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The use of multiscale transfer functions for understanding the impact of successive mechanical treatments on surface topography

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ABSTRACT

This paper shows how a multiscale transfer function can be used to understand the impact of successive mechanical treatments (superfinishing, sandblasting and brushing) on topography. The multiscale analysis indicates that the changes of roughness induced by brushing are not uniform on the entire range of frequencies. The transfer function built with the arithmetic mean deviation (S_a) leads to identify two regimes of roughness: the ability of brushing to “create roughness” and the ability of brushing to “remove roughness” caused by blasting.

1. Introduction

Topography conditions several key properties of surface: mechanical and tribological properties (e.g. wear resistance [1], adhesion [2], hardness [3]), chemical properties (e.g. corrosion [4]), optical properties (e.g. gloss [5]), thermal properties [6], electrical properties [7], …. Different strategies have been developed in order to link the topography with the surface functionality or the process conditions. As an example, Li et al. [8] described the relation between surface roughness and burnishing force using the assumption of Winkler foundation. Bigerelle et al. [9] used a fractal function combined with a stochastic wear model in order to model superfinishing by belt grinding process. El-Sonbaty et al. [10] developed artificial neural networks models in order to link the cutting conditions of milling and the obtained surface roughness profiles.

However, a combination of different processes (e.g. polishing, sandblasting, superfinishing, electro-discharge machining …) is often used in order to obtain the final surface functionality of a given mechanical component. After each process, the mechanical properties and topography of the surface are modified. The issue is then to understand how each step, or more precisely each process, modifies the topography in order to be able to optimize the final surface functionality. As indicated by Thomas et al. [11], this could be named ‘traceology’: this is the search of a link between the changes of topography and the steps used to produce the surface.

The transfer function of the topography, defined as the ratio between the output signal and the input signal, has already been chosen as a tool for estimating surface quality but the signals used for the investigation differ from authors to authors. Hafiz et al. [12] examined the influence of overlapping between two successive laser beam tracks on surface quality using transfer functions based on the power spectral density function computed in the spatial frequency domain. Zahouani et al. [13] used three-dimensional continuous wavelet transform in order to determine the multiscale transfer function of machining by abrasion for each step of the finishing process. Wieland et al. [14] chose to characterize surface treatments composed of several processes with a transfer function defined using individual Fast Fourier Transformation coefficients. They defined multiplicative transfer functions using sets of Fast Fourier Transformation coefficients and proposed the use of additive transfer terms when the examined process tend to create new roughness components.

This paper shows how the definition of a multiscale function based on a simple roughness parameter can help understanding how the interactions between successive surface treatments lead to get the aimed surface state. This methodology of investigation is applied to a set of surfaces that were successively superfinished, sandblasted and brushed in order to get a specific brightness for watch dials. In a previous work [15], the link between roughness and brightness was searched using different roughness parameters and filtering conditions.

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The best relation between roughness and brightness was identified using the arithmetic mean deviation S_a with a high-pass filter having a cut-off length of 15 μm. As using the arithmetic mean deviation S_a was found to be the most relevant roughness parameter for the examination of brightness, this paper is mainly focused on the changes of this roughness parameter, from which a multiscale transfer function is built. Section 2 of this paper is devoted to the description of the material, process parameters and roughness measurements. Section 3 investigates the effects of successive processes (superfinishing, blasting and brushing) on the topography using multiscale decomposition. These results are then discussed and conclusions are drawn.

2. Materials and methods

2.1. Material and process parameters

The examined material is brass. In order to analyze roughness changes induced by the successive processes, the topography obtained with different combinations of processes are examined:

- superfinishing alone is examined. It corresponds to the use of a finer grit solid abrasive to remove the thin surface layer produced by the initial grinding. Superfinishing is considered as the initial surface condition (there are 3 samples to examine reproducibility).
- superfinishing followed by sandblasting (there are 9 samples as different sandblasting conditions are tested),
- superfinishing followed by brushing. Brushing, also called dull polished metal, corresponds to a unidirectional satin finish (there are 3 samples to examine reproducibility),
- superfinishing, sandblasting and brushing (9 samples).

For superfinishing and brushing, the same process parameters are used on all the specimens. As for sandblasting, the nozzle-to-specimen height and pressure are varied while the nozzle angle and duration are kept constant. Nine specimens having different topographies are obtained by combining five pressure values and five nozzle-to-specimen height values. These combinations were chosen to vary the brightness of watch dials. Table 1 shows the different combinations with the corresponding specimen numbers.

2.2. Roughness measurements and multiscale analysis

For the measurement of topography, an optical profiler (WYKO NT9300, VEECO, United States) with a x100 objective is used. The measured areas have a surface of 127 μm x 92 μm, with a lateral resolution of 0.55 μm and a corresponding vertical accuracy approximately equal to 0.1 nm. Twenty measurements are made on each surface. The topography characteristics are analyzed using a multiscale decomposition of roughness with different types of filters:

- Robust Gaussian filters [16]: high-pass, low-pass and band-pass. The cut-off lengths (i.e. the wavelengths from which the filter starts filtering) are chosen in order to follow a geometric progression. There are equal to: 0.8, 1, 1.2, 1.4, 1.7, 2, 2.6, 3.1, 3.9, 4.8, 6, 7.5, 10, 13, 17, 24, 40, 60 and 120 μm. As for the band-pass filter, only the first-cut-off length of the filter is indicated. The bandwidth can be found by subtracting equal this value to the next larger cut-off length. As an example, for the label 'DE 10 μm', the first cut-off length is equal to 10 μm and the bandwidth is equal to (13−10) =3 μm.
- Discrete wavelet filters with different taps: Coiflet (1–3), Symlet (1–4), Daubechies(1–5) [17],
- Modal filters [18]: high-pass and low-pass.

Table 1
Pressure and nozzle-to-specimen values for the sandblasted specimens.

Specimen number	Nozzle distance (cm)	Pressure (bar)
1	20	0.9
2	20	2.6
3	5	0.9
4	5	2.6
5	10	1.7
6	30	1.7
7	0	1.7
8	10	0.5
9	10	3

The use of these different filters makes it possible to highlight different characteristics of waviness and surface microroughness.

As the arithmetic mean deviation S_a [19] was previously shown to be the best parameter for the description of the relation between roughness and brightness [15], the following investigation is mainly focused on the changes of this roughness parameter. All the mean values and confidence intervals (standard deviations) are obtained using 100 bootstraps. Bootstrapping consists in randomly sampling the data with replacement. It allows assigning confidence intervals and more generally measures accuracy.

3. Results and discussion

3.1. Multiscale analysis of each process

The examined brass specimens are successively superfinished, sandblasted and brushed. In order to examine how those successive processes change the surface morphology, surfaces that are only superfinished are investigated first. Then, surfaces that are successively superfinished, sandblasted and brushed are studied. It should be noted that morphology is analyzed using mainly Gaussian filters to determine the characteristic lengths of the topographies given by the different processes. The other filters were tested as well but were found less relevant (their results are often not shown for the sake of brevity).

3.1.1. Superfinishing process

First, topography modifications induced by superfinishing are analyzed using roughness measurements. The arithmetic mean deviation S_a is calculated using different types of filtering. Only the results given by the Robust Gaussian filter are hereafter discussed as only this type of filter indicates characteristic lengths of the process topography. Fig. 1 shows the arithmetic mean deviation S_a as a function of the cut-off length, using a Robust Gaussian band-pass filter for the superfinished specimens. This graph shows the distribution of the S_a mean values and the associated confidence intervals. All three superfinished specimens show similar arithmetic mean deviation values. Thus, the

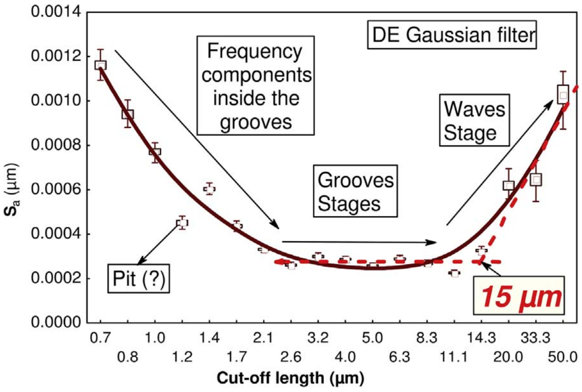

Fig. 1. Mean values and associated confidence intervals of the arithmetic mean deviation S_a as a function of the cut-off length, using a Robust Gaussian band-pass filter (DE), for the superfinished specimens.