversion and gives information about material and void volumes constituting a texture. Thus makes it possible to characterise the surface involved in contact phenomena [5].
Another possibility to analyse textures is the transduction of surface's geometry into the frequency domain. Therefore, a height difference correlation function (HDC) has been applied, which connects lateral distances with mean height differences (Eq. 2, Fig. 5). Further we can derive descriptors from HDC, like the coordinates of the cut–off point and the fractal dimension D_f, which describe dimensions of surface roughness quantitatively. [6]

$$\Gamma_H(dx) = \left\langle (z(x+dx) - z(x))^2 \right\rangle \tag{2}$$

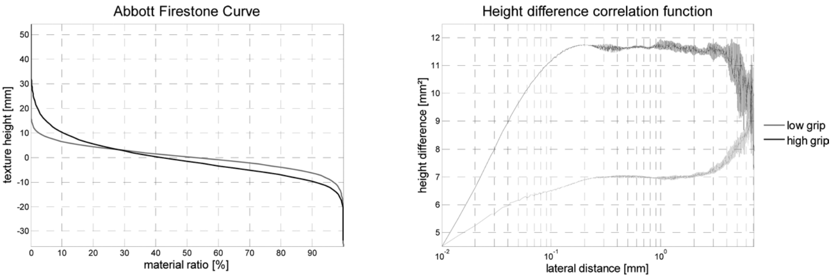

Figure 5 Abbott Firestone Curve and two–dimensional height difference correlation function of a low and a high grip asphalt sample

2.3 Creation of equivalent scale dependent textures

Nevertheless, the lower resolution limit of the microtexture, which is indeed unknown, could not been imaged. The development of an optical measurement system which fulfils the requirements would be time–consuming and expensive. Therefore, in this project, virtual texture geometries are modelled as the basis for a tribological model. Tribological models are assumed to have a multi–scale fractal structure. Asphalt as an irregular geometric object has an infinite nesting of texture across all scale ranges (Fig. 6). These textures are called self–affine.

That means statistical properties of a surface are invariant under the scaling transformation ζ (Eq. 3), where the exponent H can be related to the fractal dimension via $D_f = 3 - H$ $(0 < H < 1)$ [7].

$$x \rightarrow \zeta x, y \rightarrow \zeta y, z \rightarrow \zeta^H z \tag{3}$$

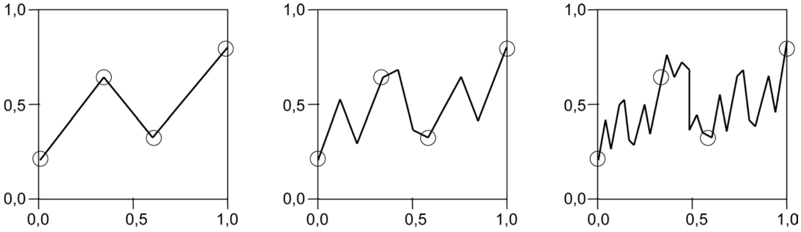

Figure 6 Irregular geometric object with infinite nesting of texture across all scale ranges

The scale invariance can be used to create virtual textures down to microscale's lower limit based on the existing geometrical parameters of asphalt surfaces from the scanned samples. Thereby textures can be formed, which qualitatively have the same texture on different scales and cover the lower wavelength range of the microtexture.

3 Outlook

3.1 Tribological model

3.1.1 Dimensionality reduction

The following simulation of the hysteresis rubber friction component is based on the generated virtual textures on different scale ranges. It has been realised long ago that surfaces are rough on a microscopic scale, and that this causes the real contact area to be extremely small compared to the nominal area [8]. The difficulty of tribological systems and their simulation is the understanding of the multi–contact conduction of rough surfaces on different scales. To handle these problems and to reduce large volume of texture data a hierarchical simulation method shall be applied [9]. Therefore, we reduce the three–dimensional contact problem into a simplified analogous system, which has the identical contact properties as the three–dimensional texture (Fig. 7).

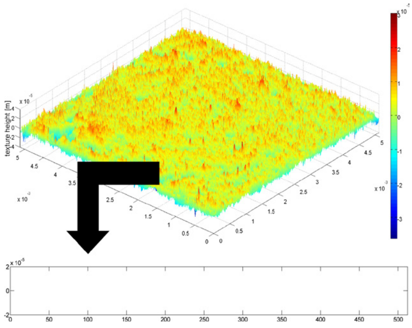

Figure 7 Reduction of the 2D surface of a texture into a simplified 1D profile

Popov [10] assumes that the topography of a two–dimensional surface (of a three–dimensional texture) can clearly be described by its power spectral density (PSD) $C_{2D}(q)$. Eq (4) allows the transfer of a two–dimensional system into a one–dimensional system with identical contact properties.

$$C_{2D}(\vec{q}) = \frac{1}{(2\pi)^2} \int \left\langle h(\vec{x}) h(\vec{0}) \right\rangle e^{i\vec{q}\times\vec{x}} d^2x = \frac{1}{\pi\vec{q}} C_{1D}(\vec{q}) \tag{4}$$

In this case the height distribution and radii of curvature of a texture have the same order as the quadratic mean of the height distribution and radii of curvature of the entire profile. It is important to consider that the roughness of the elastomer plays only a minor role in the process of hysteresis. [10]

3.1.2 Simulation of rubber friction

The simulation is based on the derived equivalent 1D–model from section 3.1.1 in which the viscoelastic material is brought into contact with the rough surface in a defined distance. That is the way profiles will be discretised into defined steps x. Depending on time step and velocity, normal and tangential force can be calculated for each discretisation step. Ratio between the mean of tangential and normal force results in a rubber friction coefficient. Microcontacts are now characterised by a respective length and are identified as connected regions in the simulation. The contact area can be calculated from the sum of the respective lengths. The tribological model will be calibrated by means of the determined roughness parameters. [10]

3.2 Validation and Optimisation

In the first step of the validation the virtually created geometric textures will be compared with real–life texture data from the scanned samples. This validation is essential to demarcate the infinite possibilities of virtual texture characteristic and to ensure asphalt geometry resembles reality as much as possible. In the second step, the determined friction coefficient from simulation will be validated against measured friction coefficients of the samples from a linear friction tester. A linear friction tester makes it possible to do measurements of all orthogonal force components during friction process. Besides the friction coefficient, elastic modulus of the applied elastomer can be determined. Facultative measurements can be undertaken by changing conditions like temperature, sliding velocity or contact pressure. By evaluation of the results of the two validation steps both texture geometry and tribological model can be optimised.

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