Wear 308 (2013) 95–104

Contents lists available at ScienceDirect

Wear

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

Criteria and properties of the asperity peaks on 3D engineering surfaces

M. Kalin [a,*], A. Pogačnik [b]

[a] Laboratory for tribology and interface nanotechnology, Faculty of Mechanical Engineering, University of Ljubljana, Bogišičeva 8, 1000 Ljubljana, Slovenia
[b] Iskra Mehanizmi, Lipnica 8, 4245 Kropa, Slovenia

ARTICLE INFO

Article history:
Received 10 April 2013
Received in revised form
17 September 2013
Accepted 20 September 2013
Available online 26 October 2013

Keywords:
Surface topography
Identification
3D asperity-peak
Radii
Real contact area

ABSTRACT

In any attempt to theoretically calculate the real contact area for 3D engineering surfaces, a criterion is needed to identify the relevant asperity-peaks that carry the load in tribological contacts. In our recent work, we investigated how different, available 2D criteria affect the properties of the theoretically determined asperity-peaks in 2D surfaces. In this work, however, we focused on a 3D surface characterisation. The effect of different asperity-peak identification criteria on the properties of the asperity-peaks (numbers, radii and heights) is studied in the 3D domain. Several different criteria that take into account the number of neighbouring points, the distances between them (lateral resolution) and their heights were evaluated for real measured surfaces with five different surface roughnesses in the broad engineering range of arithmetic surface roughness from $S_a = 0.005$ μm to $S_a = 0.529$ μm.

From the results it follows that all three chosen asperity-peak identification criteria (5PP-3D, 9PP-3D and 9PP-R-3D) result in reliable asperity-peak properties, and none of them can be favoured based on a theoretical evaluation only. There are, however, important differences between them. The data resolution in the x and y directions has a very important influence on the numbers, radii and heights of the asperity-peaks, and the results suggest that the data's lateral resolution, below 1 μm, should be used for the relevant asperity-peak identification.

1. Introduction

The real contact area is an important parameter when evaluating tribological contacts. This is because, in comparison to the nominal contact area, using the real contact area to calculate the contact temperatures and contact pressures results in much higher values [1]. These higher contact temperatures and contact pressures can thus lead to different mechanical and tribological behaviours of the materials used in the tribological contacts than would otherwise be assumed on the basis of the nominal contact area. This is especially important for materials that are very sensitive to relatively small changes in temperature, like polymers [2]. Accordingly, in order to better understand the behaviour of materials in contacts and so to properly design these contacts, an accurate estimation of the real contact area is needed.

The real contact area can be measured with different techniques [3–7] or calculated according to theoretical models. There are several different theoretical models available for the calculation of the real contact area and these can be grouped into three main categories: statistical, fractal and “deterministic” models. The statistical and fractal models are described in detail elsewhere [8–14], while this work focuses on the “deterministic” approach.

With the advances in computational power, “deterministic” 3D contact models are becoming more common [15–18]. The distribution functions used in the statistical models are replaced by simple, but real, measured 3D geometries with measurable numbers, radii and heights. In this way, the real-contact-area calculations do not depend on a statistical characterisation and the typical “averaging” of engineering surfaces.

The problem with the “deterministic” 3D models, however, remains the identification of the relevant asperity-peaks that carry the load in the tribological contacts. The level at which the measured surface data points are considered as “relevant” asperity-peaks must be determined by using certain arbitrary criteria. The level of what is considered as relevant “asperity-peak” or “micro-contact” therefore depends on our ability to identify and quantify them, as well as on our ability to determine their influence on the load carrying, the heat transfer, etc. However, the methods used for determining the asperity-peaks are seldom in the literature and are not well established.

In our previous work [19] we analysed the 2D asperity-peak properties of real engineering surfaces measured with a stylus-tip profilometer. A 2D domain was analysed as this is widely used in both industry and academia. There is also a vast amount of

* Corresponding author. Tel.: +386 1 4771 460; fax: +386 1 4771 469.
E-mail address: mitjan.kalin@tint.fs.uni-lj.si (M. Kalin).

0043-1648/$ - see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.wear.2013.09.010

experience and reference data, and this remains an important tool for surface analysis. However, this work focuses on a review of the existing asperity-peak identification criteria for surfaces in a 3D domain, which are becoming relevant with the new measuring tools and techniques. It is thus the goal of this work to investigate how the different criteria that can be applied to the measured surfaces can affect the properties of the asperity-peaks that are determined by such theoretical analyses, i.e., their numbers, heights and radii.

For the purposes of this research, steel specimens with five distinctively different surface roughnesses were prepared and measured using a 3D optical interferometer. The surface topographies were later analysed to calculate the number of asperity-peaks, their radii and their heights. The effects of (i) the different asperity-peak identification criteria (the number of neighbouring points that define an asperity peak), as well as (ii) the corrections in the z-direction and (iii) the resolution of the profile measurement in the x and y directions were evaluated for a broad range of engineering-surface roughnesses (S_a between 0.005 μm and 0.529 μm, S_a = arithmetic surface roughness).

1.1. Asperity-peak identification criteria for deterministic contact models in 3D

Surface topographies can be measured using different instruments, for example, with stylus profilometers, optical interferometers or AFMs. The 3D topography, measured with a stylus profilometer (or an AFM), consists of several parallel profile measurements, which can later be combined to obtain a 3D image of the measured surface. However, with the use of optical interferometers, 3D topographies are typically obtained directly from a single measurement. In all cases, however, the surface measurements consist of a certain number of discrete points that are spaced a certain distance apart.

Fig. 1 presents a top view of the surface (discrete data points), measured either by stylus profilometer, optical interferometer or atomic force microscope (AFM). The asperity-peak (denoted AP for asperity point) can be defined as a point that is higher than its closest-neighbour points (denoted as NP for neighbouring point). The most widely used asperity-peak identification criteria in the literature are the 5- and 9-point rectangular definitions, which are shown in Fig. 1a and b [20–24].

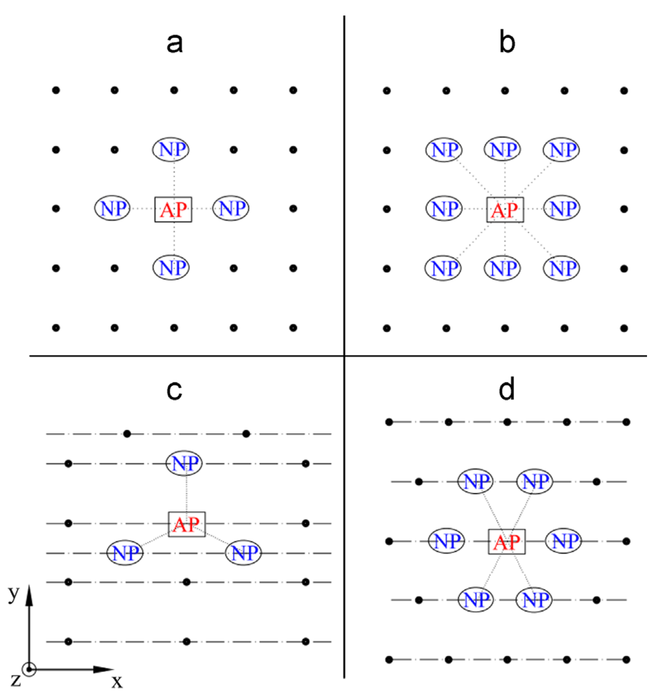

Fig. 1. Identification of the asperity-peaks on 3D surfaces (a) 5-point rectangular asperity-peak, (b) 9-point rectangular asperity-peak, (c) 4-point triangular asperity-peak and (d) 7-point hexagonal asperity-peak. "Asperity point" is indicated as AP, and "Neighbouring point" as NP.

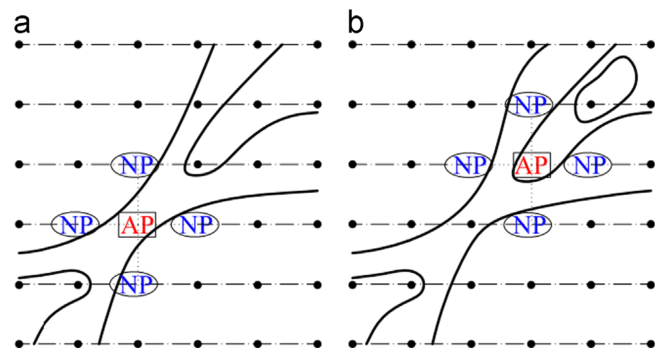

Fig. 2. False asperity-peak identification with a 5-point rectangular definition; (a) saddle point and (b) ridge point [20]. The "Asperity point" is indicated as AP, and the "Neighbouring point" as NP.

Some authors have also proposed different asperity-peak definitions in 3D. For example, they proposed a triangular asperity-peak definition (Fig. 1c) and a hexagonal asperity-peak definition (Fig. 1d) [24]. However, such definitions require different distances between parallel surface measurements and different starting points for the measurements in order to get an equal spacing between the asperity-peak point (AP) and its neighbouring points (NPs). These measurements, which can only be achieved using contact profilers or AFMs, are difficult to perform and are rarely used in practise.

Fig. 2 shows the discrete points of the surface measurement. The lines in Fig. 2 are contour lines and represent the same heights of measured surface. Greenwood [20] noted that with a 5-point asperity-peak definition in 3D (Fig. 1a) there is a significant possibility of finding false asperity-peaks, as shown in Fig. 2a and b. For example, Fig. 2a shows a saddle point *AP* that is wrongly identified as an asperity-peak if the 5-point asperity-peak definition is used. Similarly, in Fig. 2b a ridge point *AP* is presented, which is also falsely interpreted as an asperity-peak with the 5-point asperity-peak definition. Therefore, Greenwood suggested using the 9-point asperity-peak definition for the identification in 3D. Increasing the number of neighbouring points reduces the risk of missing an asperity-peak, but a finite possibility of missing asperity-peaks always exists due to a certain discretisation of the measured surface [12].

An alternative way of identifying asperity-peaks is with the use of surface-pattern recognition. The principle was first introduced by Maxwell in 1870 [25]. He suggested dividing a landscape (or surface) into regions consisting of hills (peaks) and regions consisting of dales (valleys). However, Maxwell's analysis results in an over-segmentation of the surface into tiny, shallow peaks/valleys, instead of identifying the important asperity-peaks or valleys [26]. Due to Maxwell's proposal having several drawbacks, different pattern-recognition procedures were later introduced to improve the identification of the asperity-peaks or valleys on surfaces [27–31].

1.1.1. The 5-point peak criterion in 3D (5PP-3D criterion)

Several authors have suggested using a 5-point peak (5PP-3D) criterion for the identification of asperity-peaks on 3D topographies [20,32–34]. An asperity-peak is defined as a point that is higher than its four closest neighbouring points, as schematically shown in Fig. 3a. The points of the asperity-peaks are represented by dots at different positions on the xy grid.