Characterization of blasted surfaces with mesh-based parameters

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Abstract

This paper presents an approach for the determination of surface parameters based on a mesh calculated from identified features. The resulting mesh-based parameters are used to assess the homogeneity of the feature distribution on the surface. The preparation of the data is a prerequisite for creating the mesh. The input data of a surface has to be processed in such a way that the features can be identified, which are the valleys for the examined blasted surfaces. For this, areal measurements and the application of filters are necessary to separate the features. In the next step a mesh is created. The simplest form is a triangular structure, which has already been used to describe the homogeneity of surfaces with particles. Based on this, various characteristics are evaluated and analyzed statistically. The method has been applied to four surfaces blasted with different blast media as an example.

Keywords areal surface characterization, mesh-based parameters, surface topography.

Introduction

To study the effect of manufacturing processes or the function, e.g. wear behaviour or optical appearance, the geometrical microstructure can be characterized. The new ISO 21920-2 in 2D and the ISO 25178-2 in 3D offer parameters to assess the properties of surfaces. [1, 2] Many of these parameters are based on the evaluation of amplitudes. In the context of blasted surfaces additional information can be gained from the distribution of areal surface characteristics and the homogeneity of surface features.

From a mathematical point of view there is "no accepted metric for the level of inhomogeneity in a given node pattern". [3] There exists no generalization of results and so they are only valid for the special investigated scenario. [3] In engineering, there are different applications where homogeneity is important, for example for composite materials.

Various papers have been published where the Delaunay triangulation is used to describe the distribution of particles in composites. Zhang et al. give an overview of different methods to evaluate the inclusion homogeneity of composites, including Delaunay triangulation as one method based on the inter-distance of points. [4] In general, the method consists of two main process steps: detecting the features (points) and calculating the mesh with the resulting parameters. Bray et al. applied the Delaunay network to describe the nanoparticle dispersion of composites. [5] They processed the image and identified the hull of particles. Then calculated the center of mass points and meshed those. Sul et al. include the Motif analysis in the image processing. [6]

Two more examples are the application of this approach for the classification of polyps from endoscopy pictures in medicine and the analysis of particles in cement in construction engineering. [7, 8] Both use image processing to extract the features. In this paper, we describe a process how to adopt the existing method for blasted surfaces and derive an approach to calculate parameters for the evaluation of homogeneity.

Experimental Methods

Materials

As examples, four different surfaces created with different blast media are used. The blast media is varied in two sizes and two different geometrical designs. The letter S stands for spherical media named CHRONITAL, which is highly break-resistant and durable. The other media is GRITTAL GM with angular broken shape. The size is indicated by the number (60 = 0,7 - 1,25 mm and 10 = 0,05 - 0,2 mm).

A special developed blasting machine, called Twister, has been used to machine the specimens. There is a spin wheel located in the middle of the machine that distributes the blast media in a defined way for a uniform surface finish. The workpiece carrier rotates around itself and around the spin wheel. For the examples a speed of 9000 min^{-1} and a process time of 10 min has been applied.

Measurement

A confocal microscope with a 20 times objective has been used to extract a part of the blasted surface. The generated data is the basis for the identification of the features, which are the holes resulting from the impact of the blast media. The aim is to describe these features as points and to create the mesh in the following step. Figure 1 shows the blast media on the left and the measurement result for the four different surfaces.
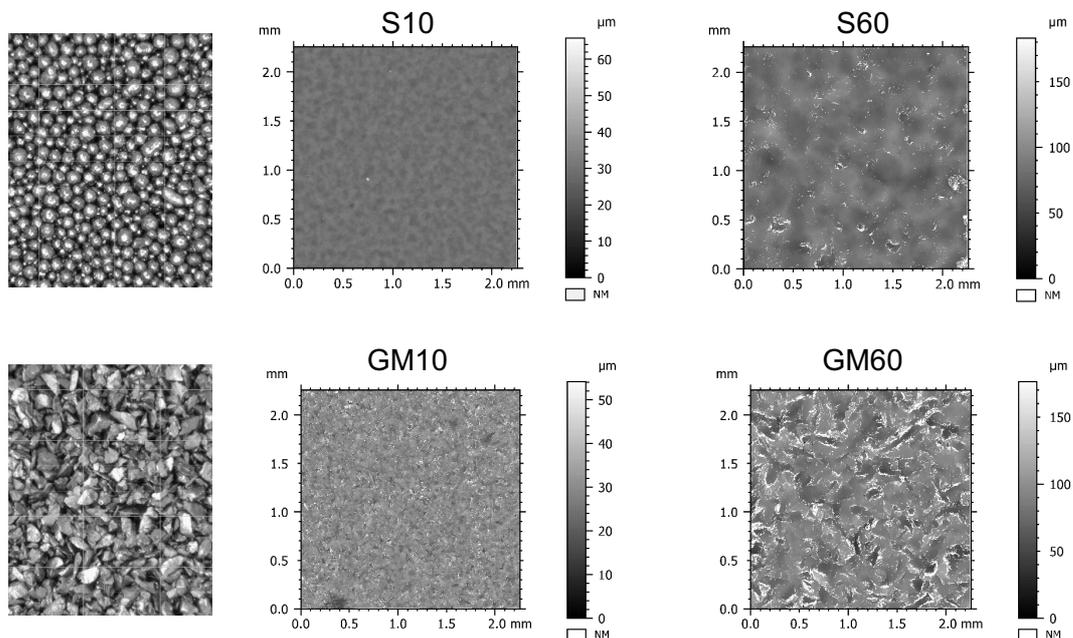

Figure 1. Blast media (left) and surface data for four probes

Data processing and filtering

The software MountainsMap® has been used to calculate all pre-processing steps and generate surface pictures. All four surfaces are prepared and then filtered with the same strategy to get comparable results. The data preparation follows three steps (Figure 2):
1. Extract topography layer, since the data of the measurement is multichannel data consisting of the topography and the intensity
2. Crop the data to 1x1 mm
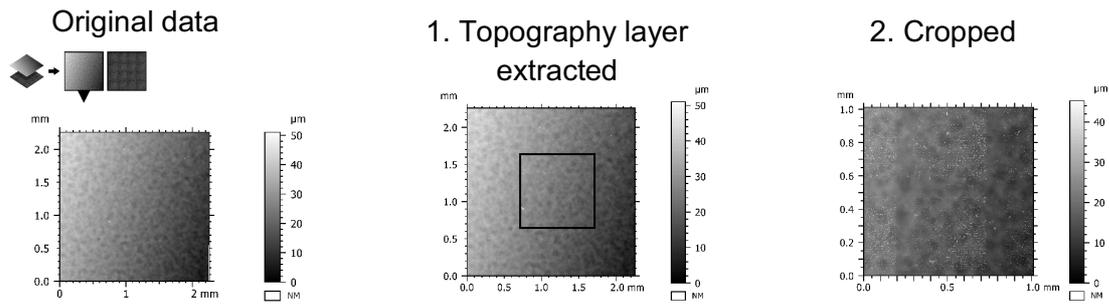3. Fill non-measured points

Figure 2. Data preparation of the surface (example S10)

After that, filters have been applied to detect the valleys as features. The filtering process is a combination of Gaussian filter to create the S-F-surface [2] and the Motif Analysis with Wolf-Pruning. [9] In the first step the alignment with LS-plane removes the tilt of the probes and so the form (F) by cutting long wavelengths. The S-Filter removes short wavelengths (roughness) with a Gauss filter of 8 µm. The result is the extracted waviness of the surface.

Motifs identify structures on surfaces as watershed segmentation method. [9] The method fills insignificant valleys slowly with water. On the saddle point, the water will flow into the adjacent valley. If that valley is significant they are combined, otherwise the filling is continued. A change tree shows the results and is the base for wolf pruning (Figure 3). Therefore, the difference in height between valley or peak and the adjacent saddle point is calculated. The pruning method finds those with the smallest height difference and combines with the adjacent saddle point. The process continues until a specific threshold is reached. Here the threshold is a percentage of the value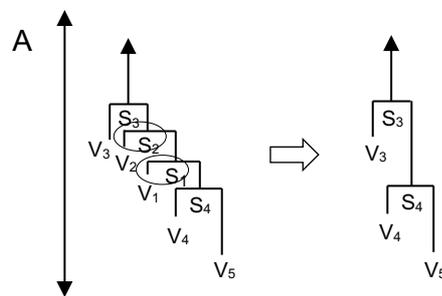 Sz and as second criteria a percentage of the surface area. Table 1 gives an overview of the applied filters for each probe.

Figure 3. Change tree with A (height in µm), V (Valleys), S (saddle point) (after [2])

Table 1. Summary of filters

probe	Gaussian filter (in µm)	Motif analysis		
		Size of smoothing filter	Pruning (%Sz)	Pruning (%Surface area)
S10	8	5x5	5	0,1
S30	8	5x5	5	0,17
GM10	8	5x5	5	0,1
GM60	8	5x5	5	0,15

The point cloud represents the extreme values (x and y-coordinate) for each motif. Points which lie within a distance from 0 to 0,01 mm from the four edges are deleted. They are on

or near the edge and it is impossible to know if these points are really the extreme points of the valleys or the valley is deeper outside the section.
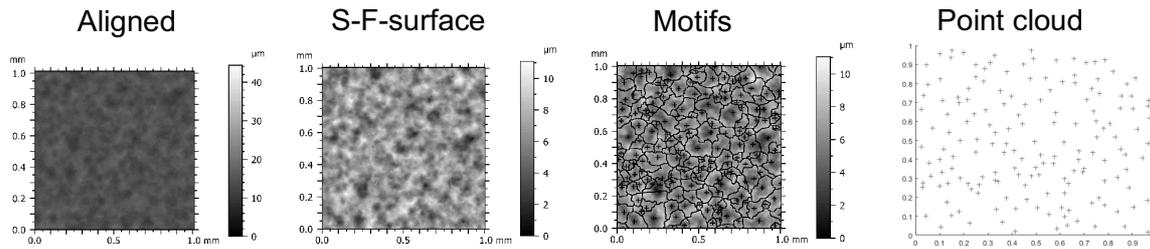

Figure 4. Filtering for example S10

Meshing

The next step is to create a mesh of the determined points of the surface (2D). The simplest structure are triangles, since they connect the points in the smallest possible distance. The Delaunay-Triangulation creates a mesh in such a way that no point is inside the circumcircle of any triangle, therefore it maximizes the minimum of all angles of the triangles. As stated in [4] these properties are suitable to describe homogeneity in general. Therefore, this algorithm is suitable and here applied for blasted surfaces. The algorithm and the following calculation of parameters are executed with MatLab.
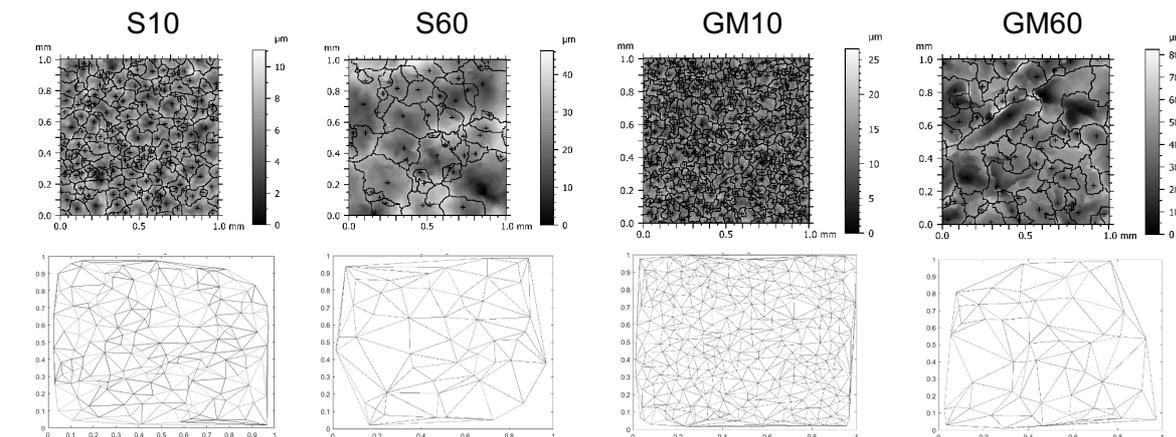

Figure 5. Surfaces with Motifs and the created Delaunay triangulation

Parameter

The Delaunay method creates triangles that can be geometrically described by side length and area. These two parameters are statistically analysed by calculating the mean value and standard deviation. Regular patterns show low values for standard deviation and irregular ones high values. In reference to other papers, the Area Disorder AD is calculated by

$$AD = 1 - \left(1 + \frac{\sigma_A}{\bar{A}}\right)^{-1}$$
(1)

and the variation index DT by

$$DT = \frac{\sigma_A}{\bar{A}}$$
(2)

where σ_A is the standard deviation of the triangle area and $\bar{A}$ the mean area. [4, 10] AD has a range from 0 to 1. The value 0 describes perfect order. A high value AD or DT means

clustering and poor homogeneity. The histograms of side length and area show the distribution of these parameters.

Experimental Results

Table 2 presents the results for Sa and the number of Motifs as an example of standard parameters from the ISO standards. Comparing the results does not provide an information about the distribution of the features. The parameters in Table 3 on the other hand are a new possibility to describe the homogeneity.

Table 2. Results for selected standard parameters

Probe	Sa (µm)	Number of Motifs
S10	1,09	185
S60	5,66	54
GM10	2,2	388
GM60	9,73	68

Table 3. New parameters for four different blasted surfaces

Probe	Mean side length (mm)	Standard Deviation of side length (mm)	Mean Area (mm^2)	Standard Deviation of Area (mm^2)	DT	AD
S10	0,093	0,056	0,00275	0,00157	0,57	0,36
S60	0,177	0,104	0,00859	0,00580	0,68	0,40
GM10	0,065	0,050	0,00130	0,00078	0,60	0,37
GM60	0,164	0,094	0,00796	0,00611	0,77	0,43

The values show a bigger difference between the 10 and 60 than between the blast media S and GM. This could also be due to an influence of the size of the considered section, since there are fewer points for the bigger size blast media. The side length is influenced by the edge of the mesh where big ones can occur in long pointed triangles. The values DT and AD without units give similar results as expected.

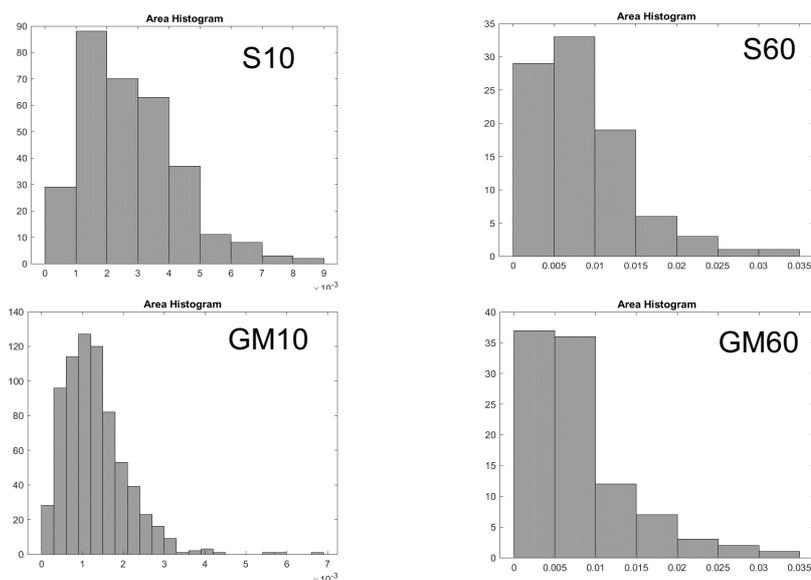Figure 6 displays the histograms for the area.

Figure 6. Histograms of the triangle area distribution

All four surfaces show a regular mesh pattern and together with the parameters can be categorized as homogeneous.

Discussion and Conclusions

The general approach with image processing, generating a mesh and calculating parameters is successfully applied. To validate the findings the method has to be applied on a wider range of surfaces. First for a larger number of surfaces manufactured the same way. Secondly for different process parameters for example with different process time. The shown examples are all homogeneous and it is of great interest to compare the results also to inhomogeneous surfaces. The aim is to define the limit of at least one parameter for a homogeneous surface (Figure 7).
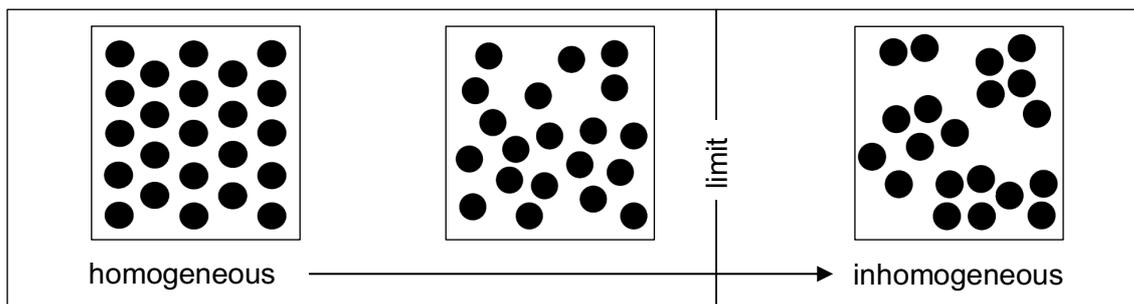

Figure 7. (In)homogenous surface

In general, the approach only focusses on the homogeneity of features and lacks the complete description of the surface as 2,5/3D topography. Therefore, the dimension of the features, for example the z-values or volume, will be described as a next step.

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