Tribology International 93 (2016) 137–141

Contents lists available at ScienceDirect

Tribology International

journal homepage: www.elsevier.com/locate/triboint

Comparing surface topography parameters of rough surfaces obtained with spectral moments and deterministic methods

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ARTICLE INFO

Article history:
Received 5 May 2015
Received in revised form
12 August 2015
Accepted 6 September 2015
Available online 14 September 2015

Keywords:
Surface topography
Spectral moments
Deterministic analysis

ABSTRACT

Understanding contact between rough surfaces is of critical importance to the design of many engineering applications. Contact models rely on material properties and surface topography of the contacting surfaces as input parameters. Hence, the relevance of the contact models is dependent on their inherent assumptions and the accuracy with which the input parameters are determined. We have evaluated the difference between the surface topography parameters calculated with a statistical and deterministic approach for actual engineering surfaces. We have found topography values that change up to 300% depending on the method used, and attribute this to the stringent definition of an asperity-peak in the case of deterministic analysis as opposed to statistical analysis, which not only considers asperity-peaks but also asperity-shoulders.

1. Introduction

Understanding the mechanical interaction between rough surfaces is of critical importance to the design of many engineering applications. Oftentimes, multi-asperity elastic, elastic–plastic, and plastic contact models are used to predict contact parameters such as the real area of contact, normal load, and electrical conductivity as a function of the separation between two contacting rough surfaces [1,2]. These contact models rely on material properties and surface topography of the contacting surfaces as input parameters. Hence, the relevance of the contact models is dependent on their inherent assumptions and the accuracy with which the input parameters are determined [3,4]. The surface topography of an engineering surface can be determined experimentally using e.g. a stylus profilometer, optical profilometer, or an atomic force microscope (AFM), depending on the size of the specimen or the area that is analyzed, and the desired measurement resolution. The surface is often represented as a matrix of surface heights $z=f(x,y)$, where z is the surface height at coordinates x and y. The surface topography of an engineering surface is typically characterized by means of the asperity-peak density η, mean asperity-peak radius ρ, and standard deviation of asperity heights σ_s. Two methods are commonly used to calculate these surface topography parameters from an engineering surface represented as $z=f(x,y)$.

McCool [5] described a statistical method to determine the surface topography parameters of a three-dimensional (3D) isotropic rough surface, based on the spectral moments of a single arbitrary two-dimensional (2D) trace of that rough surface. This method has been widely adopted, see for instance [6–10]. However, realistic engineering surfaces are typically not isotropic as almost all manufacturing techniques result in a surface topography with a preferential direction. Furthermore, it has been shown that the spectral moments may vary significantly for any arbitrary 2D trace of a rough surface [3,11]. To address this problem, several authors have used average values of the spectral moments obtained from a finite number of traces of the 3D surface to calculate the topography parameters [2,3,11–15].

Another commonly used method is based on individually identifying asperity-peaks as local maxima of $z=f(x,y)$ [16–18]. The topography parameters are then calculated directly from these asperity-peaks [17,18] as opposed to relying on statistical methods. This deterministic approach avoids the statistical averaging inherent to the previously described spectral moments approach, and is based on the actual 3D surface topography. Different schemes can be used to identify local maxima, such as the 9 point-peak neighbor [18–20] and the 5 point-peak neighbor [18,19,21,22] schemes. The 9 point-peak neighbor scheme seems to be the most accurate one [11]. Few works have compared the surface topography parameters calculated with different deterministic methods. Pogacnik and Kalin evaluated the surface

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http://dx.doi.org/10.1016/j.triboint.2015.09.013
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topography parameters for 2D profiles [4] and for 3D topography [23] obtained from real engineering surfaces with different roughness. They used a deterministic approach based on three, five, seven and nine neighboring points of a 2D and 3D surface characterization and concluded that the choice of the lateral resolution, roughness, and especially the number of neighboring points significantly affects the surface topography parameter results. Pawar et al. [3] calculated the contact parameters of the Greenwood–Williamson (GW) model, based on surface topography parameters obtained with different methods for 3D isotropic numerically generated surfaces. They included McCool's statistical method based on single and multiple traces of the rough surface and the deterministic approach based on a 9 point-peak neighbor scheme in their analysis, and also concluded that the GW contact parameters vary significantly depending on the method that is used to determine the topography parameters, which serve as input to the GW contact model. However, they did not verify their analysis with real engineering surfaces.

Thus, both statistical and deterministic methods suffer from various sources of uncertainty. However, no publications exist that compare these two approaches in a comprehensive way for real engineering surfaces of different surface roughness. Accordingly, the objective of this paper is to evaluate the difference between the surface topography parameters calculated with a spectral moments and deterministic approach. The characterization of surface topography parameters is based on the experimentally measured 3D engineering surfaces analyzed in [4,23] and not numerically generated surfaces as employed in [3].

2. Materials and methods

2.1. Specimen geometry and surface roughness

We have used five different stainless steel (100Cr6) specimens, prepared with a sequence of grinding and polishing steps (Roto-Pol-21, Struers, Denmark) to achieve a distinct average surface roughness, S_a, ranging from smooth ($S_a=0.005$ μm) to rough ($S_a=0.529$ μm). The specimens are manufactured to have an isotropic surface roughness. The hardness of the specimens is 850 $HV_{0.15}$ (62 HRC), measured with a micro-hardness tester (Leitz Miniload, Wild Leitz GmbH, Wetzlar, Germany). An optical interferometer with an additional 20 × magnification lens (Contour GT-K0, Bruker, Arizona, USA) is used to measure the surface topography of the specimens over an area of 0.0434 mm^2, identical for all specimens to maintain constant pixel size, and with a lateral resolution of 0.187 μm. Fig. 1 shows an optical interferometry image of each of the five specimens, depicting their surface topography. The roughness of each specimen is measured at five randomly selected locations on the specimen to confirm consistent sample preparation. The average and standard deviation of the surface roughness parameters, including the average surface roughness S_a, the root mean square (RMS) roughness S_q, the

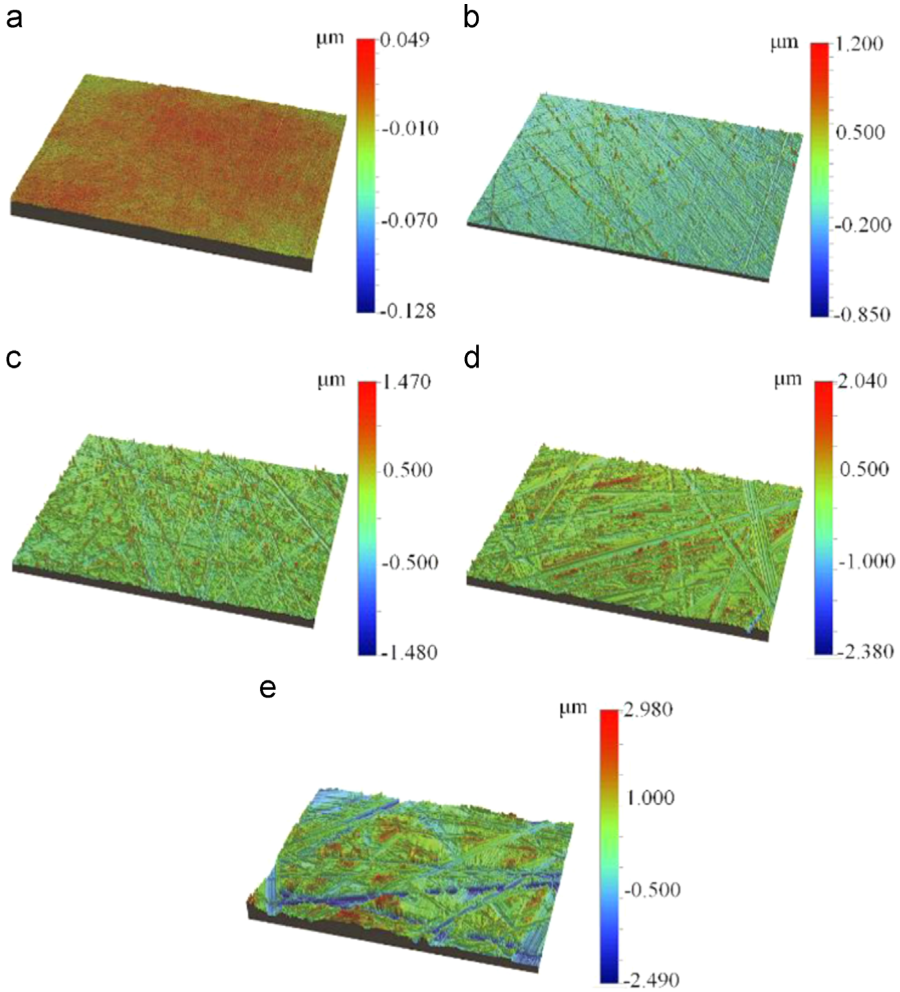

Fig. 1. Optical interferometry images of all five specimens, illustrating the surface topography. (a) $S_a=0.005$ μm, (b) $S_a=0.057$ μm, (c) $S_a=0.116$ μm, (d) $S_a=0.218$ μm, and (e) $S_a=0.529$ μm. The area of the images covers 0.0434 mm^2.