Serbian Tribology Society

SERBIATRIB '11

12th International Conference on Tribology

Faculty of Mechanical Engineering in Kragujevac

Kragujevac, Serbia, 11 – 13 May 2011

EVALUATION OF THE SPREAD RANGE OF 3D PARAMETERS FOR COATED SURFACES

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Abstract: *3D measurement on surface roughness could be used to assess the surface quality but the procedure is time-consuming and the better the equipment and its performances, the smaller the investigated surfaces. There were investigated the spread ranges for several 3D roughness parameters in order to use the information for establishing a less-time consuming, but acceptable set of measurements. The results pointed out there are some parameters with larger spread range (Sa, Sq, St)and others with narrower spread range (Ssk, Sku).*

Keywords: *spread range, 3D amplitude and functional parameters, surface topography, coating.*

1. INTRODUCTION

3D measurements of surface roughness could be used to assess the surface quality but the procedure is time-consuming and the better the equipment and its performances, the smaller the investigated surfaces. Modern 3D profilometry units evolved and are now capable of reaching a higher accuracy in measuring surface profilometry, but in the same time a smaller scale suppose a smaller area of investigation [1, 10].

Multiple measurements in different areas on the sample can produce results within a large range. This range is due to variations of the surface texture across the sample surface. Consequently, the results of any single measurement may not be representative of the overall surface quality [1].

A solution to statistically solve the problem of variation in the measured values is to do multiple measurements in different areas of the surface. The average surface texture will be described with good enough accuracy by the arithmetic average of the parameters. The number of measurements that are taken on a part is determined by the measured results and the part tolerances. How many measurements does one have to perform to be inside the recommended or imposed tolerances? How different could be the spread ranges for a particular parameter or a set of parameters?

The expectation of 3D measurement is that only one measurement (or at least a small number) should be sufficient for the analysis of a part, mainly due to the time needed per measurement. The large number of data points in one 3D measurement was hoped to give a statistically stable basis for the analysis of a surface [1, 3, 6, 7].

This study investigated the spread ranges for several 3D roughness parameters in order to use the information for establishing a less-time consuming, but acceptable set of measurements and for the assessment of the surface quality before and after deposition.

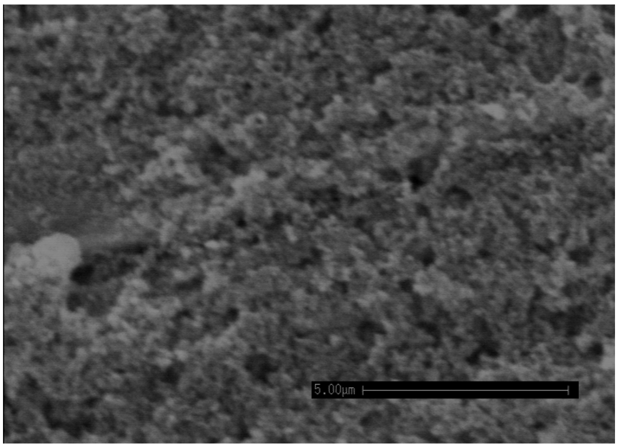
2. MEASURING METHODOLOGY

2.1 Materials

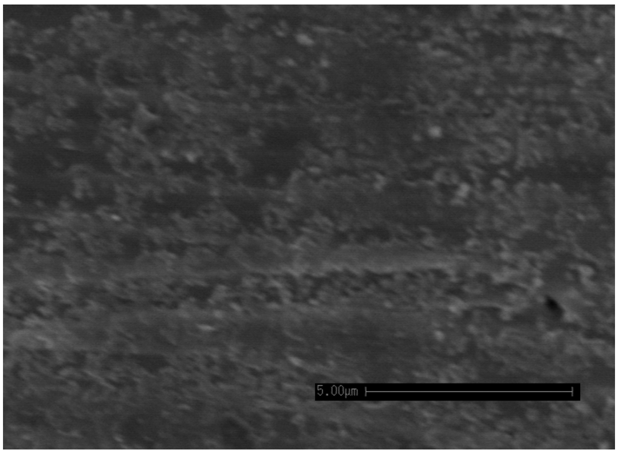
Commercially available 316L stainless steel specimens having the composition Fe + Cr: 18.00; Ni: 12.00; Mo: 2.50; Mn: 1.70; P: 0.04; C: 0.02; S: 0.01; Si: 0.15 (wt. %) were used as the substrate for a hard coating. The electrochemical process of deposition was performed in a small three-electrode cell on plate specimens. The process was carried out potentiostatically with a potentiostat/ galvanostat connected to a computer [2].

In this study there was used the following notation: sample 1 for the simple steel surface as grinded; samples 2 and 3 have TiO_2 coating, the first being obtained after 30 minutes, the second being obtained after 60 minutes (the coating parameters were kept constant).

Prior to make electrical contacts, the plates were mechanically polished using 600 and 1200 grit emery paper, organically degreased with acetone, etched in a 1:1 $HCl:H_2O$ solution for 60 seconds, chemical degreased with ethylic alcohol for few seconds and rinsed with distilled water. Then, the samples were activated by cathodisation at -1.1 V vs. SCE in a 0.1 M NaOH solution for 2 minutes and finally rinsed with doubly-distilled water. The deposition was performed at room temperature (23-25ºC) at -1.43 V potential vs. Ag/AgCl electrode. The deposited layer was then, heated in air at 400 ºC for 1 h in air to obtain crystalline TiO_2 film. The substrates were weighed prior the coating and after annealing to determine the amount of deposited TiO_2. Aspects of the investigated surfaces for Sample 2 and 3 are given in Figure 1 [2].



Sample 2



Sample 3

Figure 1. Surface of the coated samples

2.2 Measuring method

The 5 measurements for each sample were done with a contact profilometer, with the same set parameters: investigated areas: 500 μm x 500 μm (Fig. 2), 5 μm step between lines, the vertical range 500 μm, the scan speed was set at 35 μm/s and 200 points per scan line. All parameters are calculated from the raw profiles. Specialists talk about an actual measuring strategy.

Each of the discussed parameters are given as

$$Parameter\ Average\ value^{+\max value\ above\ the\ average\ (\%)}_{-\min value\ below\ the\ average\ (\%)} \quad (1)$$

where the average value is calculated for 5 measurements and the max value above average is the maximum value among the five ones, the min value below the average is the minimum value among the same five values. The maximum and minimum spread from the average values spreads from are given in percentage as

$$As(\%) = max\ value\ above\ the\ average = \frac{As \cdot 100}{Av} \quad [\%] \quad (2)$$

$$Ai(\%) = min\ value\ above\ the\ average = \frac{Ai \cdot 100}{Av} \quad [\%] \quad (3)$$

where

$As = max\ value\ above\ the\ average - the\ average\ value$

$Ai = min\ value\ below\ the\ average - the\ average\ value$

$Av = \sum_{i=1}^{5} P_i$ is the average value for parameter P.

The following parameters were calculated as given by [9, 10] and discussed:

amplitude parameters:
- the roughness average, *Sa* [μm],
- the root mean square parameter, *Sq* [μm],
- the surface skewness, *Ssk* [-],
- the surface kurtosis, *Sku* [-],
- the peak-valley height, *Sy* [μm];

functional parameters
- the reduced summit height, *Spk* [μm],
- the core roughness depth, *Sk* [μm],
- the reduced valley depth, *Svk* [μm].

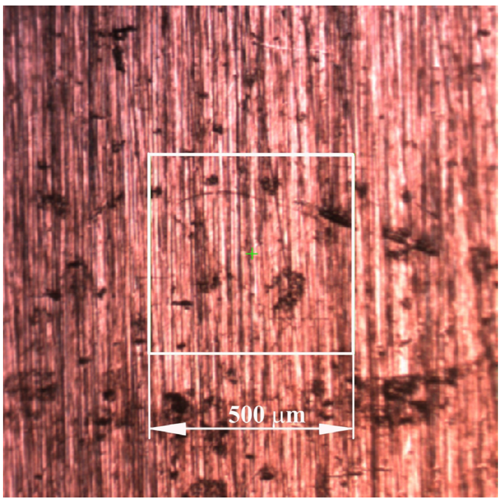


Figure 2. Example of the investigated area (measurement no 4 for Sample 1)

Figure 3 presents the measured values and the average of the amplitude parameters. Figure 4 presents the values of three functional parameters: *Svk*, *Sk* and *Spk*. In order to better estimate their values, for one measurement the column represents the sum (*Svk*+*Sk*+*Spk*). The Sample 1 has larger ranges for the three functional parameters, meaning the polishing process does not offer yet a uniform quality of the surface. It could be improved. The coated surfaces (Sample 2 and 3) have a more uniform distribution of these parameters but for sample 3 the values for *Sk* and *Spk* are larger than for those for Sample 2. It is possible to reflect the fact that the deposition follows the actual topography of the steel surface but emphasizing the heights (*Spk*) and enlarging the core zone (*Sk*). Thus, the coating does not cover the voids of the steel support.

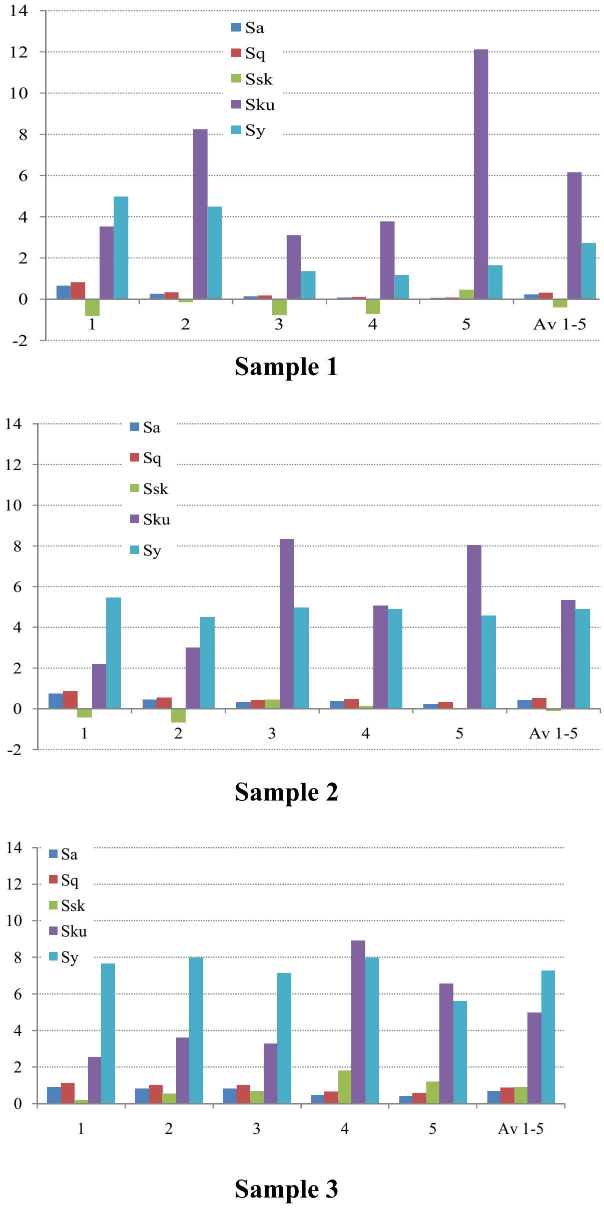


Figure 3. Several amplitude parameters for Samples 1, 2 and 3. Last parameter set was obtained as average of all 5 measurements.

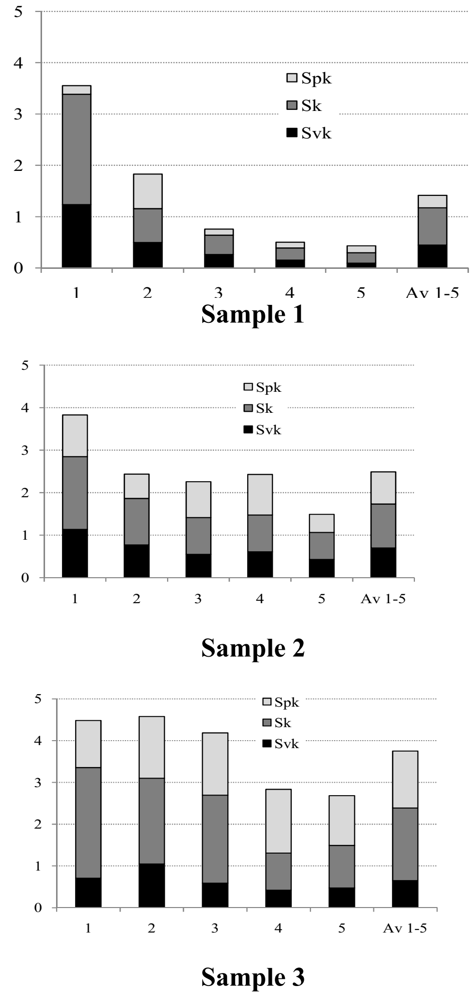


Figure 4. Functional parameters for Sample 1, 2 and 3. Last parameter (*Spk*+*Sk*+*Svk*) was obtained as average of all 5 measurements.

Surfaces with *Ssk*~0 have symmetric height distributions. Sample 2 has several measurements with *Ssk* <0, meaning, possibly, a bearing surface with holes. Sample 3 has *Ssk* >0 and it can be a flat surface with peaks. Values greater than 1.0 may indicate extreme holes or peaks on the surface (as, for instance, measurements 4 and 5 for Sample 3). Greater values than 3 for *Sku* indicate narrower height distributions.

There are two suggestions after noticing these characteristics of the coated surfaces:

- it is obviously necessary to have a polishing process of the coated surfaces in order to eliminate high and narrow peaks and to reduce *Spk* and *Sk*;
- mechanical test are necessary for assessing the wear of the coated surfaces

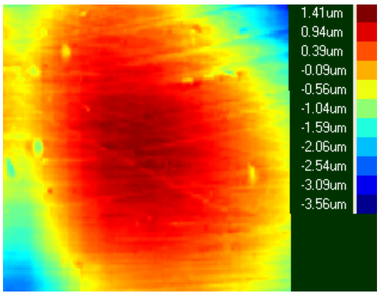
Figure 6 presents chromatographic images of the investigated surfaces. Each line is for the same sample, and includes one or two images for extreme values of some relevant parameters and one image close to the average values, at least for some of the investigated parameters.

Table 1. Amplitude parameters (average value from 5 measurements for each sample)

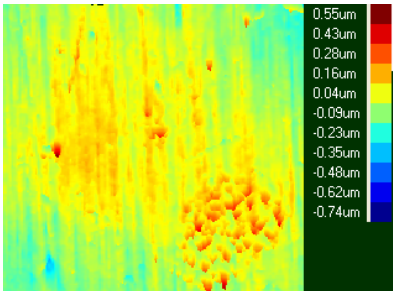
Sample 1	Sample 2	Sample 3
$Sa\ 0.243^{+0.41\,(+170.2\%)}_{-0.17\,(-73.6\%)}$	$Sa\ 0.430^{+0.32\,(+74.6\%)}_{-0.19\,(-44.7\%)}$	$Sa\ 0.681^{+0.22\,(+32.3\%)}_{-0.27\,(-40.2\%)}$
$Sq\ 0.310^{+0.52\,(+168.2\%)}_{-0.22\,(-72.9\%)}$	$Sq\ 0.528^{+0.34\,(+64.6\%)}_{-0.20\,(-39.5\%)}$	$Sq\ 0.880^{+0.23\,(+26.4\%)}_{-0.30\,(-34.8\%)}$
$Ssk\ -0.397^{+0.85\,(215.3\%)}_{-0.41\,(-104.9\%)}$	$Ssk\ -0.108^{+0.57\,(+514.8\%)}_{-0.55\,(-514.80\%)}$	$Ssk\ 0.887^{+091\,(+102.9\%)}_{-0.68\,(-77.0\%)}$
$Sku\ 6.15^{+5.95\,(+96.7\%)}_{-3.04\,(-49.9\%)}$	$Sku\ 5.334^{+3.00\,(+56.2\%)}_{-0.55\,(-58.6\%)}$	$Sku\ 4.982^{+3.93\,(78.9\%)}_{-2.44\,(-49.0\%)}$
$Sy\ 2.73^{+2.24\,(+82.0\%)}_{-1.54\,(-56.6\%)}$	$Sy\ 4.884^{+0.56\,(+11.6\%)}_{-0.55\,(-7.6\%)}$	$Sy\ 7.27^{+0.717\,(+9.86\%)}_{-1.66\,(-22.8\%)}$

Table 2. Functional parameters

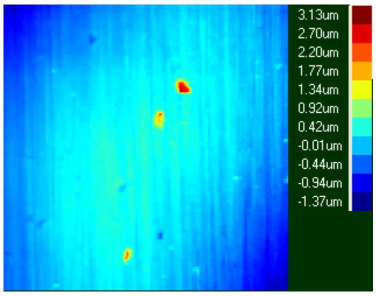
Sample 1	Sample 2	Sample 3
$Spk\ 1.363^{+0.161\,(+11.8\%)}_{-0.231\,(-16.9\%)}$	$Spk\ 0.754^{+0.22\,(+29.9\%)}_{-0.33\,(-43.9\%)}$	$Spk\ 1.363^{+0.16\,(+11.86\%)}_{-0.23\,(-16.9\%)}$
$Sk\ 1.742^{+0.904\,(+51.9\%)}_{-0.857\,(-49.2\%)}$	$Sk\ 1.03^{+0.67\,(+65.1\%)}_{-0.39\,(-38.4\%)}$	$Sk\ 2.646^{+0.90\,(+51.9\%)}_{-0.85\,(-49.2\%)}$
$Svk\ 0.646^{+0.401\,(+62.1\%)}_{-0.224\,(-34.6\%)}$	$Svk\ -0.697^{+0.43\,(+62.8\%)}_{-0.26\,(-38.5\%)}$	$Svk\ -0.646^{+0.40\,(+62.1\%)}_{-0.22\,(-34.6\%)}$



Measurement no. 1: the parameter values are different from the average ones

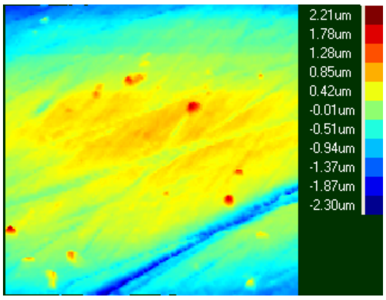


Measurement no. 5: the highest value for *Sku*

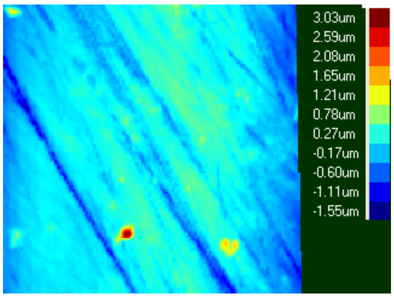


Measurement no. 2: the amplitude parameters are closer to the average ones, except *Sku* and *Sy*

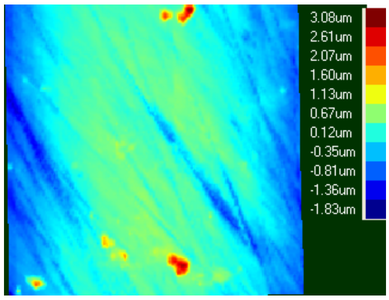
Sample 1



Measurement no. 2

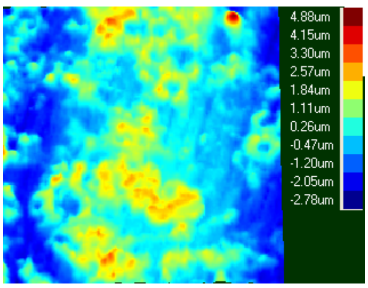


Measurement no. 5

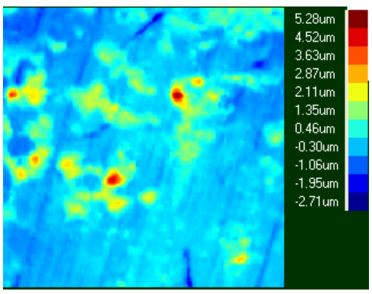


Measurement no. 4: closer values to the average ones, *Ssk* is negative for the average, but close to zero

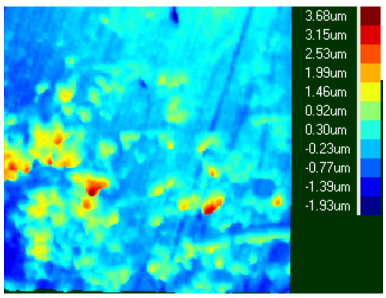
Sample 2



Measurement no. 1



Measurement no. 4



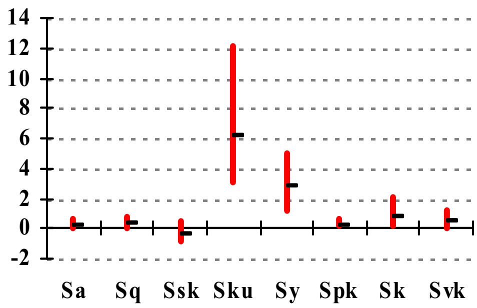
Measurement no. 5: closer values to average but not for *Sa* and *Sq* smaller than the average ones

Sample 3

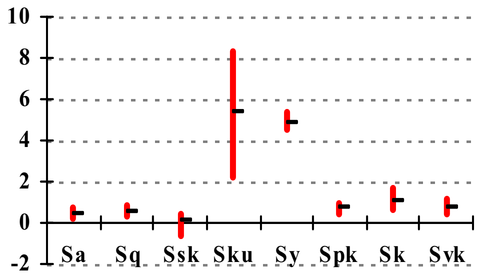
Figure 5. Chromatic images of several investigated surfaces for each sample

Analysing the values given in Tables 1 and 2 one may notice that for the amplitude parameters, the spread ranges were reduced after coating, except *Ssk* that has the lowest average measured value for Sample 2 and then increasing for Sample 3. It is also this parameter that has the largest ranges of spread for all samples. Standards recommend for manufactured surfaces to have spread ranges around ±16%, but it is hard to obtained that for coatings (without further polishing process).

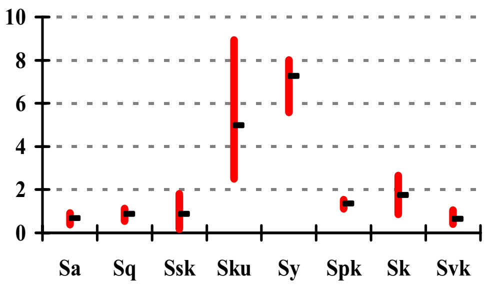
Figure 6 presents the spread ranges and the average value for each analysed parameter.



Sample 1



Sample 2



Sample 3

Figure 6. The spread ranges for each sample

3. CONCLUSION

Analysing the spread of the investigated parameters for Sample 1 the authors estimated that the polishing process could be improved in order to reduce the spread especially for *Sku*, *Sy* and *Sk*. There are few peaks but very high and narrow that could be eliminated by a better polishing, by changing the abrasive paper or even the method.

Investigating the spread of the measurements' values and their dependence on the covering process parameters will allow improving the coating technology and also the surface quality.

Therefore, it is most likely that some kind of rule (similar to the 16%) is needed to take account of the natural deviations that occur within a standard engineering surface.

If one will analyse only the amplitude parameters *Sa* and *Sq*, the conclusion does not reflect the actual quality of the surfaces. These two parameters are spread in similar ranges for all three types of surfaces. It is only possible to say that they have a slight trend to increase from values obtained for the uncoated surface.

The deposition process generates a non-uniform surface as one could see from Figures 1 and 5. It is necessary to study the surface quality after the final polishing process.

For Sample 2, the maximum value of *Sku* becomes lower but *Sy* remains with a maximum of 5.6 μm, but in a narrower range. *Spk* slightly increases, but the other two functional parameters slightly decrease in maximum values and the size of spread range.

Comparing Sample 1 and Sample 3, *Ssk* becomes positive, *Sy* increases meaning the deposition covers the high peaks, emphasis their heights. *Sk* is also increased meaning that the core of the topography is consolidated.

The coated samples (Sample 2 and Sample 3) have to bear a polishing process in order to become more uniform and without rare and sharp peaks.

The parameters could be grouped into two categories:

- **more robust**: *Sa* and *Sq* are good examples of parameters with small dispersions and they seems to be relatively insensitive to sampling.
- **less robust:** *Ssk* and especially *Sku* are parameters very sensitive to the number of measurements and have large dispersions.

The number of measurements needed for the calculation of a stable mean value depends to a large extent on which parameter is needed. It was found that it is often necessary to perform at least 5 measurements to obtain a stable mean value for many roughness parameters while others needed a larger number. The reason for this is that there is often one or a few measurements that diverge from the expected normally distributed result.

It can always be argued that this dispersion depends on the manufacturing process being unstable, resulting in a surface that is not equal at different places on a part. The point made here is that the investigated surfaces are typical engineering surfaces and the dispersions presented here will be the reality when measuring 3D surface roughness.

Therefore, it is most likely that some kind of rule (similar to the 16%) is needed to take account of the natural deviations that occur within a standard engineering surface.

Three functional surfaces have been measured in order to illustrate the comparison. The overall results showed that it was clear that single 3D surface measurements are not normally sufficient to statistically quantify a surface, the number of measurements required is usually below that required by 2D techniques. The required number is small but never the less this may be still too time-consuming in a production situation where contact measurement is the only option.

For coatings, an investigation on the surge=face topography could reveal especially the extreme values that could be than changed by an appropriate grinding process.

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