

## Spikes removal in surface measurement

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**Abstract.** Several cylinder surface topographies made from grey cast iron were measured by Talysurf CCI white light interferometer with and without use of spikes filter. They were plateau honed by abrasive stones. Measured area was 3.3 mm x 3.3 mm, height resolution was 0.01 nm. The forms were eliminated using polynomial of the 3<sup>rd</sup> degree. After it, spikes were removed using four methods. These approaches were compared. Parameters of the smaller and highest sensitivity on spikes presence were selected.

### 1. Introduction

The initial assessment of surface topography was made simply by running a fingernail across the surface. This technique survives to this day as tactile comparison. The first surface topography measuring instrument was the light section microscope developed in Germany early in the XX century. The subject of surface roughness measurement began when a simply profilometer was developed. The measurement process was achieved by drawing a stylus across a surface and recording vertical deviations of the surface. From the late 1970s analogue instruments were replaced by those supported by computers [1]. A number of profiling techniques have been developed for measuring the topography of rough surfaces. There are several types of optical techniques in addition to the contacting stylus method and atomic force microscopy. These include white light interferometer [2], confocal methods [3] and others [4, 5, 6]. Optical measurement suffers from the same intrinsic constraints as the stylus technique but also has additional problem that the scattered light from the surface does not entirely react normally to the surface which restricts optical use in some application [4]. During the period of development of traditional stylus type instrumentation for areal (3D) measurement huge progress was made (mainly in the USA) with regard to development of optical systems. Contrary to stylus methods which are robust but slow optical methods are fast but more sensitive to extraneous effects. Optical methods need isolation of devices from the external environment. Both thermal and vibrations changes influence reliability of the results. Very careful cleaning of the measured surface is necessary from the point of view of the industrial application. Sharp edges, inclusions, defects and other peculiarities of the surface can cause outliers and dropouts of data points in the topographical images measured with optical methods, more than with stylus technique.

Scanning white-light interferometry is gaining more and more importance in research and development as well as in manufacturing quality control [7, 8]. It is probably the most useful optical instrument at present in use for measuring surfaces, films and coatings [4]. White light interferometer has been shown to be susceptible to a skewing effect when the amplitude is less than the coherence length of the light source. This skewing effect leads to spikes in the profile data near steep edges



[1, 9]. Although new types of measurement interferometers are produced, the noise-like spikes presence is still a real problem.

Spikes in the data points should be detected and points interpolated to prevent singularities. There are various selective spike-removal filters. Application of morphological filters [10] and removal through detection of points of high slopes [11] can be the examples.

The fundamental aim of investigation is to compare different methods of spikes removal from the data points. The other aim is to select parameters of the smallest sensitivity on spikes presence.

## 2. Material and methods

Several cylinder surface topographies made from grey cast iron are the object of investigations. They were plateau honed by abrasive stones. Cylinder liners were measured by Talysurf CCI white light interferometer. Measured area was 3.3 mm x 3.3 mm, height resolution was 0.01 nm. Surfaces were measured in the same place with and without use of spikes filter. The forms were removed using polynomial of the 3<sup>rd</sup> degree. After it, spikes were removed using different methods. Areal surface topography parameters were then calculated using software Talymap Gold for surfaces with and without removed spikes.

The parameters from ISO 25178 standard [12] were analysed:

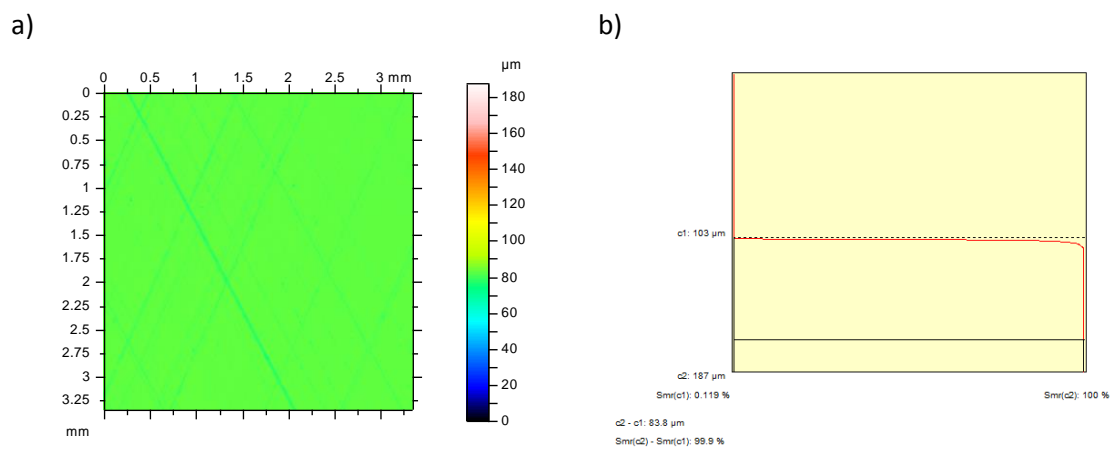
- height: Sq, Sa, Ssk, Sku, Sp, Sv and Sz,
- functional: Smr, Smc and Sxp,
- spatial: Str, Sal and Std,
- hybrid: Sdq and Sdr,
- functional volume : Vm, Vv, Vmp, Vmc, Vvc and Vvv,
- feature: Spd, Spc, S10z, S5p, S5v, Sda, Sdv and Shv.

Feature parameters were computed after a discrimination by segmentation using a Wolfpruning of 5% of the value of the Sz parameter. Also parameters from the Sk family were calculated: Sk, Spk, Svk, Srl, Sr2, Sa2 and Sa1. Digital filtration was not used.

In addition, surfaces were measured in the same place (mechanical relocation method was applied) using spikes removal procedure of measuring equipment.

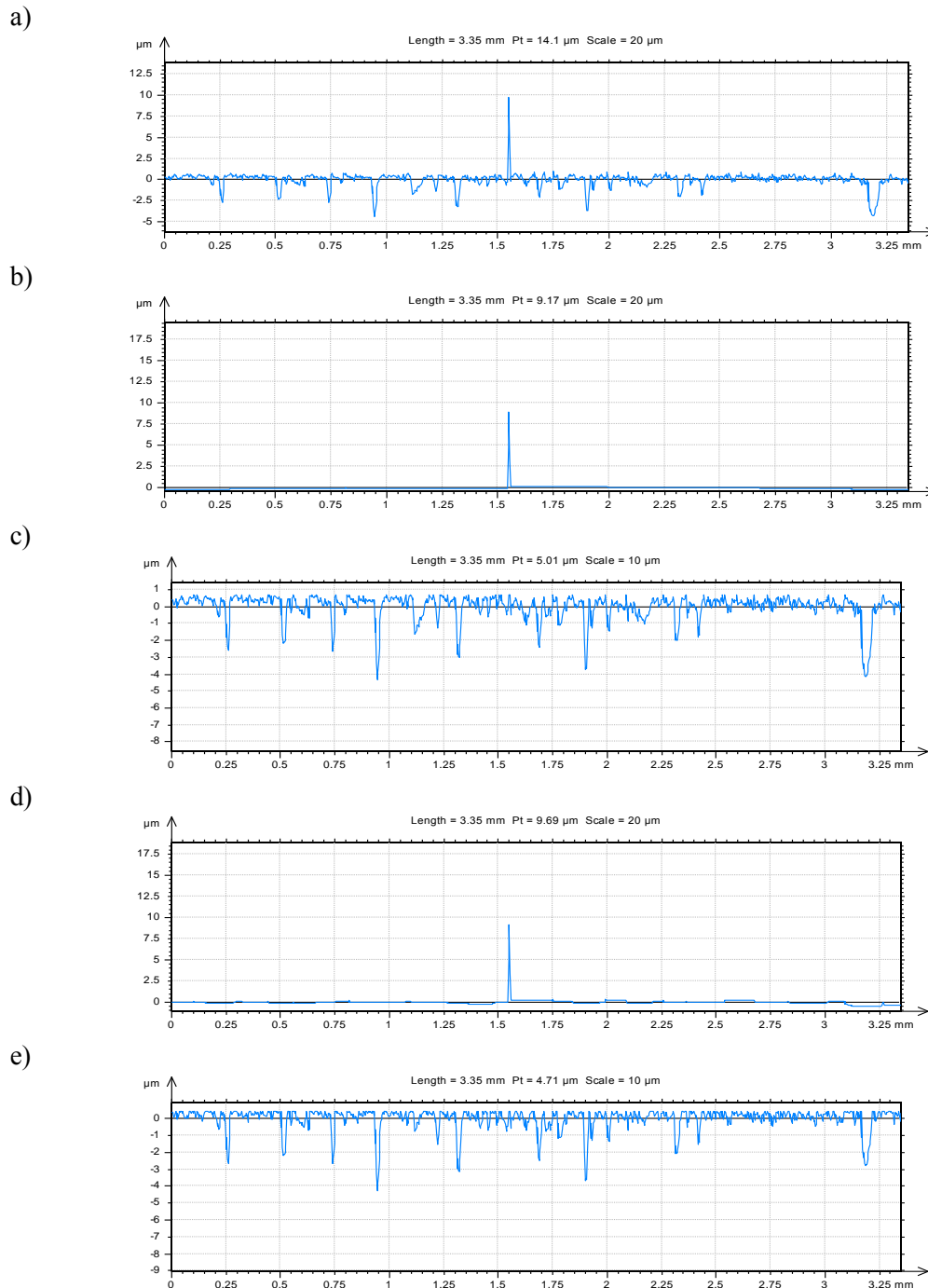
## 3. Methods of spikes removal

The first method used is based on the shape of material ratio curve. About 20 cylinder liners were analysed. When spikes are presented, the initial upper part of this curve forms a straight vertical line (see Figure 1 b).



**Figure 1.** Contour plot of cylinder surface containing spikes (a), material ratio curve of this surface (b)

For spikes removal, the point of material ratio curve shape changing should be determined and then surface ought to be truncated from ordinate of this point. After analysis of many surfaces, it was decided to threshold the surface from point of material ratio 0.13%, which means that when material ratio is smaller than 0.13%, the ordinate should be equal to height corresponding to this ratio.

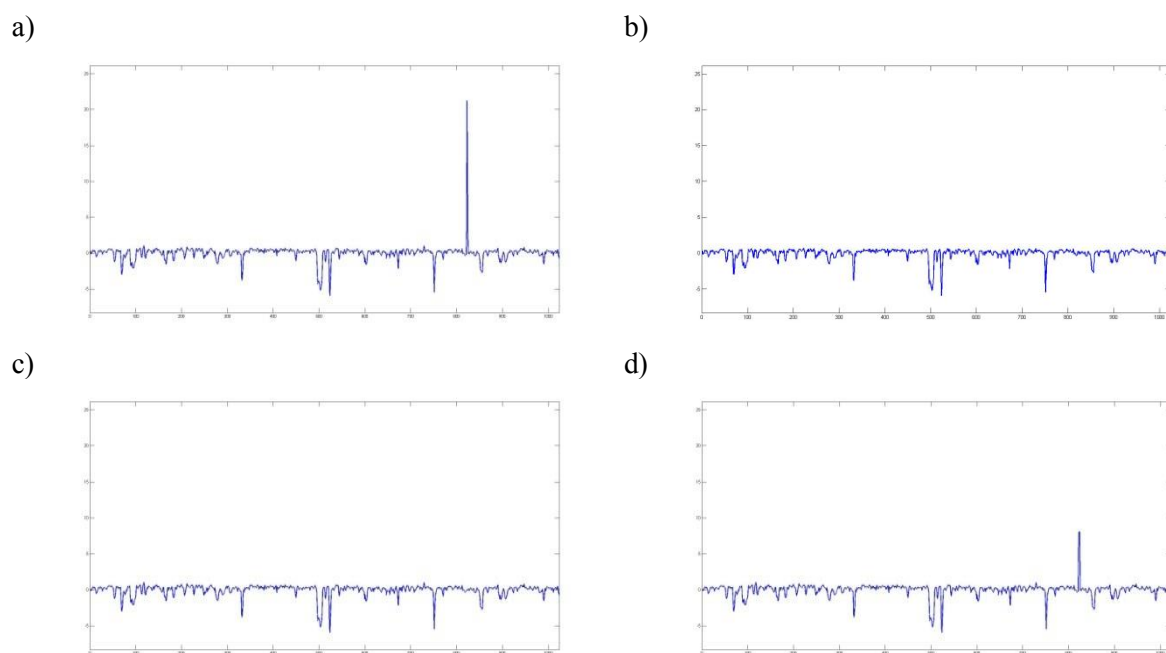


**Figure 2.** Cylinder profile containing spike (a), filtered profile using horizontal line of 0.2 mm length (b), residue profile without spike (c), filtered profile using horizontal line of 0.05 mm length (d), residue profile without spike (e)

Additionally, for random surface of Gaussian ordinate distribution height difference between material ratios 0.13-99.87% is equal to 6 standard deviation of surface amplitude [13]. It was also found previously that when height of areal cylinder surface is limited to material ratios between 0.13% and 99.87% areal (3D) surface height is similar to that of 2D profile [14].

In the other method closing filter was used with structuring element of horizontal plane shape. The filtered surface is the upper envelope. Residue surface (unfiltered minus filtered) doesn't contain spikes. The length of this shape should be selected carefully. When it is too small, the structuring elements penetrates into deep valley, so residue surface can be distorted. For too big length, large wavelengths are eliminated. The intention of the present authors was to remove spikes only. The length of structuring elements should be smaller than distance between two adjacent spikes. Therefore in selection of length of structuring elements the widths of valleys and distances between spikes should be considered. After taking these limitations into consideration it was decided to select length of structuring element as 0.2 mm. Figure 2 presents illustration of this method. When length of structuring element was too short (0.05 mm) the filtered profile was affected by some irregularities (for example wide valley in the right side of figures) and consequently the height of residue profile was underrated. When the length of structuring element is 0.2 mm, filtered profile contains mainly spike.

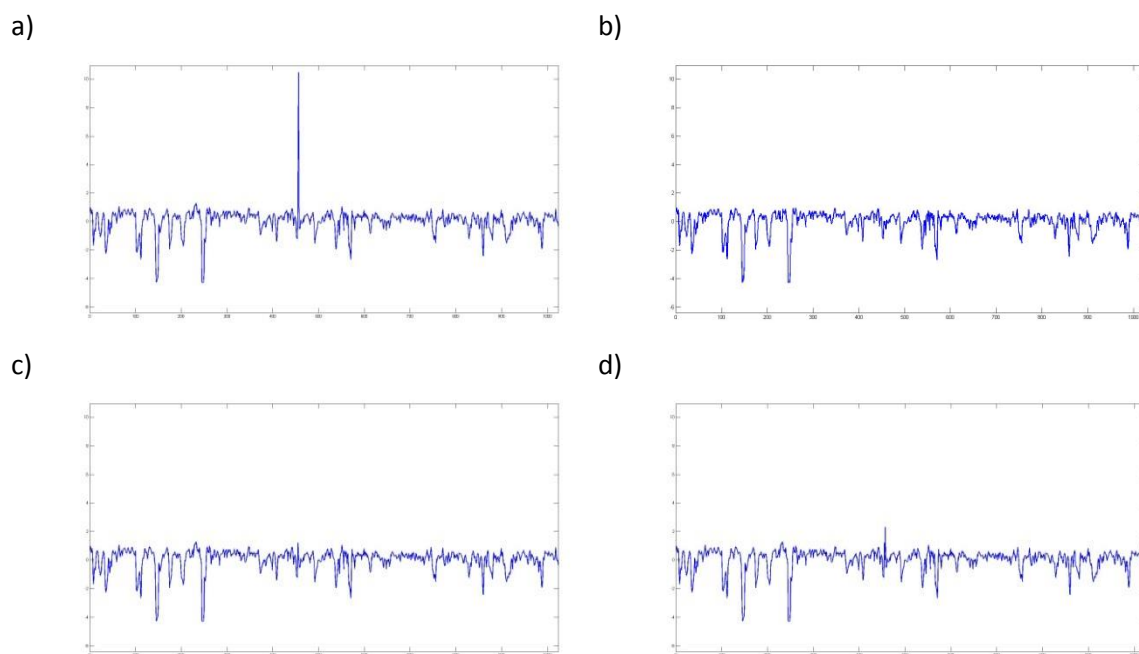
Third method based on the comparison of standard deviations. For each point of surface standard deviation of height was calculated for this point and its neighbors. Then standard deviation of all the points was averaged. Then for points lying above surface mean plane spikes were identified as points, for which vertical distance to mean plane was higher than multiplication of  $k_{sd}$  and averaged height standard deviation. Then the ordinates of spikes were replaced by average value of neighbors, not being spikes.



**Figure 3.** Profile containing spike (a), profile with removed spike for  $k_{sd}$  value of 2.5 (b), 10 (c) and 12 (d)

Selection of the  $k_{sd}$  value is important. If it is too small, height of some individual peaks can be reduced, when too large, only upper part of spikes can be removed. After analysis of many surfaces the  $k_{sd}$  value was set to be 10. Figure 4 shows example of this method implementation.

Fourth method is based on calculation of rms. slope. It is based on elimination of points of the highest slope. Slope was calculated for each surface point. Then average surface slope was computed. When slope of points lying above surface mean line was larger than selected  $k_{sl}$  value multiplied by average slope, these points were qualified as spike. For determined spikes, similar to the previous method, their ordinates were replaced by average ordinate value of neighbors, not being spikes.



**Figure 4.** Profile containing spike (a), profile with removed spike for  $k_{sl}$  value of 2.5 (b), 7.5 (c) and 12 (d)

This approach seems to be of more importance than the previous approach based on standard deviation, because surface slope depends on both amplitude and spatial parameters of the surface. The  $k_{sl}$  value was selected to be 7.5. Figure 4 presents illustration of this method.

#### 4. Results and discussion

Detailed analysis of one surface is given. Table 1 presents parameters of surface before and after removal of spikes using four methods. In order to compare the results with those obtained using spikes removal during measurement, the measured surface was initially thresholded (truncated) to material ratio range of 0-99.87%. In addition, Figure 5 presents contour plots and Figure 6 material ratio curves of measured surfaces.

It is evident that spikes removal caused decrease of the majority of height parameters describing peak surface part. The change of the  $S_p$  parameter is the largest (up to 99%) after using closing filter. In this case the height parameters are the smallest. Decrease of the  $S_{5p}$  parameter is high, too. Decreases of the  $S_{pk}$  parameter is smaller than 40%, because of its definition ( $S_{pk}$  is reduced peak height). Maximum height also decreases as a result of spikes removal.

After application of closing filter the value of the  $S_k$  parameter was the smallest. Differences between parameters describing the valley part  $S_v$  and  $S_{vk}$  were negligible. Surface correction caused changes of the  $S_k$ ,  $S_q$  and  $S_a$  parameters of a few percents. Especially the small relative changes of the  $S_q$  parameter were confirmed for other analysed surfaces.

The skewness  $S_{sk}$  and kurtosis  $S_{ku}$  decreased as a results of spikes removal, the largest changes were obtained after using closing filter. The functional  $S_{xp}$  parameter is stable on surface independently of spikes removal method, contrary to unstable parameters  $S_{mr}$  and  $S_{mc}$ . The spatial parameter  $S_{al}$  was

constant. The Str parameter decreased due to surface correction. As predicted, surface main direction Std did not change as a results of spikes removal.

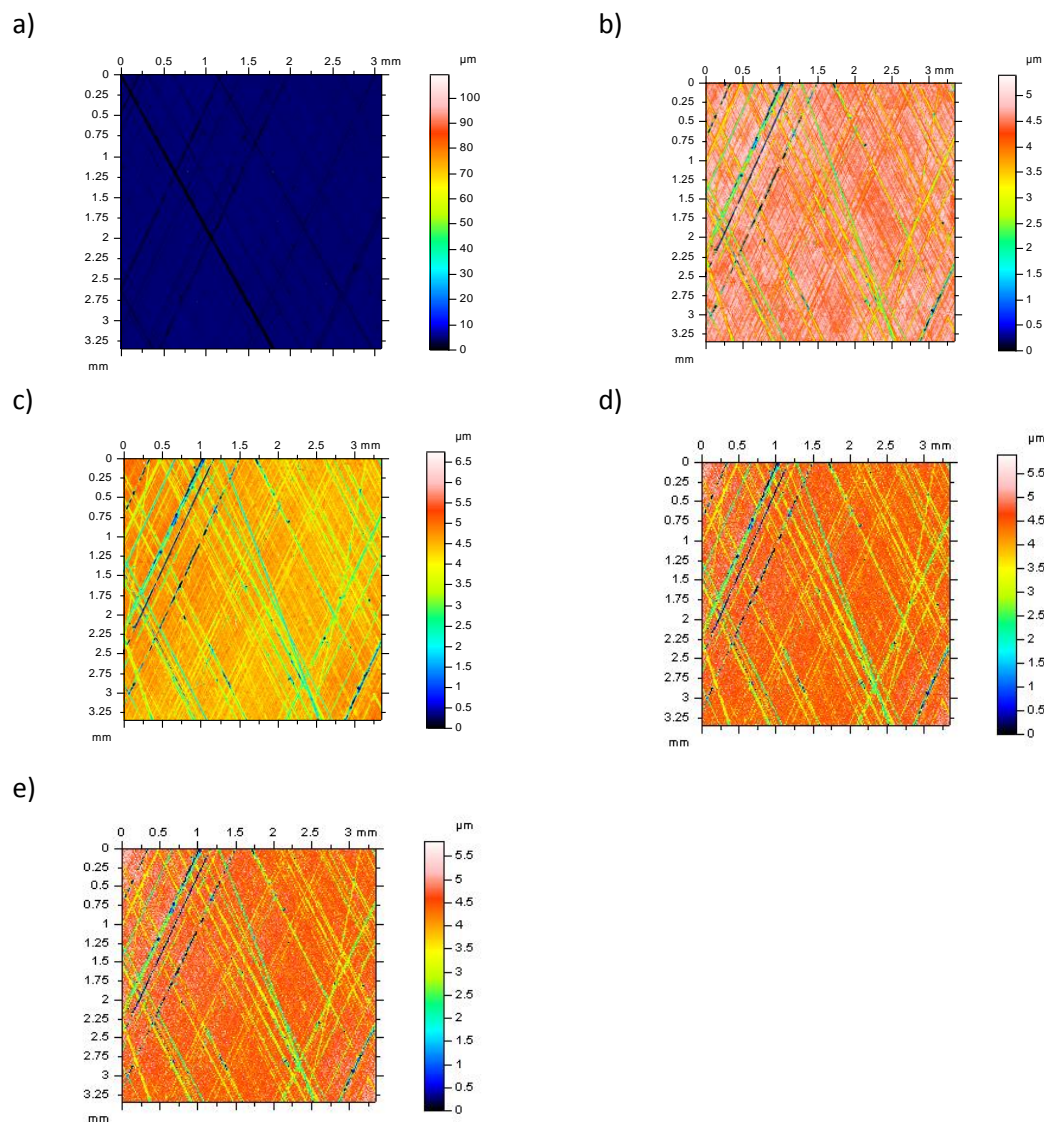
Sdq and Sdr parameters decreased after surface modification, which is related to amplitude decrease. Material volume parameters decreased as a results of peak removal, however changes of parameters Vv, Vvc and Vvv were rather small. Summit density Spd increased, after spikes removal is the smallest value was obtained for truncated surface. Peak density Spd increased, the highest value was found after surface thresholding. Feature parameters Sda, Sha, Sdv and Shv decreased due to spikes removal.

**Table 1.** Parameters of plateau-honed cylinder surface for various methods of spikes removal

	Surface with spikes	Application of closing filter with 0.2 mm length of horizontal plane	Peak part truncation, corresponding to material ratio of 0.13%	Algorithm based on standard deviation	Algorithm based on rms. slope
Sq, $\mu\text{m}$	0.806	0.768	0.771	0.77	0.77
Ssk	5.01	-2.52	-2.4	-2.42	-2.42
Sku	795	11.2	10.6	10.6	10.6
Sp, $\mu\text{m}$	109	1.09	2.48	1.64	1.55
Sv, $\mu\text{m}$	4.27	4.32	4.27	4.27	4.27
Sz, $\mu\text{m}$	114	5.41	6.75	5.91	5.82
Sa, $\mu\text{m}$	0.52	0.513	0.519	0.518	0.518
Smr, %	0.0000954	62.5	0.039	8.85	14.9
Smc, $\mu\text{m}$	109	0.488	1.86	1.02	0.934
Sxp, $\mu\text{m}$	2.42	2.44	2.42	2.42	2.42
Sal, mm	0.0164	0.0164	0.0164	0.0164	0.0164
Str	0.0235	0.0198	0.02	0.02	0.02
Std, °	117	117	117	117	117
Sdq	0.175	0.14	0.14	0.14	0.14
Sdr, %	1.35	0.962	0.96	0.953	0.954
Vm, $\text{mm}^3/\text{mm}^2$	9.72e-006	1.12e-005	1.31e-005	1.27e-005	1.25e-005
Vv, $\text{mm}^3/\text{mm}^2$	0.00069	0.000614	0.000634	0.000633	0.000634
Vmp, $\text{mm}^3/\text{mm}^2$	9.72e-006	1.12e-005	1.31e-005	1.27e-005	1.25e-005
Vmc, $\text{mm}^3/\text{mm}^2$	0.000437	0.000461	0.000471	0.000471	0.000471
Vvc, $\text{mm}^3/\text{mm}^2$	0.000496	0.00043	0.00045	0.000449	0.00045
Vw, $\text{mm}^3/\text{mm}^2$	0.000194	0.000184	0.000184	0.000184	0.000184
Spd, $1/\text{mm}^2$	1.61	1042	754	927	946
Spc, $1/\text{mm}$	4.24	0.0666	0.0724	0.0698	0.0695
S10z, $\mu\text{m}$	-	5.77	5.96	5.61	5.61
S5p, $\mu\text{m}$	85.7	1.83	2.17	1.83	1.83
S5v, $\mu\text{m}$	-	3.94	3.78	3.78	3.78
Sda, $\text{mm}^2$	10.6	0.0106	0.0148	0.0125	0.0131
Sha, $\text{mm}^2$	25	0.0079	0.0121	0.00946	0.00927
Sdv, $\text{mm}^3$	0.0122	7.07e-008	7.75e-008	6.8e-008	8.13e-008
Shv, $\text{mm}^3$	0.000285	5.41e-007	9.41e-008	6.56e-008	6.39e-008

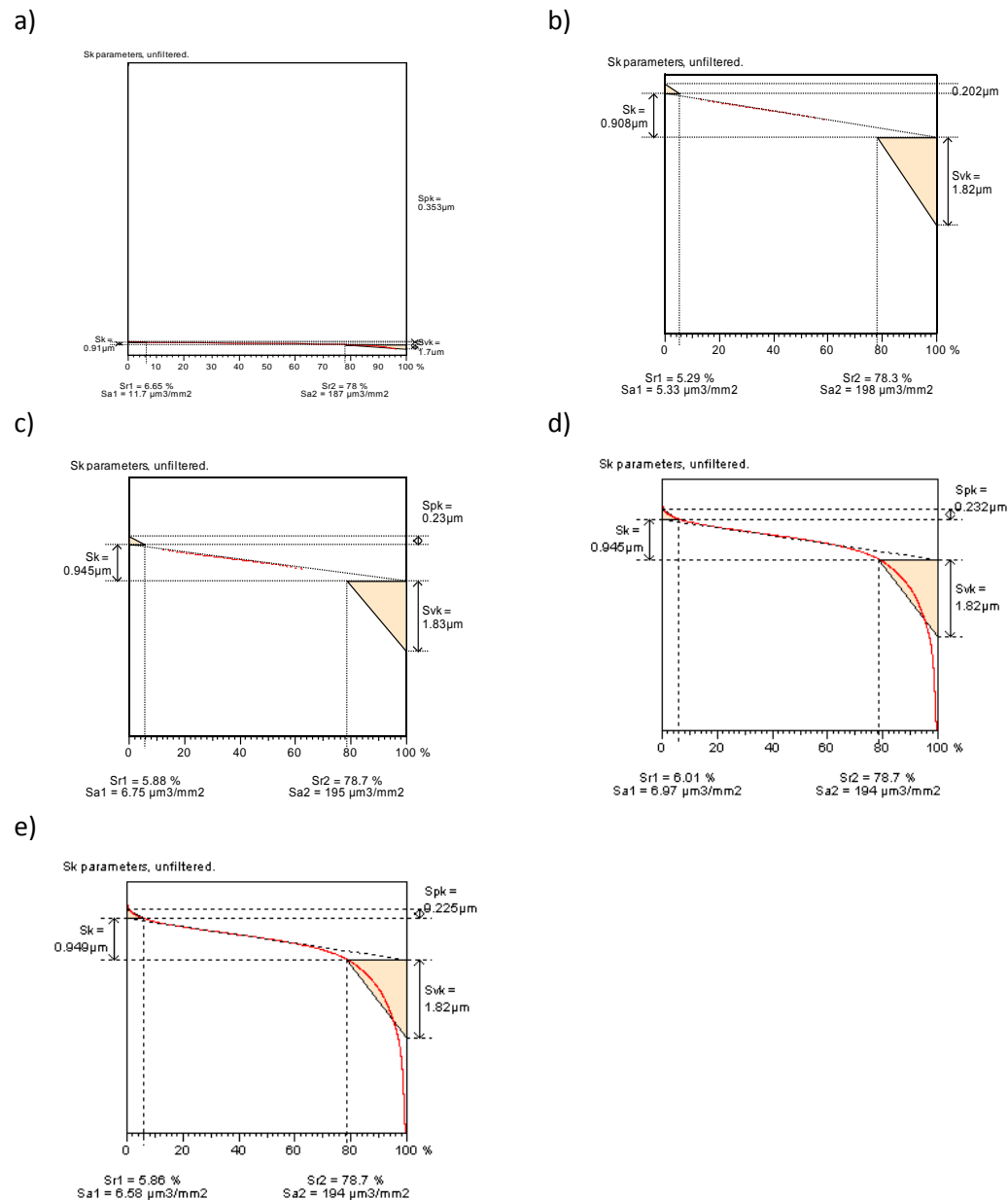


Generally, application of algorithms based on standard deviation and rms. slope gave similar values of all the analysed parameters, height parameters and hybrid parameters were also similar to those obtained by truncation. However application of upper thresholds caused different values of parameters characterizing peaks than use of the other methods; it was probably caused by truncation of peak surface part. This should be treated with a care when peak parameters are important. Maybe this method should be changed by replacing spikes by ordinates calculated from neighboring points. The method based on closing filter gave usually the smallest values of height and hybrid parameters from all the analysed methods. When length of structuring element is too big, some narrow valleys can arise, they can be removed by subsequent thresholds.



**Figure 5.** Surface containing spike (a), filtered using closing filter of 0.2 mm length of horizontal plane (b), after peak part truncation, corresponding to material ratio of 0.13 (c) and after using algorithms based on standard deviation (d) and rms. slope (e)

It was found from the measurement of surface with filter removing slopes that obtained parameters were close to those obtained by surface truncation.



**Figure 6.** Material ratio of surface containing spike (a), filtered using closing filter of 0.2 mm length of horizontal plane (b), after peak part truncation, corresponding to material ratio of 0.13 (c) and after using algorithms based on standard deviation (d) and rms. slope (e)

## 5. Conclusions

Surface character should be taken into consideration in selection of parameters in procedures of spikes removal. Elimination of spikes caused decrease of amplitude parameters characterizing maximum height and peak parts; parameter describing valley part are almost constant. Parameters Sq and Sa1 were found to be stable on surface contrary to Smr and Smc. Change of hybrid parameters as well as feature parameters Spd, Spc, Sda, Sha, Sdv and Shv are also comparatively high.

Applications of algorithms based on slope and standard deviation gave similar results. In these cases hybrid and height parameters are similar to those obtained using surface truncation



(thresholding), however application of closing filter with 0.2 mm length of horizontal plane gave the smallest value from all the analysed method.

Use of surface thresholds (truncation) corresponding to material ratio in the range 0.13-99.87% doesn't require selection of any other parameters. This method can be used for one-process and two-process random surface. It can be further modified by replacing ordinates of identified spikes by ordinates calculated from neighboring points, instead of surface truncation.

## 6. References

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