Tribology International 59 (2013) 190–202

Contents lists available at SciVerse ScienceDirect

Tribology International

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

An expert system to characterise the surfaces morphological properties according to their tribological functionalities: The relevance of a pair of roughness parameters

M. Bigerelle [a,b,*], D. Najjar [c,d,e], T. Mathia [f], A. Iost [c,d,e], T. Coorevits [c,d,e], K. Anselme [g]

[a] Laboratoire Roberval, UMR 6253, UTC/CNRS, Centre de Recherches de Royallieu, BP20529, 60205 Compiègne, France
[b] Laboratoire TemPo/LAMIH UMR 8201, Université de Valenciennes et du Hainaut Cambrésis, Le Mont Houy, 59313 Valenciennes, France
[c] Université Lille Nord de France, F-59000 Lille, France
[d] Arts et Metiers ParisTech, Laboratoire de Mécanique de Lille, F-59000 Lille, France
[e] CNRS, UMR 8107, F-59650 Villeneuve d'Ascq, France
[f] Laboratoire de Tribologie et Dynamique des Systèmes, UMR 5513, Ecole Centrale de Lyon, 36 Av Guy de Collongue, 69134 Ecully Cedex, France
[g] Institut de Chimie des Surfaces et Interfaces, UPR CNRS 9069, 15 rue Jean Starcky, BP2488, 68057, Mulhouse Cedex, France

ARTICLE INFO

Article history:
Received 1 September 2011
Received in revised form
27 February 2012
Accepted 20 April 2012
Available online 11 May 2012

Keywords:
Roughness
Discriminant analysis
Femoral head
Third body abrasive mechanism

ABSTRACT

Knowing that a surface or profile can be characterized by numerous roughness parameters, the objective of this investigation was to present a methodology which aims to determine quantitatively and without preconceived opinion the most relevant pair of roughness parameters that describe an abraded surface. The methodology was firstly validated on simulated fractal profiles having different amplitudes and Hölder exponents and it was secondly applied to characterise different worn regions of a retrieved metallic femoral head articulated against an ultra-high molecular weight polyethylene (UHMWPE) acetabular cup containing an embedded metallic fibber into its surface. The methodology consists in combining the recent Bootstrap method with the usual discriminant analysis. It was validated on simulated fractal profiles showing that, among more than 3000 pairs tested, the total amplitude R_t and the fractal dimension Δ is the most relevant pair of roughness parameters; parameters corresponding to the variables modulated in the analytical expression of the fractal function. The application of this methodology on a retrieved metallic femoral head shows that the most relevant pair of parameters for discriminating the different investigated worn regions is the arithmetic roughness parameter R_a paired with the mean peak height R_{pm}. This methodology finally helps in a better understanding of the scratch mechanism of this orthopedic bearing component.

1. Introduction

The topography of machined surfaces plays a key role with regard to their properties and therefore to the potential applications of the manufactured products. However, the characterization of a surface topography made through the estimation of roughness parameters remains a large subject of debate. Indeed, because of the various industrial and scientific interests, a proliferation of roughness parameters, termed by Whitehouse the "parameter rash" [1], has been triggered to describe the different kinds of natural, manufactured and modeled surface topographies. Probably running into hundreds, these roughness parameters include amplitude, frequency and hybrid parameters.

This multiparameter representation of surface roughness has been outlined in various works and some efforts have been done in previous ones to define a method for selecting relevant parameters [2–6]. However, only a limited set of parameters was systematically analyzed in these works. In fact, deciding which parameter is the most relevant to describe a surface topography with regard to a specific application remains a difficult task of paramount importance. That is why we developed some years ago a quantitative methodology to select, without preconceived opinion and among a high number of roughness parameters, the most relevant one with regard to different applications [7–11]. Based on the combination of usual statistical methods (least squares linear regression or analysis of variance depending on the application) with the Computer Based Bootstrap Method, the aim of this methodology is to define a numerical indicator of relevance associated with a statistical confidence interval for each roughness parameter under investigation. The higher the value of this indicator, the more relevant is

* Corresponding author at: Laboratoire TemPo/LAMIH UMR 8201, Université de Valenciennes et du Hainaut Cambrésis, Le Mont Houy, 59313 Valenciennes, France.
E-mail address: maxence.bigerelle@utc.fr (M. Bigerelle).

0301-679X/$ - see front matter
http://dx.doi.org/10.1016/j.triboint.2012.04.027

the related roughness parameter to describe the surface topography with regard to the application considered.

For sake of simplicity and by analogy with most of the works dealing with the characterization of topography of profiles or surfaces, our purpose was focused only on the relevance of a single roughness parameter in the aforementioned studies. Nevertheless, because a roughness profile is usually described physically by frequency components of different amplitudes, the aim of the present investigation is to present a new methodology designed to select the most relevant pair of roughness parameter to be used to describe the topography of a machined surface. Based on the combination of the Discriminant Analysis and the Computer Based Bootstrap Method, this methodology is calibrated on simulated fractal profiles for which the scaling amplitude factor and the Hölder exponent have been intentionally modulated.

2. Problematic characterization of surfaces by a pair of roughness parameters

The relevance of characterization of surfaces by two roughness parameters are illustrated by scheme described in Fig. 1a. To characterise both frequency and amplitude components, two roughness parameters are considered. These roughness parameters are an amplitude parameter (total amplitude, R_t) and a frequency parameter (mean distance between profile elements, S_m,). As it could be graphically observed, surfaces A and B get the same S_m value but different R_t values as well as surfaces C and D. On the contrary, surfaces A and C get the same R_t value with different S_m values, such as B and D surfaces. By plotting values of parameters (S_m, R_t) of the four surfaces (Fig. 1b), it becomes obvious that it is impossible to characterise profiles considering a single roughness parameter; either R_t or S_m parameter: R_t does not differentiate A and C surfaces (or B and D) as well as S_m does not differentiate A and B surfaces (or C and D). Consequently, in this schematic example two parameters are necessarily required to characterise the four surfaces.

3. Creation and characterization of simulated roughness profiles

3.1. Creation of fractal profiles

To validate the methodology that allows us to find the most relevant pair of roughness parameters for discriminating different topographies, simulated profiles have been created using the analytical expression of a fractal function depending on two parameters: a scaling amplitude factor A and the Hölder exponent $H \in [0-1]$; exponent related to the fractal dimension Δ of the profiles by the relation $\Delta = 2-H$. In fact, the fractal function considered in this investigation was created earlier by the authors to simulate profiles resulting from a random grinding process of a metallic surface by abrasive particles having a hemispherical shape [10]. Called the Stochastic Fractal Circle Function (SFCF), it is defined as follows:

$$F_{SFCF}(x,p) = A\sum_{n=0}^{\infty} \Psi_n 2^{-(nH/p)} g(2^{n/p}x + \phi_n) \quad (1)$$

with $g(x)$ an elementary term to which is associated an half-circle representation simulating the shape of the grooves generated during the grinding process. This elementary function is of period 1 and is defined on the $[0-1]$ interval as follows:

$$g(x) = \sqrt{0.5^2 - (x-0.5)^2} \quad x \in [0-1] \quad (2)$$

In Eq. (1), p is an integer higher than unity, Ψ_n are positive Gaussian random numbers that physically simulate the stochastic variation of penetration depth of abrasive particles during the grinding process, and φ_n are uniform random numbers that simulate the random disorientation between the grooves. In this investigation, this function is used to take benefit from these stochastic components which enable to introduce some variability in our methodology.

Fig. 2 shows 16 roughness profiles simulated with different values for A and H. As a consequence, it is obvious that a single roughness parameter cannot be sufficient to differentiate these profiles intentionally created by modulating two roughness parameters: an amplitude roughness parameter and the fractal dimension. To create a databank with a view to assessing the relevance of a high number of roughness parameters, 100 profiles of 10,000 points have been simulated for the different pairs (A, H) under study. For each profile, the least squares mean line has been selected for use as reference datum.

3.2. Computation of roughness parameters

In this investigation, 78 roughness parameters have been computed and assessed for each profile thanks to a personal computer program [9]. Some of the most important roughness parameters considered in this investigation are listed in Table 1. From a general point of view, these roughness parameters are amplitude ones like the total amplitude R_t, the arithmetic roughness R_a or the root mean square roughness R_q, frequency ones like the mean distance between profile elements, S_m and, finally, hybrid ones like the average curvature radius of peaks R_{wz}, the mean slope of the profile D_a and the fractal dimension Δ estimated by different methods (like the oscillation [14], the structure [14], the spectrum [15] and the ANAM [16] methods). In summary, this computational procedure enables to create a databank containing a set of $4 \times 4 \times 100 \times 78 = 124{,}800$ roughness parameters values available for a subsequent statistical analysis.

Fig. 3 shows some examples of paired roughness parameters for each pair (A, H) called a class hereafter. It can be observed on the graph (Δ_{ANAM}, R_t) that the data related to each class seem to be clustered with the clusters being significantly spaced each other. In other words, this means that, as expected, the pair of parameters 'total amplitude R_t–fractal dimension estimated by the ANAM method Δ'_{ANAM} seems relevant to differentiate each class.

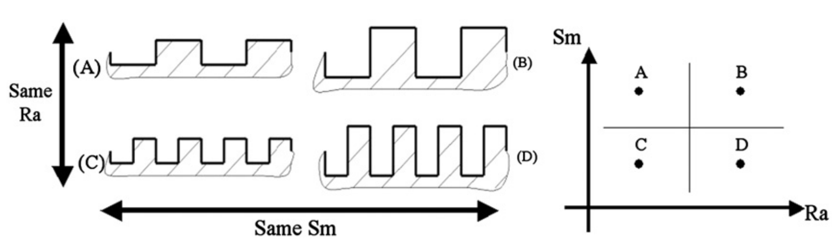

Fig. 1. Example of the necessity to differentiate four surfaces noted A, B, C, D by a pair of roughness parameters (S_m, R_t).