Multi-scale geometric analyses and the metrology of surfaces created by micro-EDM

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Abstract

Topographies created by micro-EDM are studied using multi-scale area, complexity and curvature analyses. Previously, the relative areas and area-scale complexities were found to correlate strongly with the discharge pulse energy [1]. In the current work, the scale of the maximum area-scale complexity is found to increase with the discharge energy. At finer scales the complexities all decrease and the frequency of the changes in the curvature with respect to position increase markedly as the discharge energy decreases, consistent with the crater size and re-solidified textures.

1. Introduction

The objective of this work is to advance the analysis of micro metrology to improve the multi-scale characterization of manufactured topographies. Appropriate analysis and characterization of measured topographies is critical for finding functional correlations with processing parameters. These functional correlations are valuable for the design of products and processes. The discovery of functional correlations is facilitated by multi-scale analyses [1]. Earlier work found strong correlations between the energy for micro-electric discharge machining (µEDM) of stainless steel and the resulting surface topography between 10 and 200 µm² [1] using area-scale and area-scale complexity analyses [2, 3]. These analyses are examined further and curvature-scale analysis is introduced. Curvature has been used to find functional correlations with fatigue limits of steel machined by ball-end milling [4].

2. Methods

Stainless-steel was µEDMed with five pulse energies from 18 nJ to 16 500 nJ [1]. They were each measured four times with a Scanning Laser Confocal Microscope (Olympus LEXT OLS 4000) with a 100X objective (NA 0.95; wavelength 405 nm). The measurement region was 128x128 µm and sampling interval was 125 nm, which is close to the limit given by the Sparrow criterion (about 200 nm). Area-scale and complexity-scale relations [2, 3] were calculated using Sfrax (www.Surfract.com). The scale of the maximum complexity was determined. Curvatures were calculated as a function of scale and position based on Heron's formula, as a function of scale and position, on profiles extracted from the areal measurements [4].

3. Results

Renderings of confocal measurements of surfaces µEDMed with pulse energies from 16 500 nJ and 24.5 nJ are shown in Fig. 1. Individual discharge craters are discernible at the larger discharge energy and much finer at the lower, which is consistent with expectations and previous findings on the smooth-rough crossover [2, 3] correlating with pulse energy [1]. The interior of the craters appears to be relatively smooth at the larger energy and is not discernible at the lower.

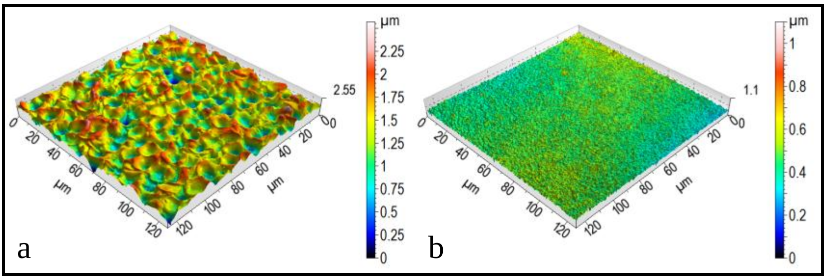

Fig 1. Renderings of confocal microscope measurements of surfaces µEDMed with pulse energies of 16 500 nJ (a) and 24.5 nJ (b).

Area-scale and complexity scale plots of the mean relative areas and area-scale complexities are shown in Fig. 2. The complexity scale represents the change in relative area versus scale. The scale at which the maximum complexity occurs for each discharge energy decreases with decreasing discharge energy. The complexities at the finest scales tend to diminish.

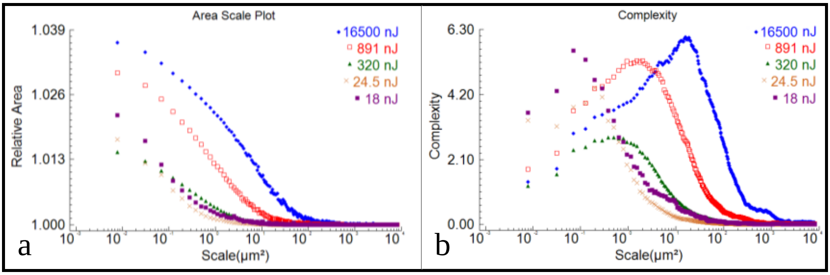

Fig 2. Multi-scale areal analyses showing the relative areas versus scale (a) and the complexity versus scale (b) for the indicated energies.

Curvatures are shown versus position and scale in Fig. 3. The vertical axis is the curvature and the scale is shown on a log axis to the right with the position along the analyzed profile on the left. The frencuency of the change in curvatures is clearly greater at the lower discharge energy. Concave up features have positive curvatures, which correspond to the bottoms or craters. Convex up are negative features and correspond to the ridge-like features and peaks at intersections between the craters.

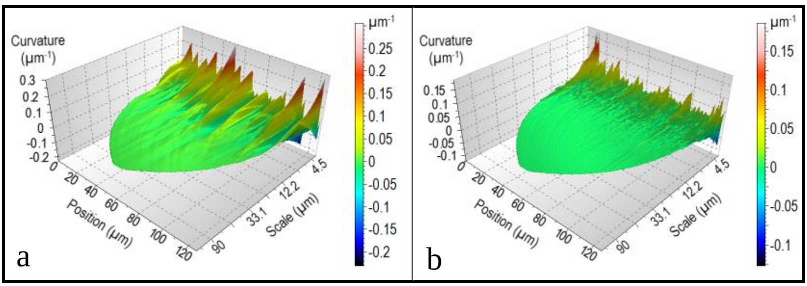

Fig. 3. Plots of the curvature versus position and scale for discharges of 16 500 nJ (a) and 24.5 nJ (b)

4. Discussion and Conclusions

The action of the discharge melting the surface, and flow and re-solidification of the melted material forming craters is consistent with the features in the measurements.

Larger pulse energies produce larger relative areas and maximum complexities at greater scales. The relative areas at the fine scales include the influence of large scale features. Complexity analysis characterizes the change in relative area with respect to scale. Unlike relative areas complexity is not influenced by the features at larger scales, and therefore has advantages for comparing topographies at the finer scales. The tendency towards similarly low complexities at the fine scales could be indicative of the common relative smoothness of the re-solidified material. However this could also be due to the decreasing resolution at the finer scales as the limit given by the Sparrow criterion is approached.

The relative area can be related the slopes on the surface. The spatial derivative of the slope is related to the curvature. The curvatures appear to mostly positive and be dominated by the discharge craters rather than the ridges and peaks between the craters

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