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FEATURE ORIENTED CHARACTERIZATION OF WORN SURFACES FOR A SLIDING TEST

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ABSTRACT

In this paper a novel 3D surface characterization technique - Feature Oriented Characterization - is applied to analyze worn surfaces for a sliding test. This technique concentrates on analysis of surface features such as hills or valleys. A filtering technique through wavelet analysis is exploited, in order to remove shapes and unnecessary features of surfaces. Then the significant features related to the tribological behavior are extracted by means of segmentation of the surfaces. As result, the relationship between the feature oriented parameters and tribological behavior is presented.

INTRODUCTION

The tribological behavior of surfaces is dependent on materials, surface topography, lubricants, external loads, relative motion, etc. Generally, the surface roughness has influences on tribological behavior. The relationship between the surface roughness parameters (2D and 3D) and the tribological behavior is well studied [1,2]. Additionally, the 3D surface motif characterization techniques are also applied in tribology [3,4].

This paper presents an alternative surface characterization technique - feature oriented surface characterization - to investigate the topography of the worn surface. This technique can analyse the features of interest on the surface which can directly describe the tribological effects. It is well known that the contact of two surfaces takes place at the peak of the asperities [5]. Therefore it is necessary to investigate the relationship between the shape of asperities and tribological behavior. For some hard and brittle surfaces such as ceramics, after wear pore-like features occur on the surface. These pores may also relate to the wear and normal load.

A feature oriented characterization technique was published, which can characterize the surface according to the texture primitive [6]. This means, like a landscape, a surface can be divided into regions consisting of hills and regions consisting of valleys. These regions consist of some critical points (peaks, saddle points and pits). The boundaries between the hill regions are the course lines and the boundaries between the valley regions are the watershed lines. Using a Wolf Pruning method [7] the information not relevant to the application can be removed. By using this surface characterization technique the hill or valley regions can be segmented out.

A method for detecting particle and pore structures on a surface was also developed to characterize an AlSi cylinder liner surface [8]. Through detecting the maximal image gradient of the particles and pores and subsequent region merging, the particles and the pores on the surface can be extracted.

The aim of this work is to study the relationship of surface topography and tribological behavior, such as friction and wear mechanisms, by analysing the features of the worn surfaces using the Feature Oriented Characterization technique.

EXPERIMENTAL DETAILS

A “ball on disc” tribometer was used for measuring the coefficients of friction of a surface under different loads. Three 100Cr6 steel disc samples with a calculated roughness of $S_a = 0.12$ µm were prepared through grinding. Al_2O_3 ceramic balls with nominal diameter of 10 mm were used as counterparts in the test. The Vickers hardness of the ball is larger than 1500 HV and for the steel disc, it is about 700-800 HV. Three sliding tests were carried out under the same condition, varying the normal loads from 1N to 2N and 5N. The coefficients of friction were monitored for a sliding distance of 50 m at the sliding speed of 0.05 m/s under lubricated condition (lubricant: pure PAO). Each test was carried out twice and the mean values of the coefficients of friction in the steady states under 1N, 2N and 5N are $0.162 \pm 4.2\times10^{-5}$, 0.152 ± 10^{-3} and $0.137 \pm 5.2\times10^{-4}$, respectively.

A white-light confocal microscope (µSurf, Nanofocus, Germany) was employed to acquire the surfaces topography of the wear tracks. An objective with a numerical aperture of 0.8 was used in order to reduce the optical artefacts in the measuring results. The vertical and lateral resolutions for this objective are 2 nm and 312.5 nm respectively.

RESULTS & DISCUSSION

The topography of the wear tracks was segmented according to the feature of interest. For the case presented here, the hills on the surface are interesting for the description of friction and wear mechanisms. At first, the critical points are extracted according to the algorithms given in [9]. Than after Wolf Pruning the significant peaks are remaining. Finally, the surface is segmented by means of Marker Controlled Watershed [10] by setting the remaining peaks as Markers.

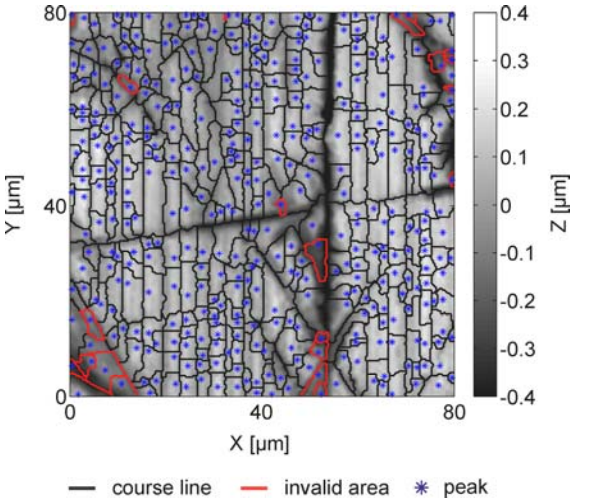

Figure 1: Hill segmentation of the surface on the wear track under a load of 5N.

The result of segmentation is presented in Figure 1. Each hill feature is bordered by its course line and has a shape that is effected by the solid contact during sliding. In order to characterize the shapes of the hill features, the following feature oriented parameters are defined. Mean Height is the average height of the features in a sampling area. The height of a feature is defined as the difference between a peak and its course line. Mean Area is the average area of features. Mean Aspect Ratio denotes the average lateral aspect ratio of features in the sliding direction. The sliding direction can be identified by calculating the most frequent orientation angle of the features. If the aspect ratio of a feature is small, it means the feature tends to have a longish form. Contrariwise, the feature tends to have a round form. Mean Peak Curv S indicates the average value of the approximate peak curvatures in the sliding direction. It is obtained by a least square 2^{nd} order polynomial surface formed by the surrounding points. Similarly, Mean Peak Curv PS is the average value of the peak curvatures in the direction perpendicular to the sliding direction. Larger peak curvature indicates a sharper shape of peak. Peak RMS denotes the root mean square value of the peaks. This parameter indicates the vertical distribution of the peaks in a sampling area. Peak Density is the number of the peaks in a unit area. This parameter describes the lateral distribution of the peaks.

Load	1N		2N		5N	
	mean	std	mean	std	mean	std
Mean Height [µm]	0.168	0.009	0.163	0.016	0.155	0.009
Mean Area [µm²]	17.31	1.55	16.52	1.71	14.57	1.17
Mean Aspect Ratio	0.497	0.008	0.466	0.026	0.470	0.015
Mean Peak Curv S	0.121	0.013	0.108	0.017	0.098	0.009
Mean Peak Curv PS	0.218	0.013	0.236	0.015	0.268	0.013
Peak RMS	0.070	0.009	0.066	0.007	0.063	0.004
Peak Density [1/µm²]	0.057	0.005	0.059	0.006	0.067	0.005

Table 1: Comparison of the parameters of the surface on the wear tracks under different normal loads. (std: standard deviation)

Ten positions on a wear track under different normal load were measured and the respective mean values of the parameters are presented in Table 1. The lowest 5% of all peaks in a sampling area are assumed not to be in solid contact. These regions are not taken into consideration by calculating the parameters.

The values of Mean Height and Mean Area decrease with increased load. This shows that hill features in the steady states tend to have finer structures with lower amplitude by increasing load. The values of Mean Aspect Ratio indicate that hill features tend to have more longish structures by increased normal load in the sliding direction. The Mean Peak Curv S (in sliding direction) decreases with the normal load. This shows that the peak shapes become smoother in the sliding direction by increasing load. Contrariwise, the Mean Peak Curv PS (in the direction perpendicular to the sliding direction) indicates that the shapes of peaks are sharper in this direction with increased load. The values of Peak RMS show that the height of peaks has less deviation from the mean value by increasing the normal load. Peak Density indicates the amount of peaks in a unit area increases with the normal load.

Even though the Vickers hardness of the ceramic ball is about twice as larger as the steel disc, the wear of the ceramic ball is not negligible. Therefore, the surface topographies of the balls were also characterized. Figure 2 shows the surface of the ball in the wear zone under a load of 5N. The features of interest are here the pores in the wear zone. The pore areas in the wear zone under diverse normal load change, which can indicate the wear mechanisms for the surfaces of ceramic balls.

In order to characterize the pore area and volume, an algorithm [8] was applied for detecting the pore structures. Before applying the algorithm, for reducing possible artifacts error, a double filtering to the balls topography was applied. In the first step, for flattening the surface, a least square spherical surface was removed from the original image. In the second step, the surface roughness was removed through a wavelet filter [11] with a filtering threshold for the wavelet coefficient $T = 0.5 \cdot S_a \cdot \sigma$, where S_a is the average amplitude of the surface, σ is the difference between the maximum and the minimum value of the flattened surface.

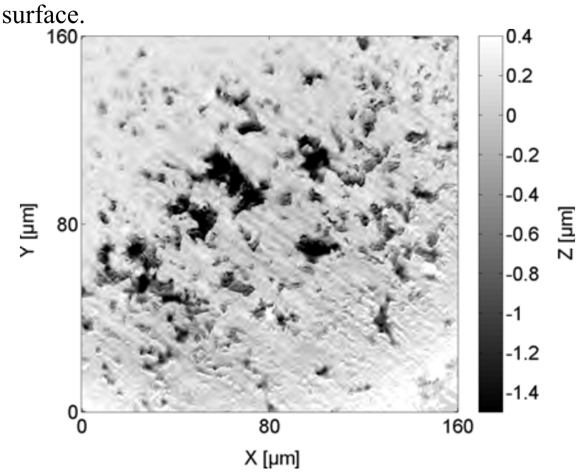

Figure 2: Surface topography after an application of a wavelet filter in the wear zone under a load of 5N in the steady state.

The result for detection of the pores in the wear zone under a load of 5N is presented in Figure 3.

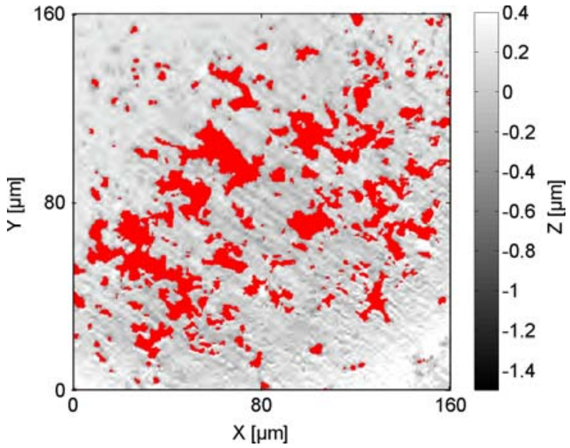

Figure 3: Result for detection of the pores in the wear zone under a load of 5N in the steady state.

Below, the feature oriented parameters designed to analyze the pore area and volume are summarized. Total Area and Volume are the total area and volume of the pores in a sampling area, respectively. Mean Area and Mean Volume are parameters indicating the average value of areas and volumes for each pore. For calculating the pore depth, 95% Depth instead of the maximal depth is used to reduce the evaluation uncertainty for the optical measurement. 95% Depth represents the depth value after removing the lowest 5% values of one pore. Mean 95% Depth is the average value of the 95% Depth of each pore.

Load	1N	2N	5N
Total Area [µm²]	2284	2762	4239
Total Volume [µm³]	1463	1722	3412
Mean Area [µm²]	15.43	11.56	16.89
Mean Volume [µm³]	9.889	7.206	13.60
Mean 95%Depth [µm]	0.6964	0.7564	0.7754

Table 2: Comparison of the parameters for the pore characterization in the wear zones of the ceramic balls under different normal loads.

Total Area and Volume of pores show a clear relationship with the normal loads. This indicates that the amount of wear debris broken from the ceramic surface increases with the normal load. Increased ceramic debris, together with the steel debris, can give rise to the decrease in friction [5]. The Mean 95% Depth represents a trend that the depth of pores increases with normal loads. This means the ceramic fragments break deeper from the surface caused by increased local contact pressure. The Mean Area and Volume do not correlate with the normal load.

SUMMARY

The feature oriented characterization technique was applied to analyze the worn surfaces after sliding tests. The feature oriented parameters can help the users to easier understand the geometrical information about the surface feature such as hill regions on the surfaces of the steel discs and pores on the ceramic balls. Most of the feature oriented parameters designed in this paper can correlate with the tribological behavior.

In comparison to calculating the standard parameters, the computational efforts of the feature oriented characterization technique are larger and it needs also priori-knowledge about surfaces.

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