INFLUENCE OF GRINDING FEED SPEED
ON 3D TEXTURE PARAMETERS

Catalin PIRVU, Constantin GEORGESCU, Lorena DELEANU

"Dunărea de Jos" University of Galati, Mechanical Faculty, 47 Domneasca, 800008, Galati, ROMANIA

email: catalin.pirvu@ugal.ro

ABSTRACT

This paper presents a study that underlines the use of 3D profilometry for evaluating the grinding process of a hardened carbon steel. Based on optical profilometry, there were selected squared areas on the grinded samples and the influence of the feed speed was established in terms of average values of a set of 3D texture parameters.

One of the main conclusions of this study is that Sa (the 3D average roughness) and even Sq (the root mean square) are not enough to characterize a grinded surface. Based on the obtained data, the authors recommend analyzing the surface quality by a set of 3D parameters, including amplitude and functional ones, especially for tribological applications. Acceptable values for both Sa and Sy (the maximum height on investigated area) were obtained for the fees speeds of 5 m/min and 15 m/min, with a larger scattering range for the lower feed speed. For this study, the feed speed of 15 m/min seems to be more adequate in terms of efficiency, especially as concerning the dependence processing time – surface quality.

Keywords: grinding process, texture parameters, amplitude parameters, functional parameters, feed speed

1. Introduction

The trend lines of grinding process try to make this process more efficient by increasing the speeds and forces, but also by optimizing costs and times of the process [1, 15, 16, 17]. Some authors underlines new technologies for having a fine quality of the surface, but classical grinding still remains a very commonly used technology for obtaining good quality in the range of Sa=0.8...1.6 microns [7]. Also, tribologists are more and more interested in evaluating the damaged surfaces by measuring different roughness parameters and evaluate their evolution as functions of time exploitation, regime or even lubricant quality [9, 11, 18].

3D measurements of surface roughness assess the surface quality, but the procedure is time-consuming and the better the equipment performances, the larger the investigated surfaces [2, 4, 5].

Multiple measurements in different areas on the processed surface can produce results within a large range. This range is due to variations of the surface texture across the surface and also to the variations of the manufacturing process. Thus, the results of any single measurement may not be representative of the overall surface quality [7].

A solution for statistically solving this problem is to do multiple measurements in different areas of the surface of interest. The average values will describe the surface quality with good enough accuracy. The number of measurements taken on a part is determined by the measured results and the part tolerances. How many measurements have to be done in order to obtain reliable information? How large could be the scattering ranges for a particular parameter or a set of parameters, or for a particular manufacturing process? The answer is relying especially on the experience and intuition of the investigator.

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 [2, 3, 8, 13].

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 grinding parameter (here – the feed speed).

2. Methodology for Measuring the Surface Texture Parameters

In order to do this comparative study, the profilometer Laser NANOFOCUS μSCAN, from "Stefan cel Mare" University of Suceava, was used. This is an optical profilometer for 2D and 3D non-contact measurement of the surface topography, with an access zone of 150 mm x 200 mm, vertical range of 1.00 μm to 18 mm and a vertical resolution of 25 nm. For calculating the parameters, the softs SPIP 5.1.11 [20] and Gwyddion 2.25 [19] were used.

There are investigated the initial surface and three surfaces, after the grinding process, each one characterized by a different feed speed (5 m/min, 15 m/min and 30 m/min, respectively). The samples were made of carbon steel grade OLC 45 (ANSI 1045), its chemical composition being given in Table 1.

The samples were quenced at 820°C-850°C, hold untill temperature was uniform and then soak for 10...15 minutes in oil. The resulted hardness was 42...48 HRC.

Table 1. Chemical composition of medium carbon steel OLC 45

Steel grade	Composition (%, wt)				
	C	Mn	P	S	Fe
OLC 45	0.42...0.50	0.60...0.90	≤ 0.040	≤ 0.050	98.51...98.98

Each measured/calculated parameter, included in this study, is characterized by:
- the maximum value, for instance Sa_{max}, Sq_{max} etc., all within the investigated areas,

- the minimum value, for instance Sa_{min}, Sq_{min} etc., all within the investigated areas.
- the average value of the parameter as obtained by averaging the values obtained for the investigated areas, separately:

$$Sa_m = \frac{1}{n}\sum_{i=1}^{n} Sa_i \qquad (1)$$

where Sa_i is the value of the parameter Sa for the i-th measurement (area), n being the number of measurements (here, $i=3$),

- the superior deviation above the average value, calculated for n measurements:

$$As = Sa_{max} - Sa_m \qquad (2)$$

- the inferior deviation below the average value

$$Ai = Sa_{min} - Sa_m \qquad (3)$$

- the superior deviation above the average as percentage of the average value for n measurements

$$As(\%) = \frac{As}{Sa_m}\cdot 100 \quad \left[\%\right] \qquad (4)$$

- the inferior deviation below the average as percentage of the average value for n measurements

$$Ai(\%) = \frac{Ai}{Sa_m}\cdot 100 \quad \left[\%\right] \qquad (5)$$

Taking into consideration these notations, a texture parameter could be expressed as $Sa_{m\,Ai(\%)}^{As(\%)}$ in Table 2.

Amplitude parameters do not offer information on spatial structure and do not differentiate the valleys and the peaks of the topography. Malburg [12] apreciated the surface quality introducing the ratio:

$$Sy/Sa = \frac{Sy}{Sa} \qquad (6)$$

for honed surfaces and the authors will comments this ratio, too, for this study.

3. Results and Discussion

This discussion is based on Tables 2 and 3 and Figures 1 and 2. It is obvious that grinding improved the surface quality, but the high speed of 30 m/min delivered values that could be obtained also by milling or turning, the grinding being less justified.

Analyzing Fig. 1, one may see that the spreading ranges for *Sa, Sq* and even *Sy* are acceptable and very narrow. *Sku* has a large range only for the initial surface, meaning that grinding makes this parameter to low, almost insensible to the value of the feed speed. The largest spreading ranges were obtained for *Ssk*. This may be explained based on the very low value of this parameter. If $Ssk \approx 0$, but not equal, any very small variation could be several times greater, without changing the meaning of this parameter. It is important that grinding, even if it does not reduce the value of *Ssk*, makes the spread range to be at least half of that characterizing the initial surface.

Table 2. The superior and inferior deviations around the average as percentage of the average value for 3 measurements

Parameter	Initial surface	Fine grinding	Medium grinding	Rough grinding
	Feed speed [m/min]			
	0	5	15	30
Sa	$1.85^{+1.4\%}_{-1.9\%}$	$0.97^{+12.6\%}_{-7.1\%}$	$0.88^{+3.2\%}_{-6.2\%}$	$1.52^{+6.8\%}_{-4.7\%}$
Sq	$2.37^{+2.8\%}_{-2.0\%}$	$1.21^{+11.7\%}_{-7.0\%}$	$1.11^{+3.3\%}_{-6.3\%}$	$1.96^{+6.7\%}_{-4.4\%}$
Ssk	$-0.05^{+653.1\%}_{-785.2\%}$	$0.09^{+135.3\%}_{-126.6\%}$	$-0.10^{+111.1\%}_{-86.3\%}$	$-0.13^{+80.5\%}_{-141.5\%}$
Sku	$7.95^{+82.2\%}_{-59.5\%}$	$3.20^{+9.3\%}_{-5.2\%}$	$3.36^{+9.3\%}_{-5.2\%}$	$4.07^{+5.3\%}_{-4.2\%}$
Sy	$53.3^{+58.1\%}_{-61.3\%}$	$17.5^{+21.0\%}_{-11.5\%}$	$19.5^{+13.6\%}_{-1.7\%}$	$33.79^{+3.6\%}_{-6.0\%}$
Spk	$3.27^{+16.5\%}_{-11.0\%}$	$1.64^{+17.6\%}_{-15.6\%}$	$1.59^{+4.7\%}_{-2.6\%}$	$2.55^{+5.1\%}_{-3.8\%}$
Sk	$5.83^{+1.3\%}_{-2.1\%}$	$1.96^{+6.7\%}_{-4.4\%}$	$2.80^{+3.4\%}_{-6.2\%}$	$4.74^{+6.3\%}_{-5.1\%}$
Svk	$2.39^{+17.5\%}_{-25.6\%}$	$1.09^{+4.1\%}_{-6.5\%}$	$1.19^{+5.1\%}_{-6.2\%}$	$2.32^{+1.1\%}_{-10.4\%}$

Deviations of the amplitude parameters *Sa*, *Sq*, *Sku* and *Sy* from their average values are in agreement with recent requirements for grinding [6, 10, 14], except *Ssk*, but this has too small values for counting in this evalutation.

If *Ssk = 0*, a symmetric height distributions is indicated, for example, a Gaussian like. If *Ssk < 0*, it can be a bearing surface with holes and if *Ssk > 0* it can be a flat surface with peaks. Values numerically greater than 1.0 may indicate extreme holes or peaks on the surface [3, 20]. It seems that a low feed speed is favorable for having isolated peaks on a flat surface. Higher speeds make this parameter to become negative and this could reveal holes (not very large), generated by material detaching at high speeds.

For Gaussian height distributions *Sku* approaches 3.0. Smaller values indicate broader height distributions and visa versa, for values greater than 3.0. The grinding process makes *Sku* to reduce its average value, but also its range.

Except *Ssk*, all the other amplitude parameters are very close for two of the tested feed speeds: 5 m/min and 15 m/min and *Ssk* is between -0.1 and 0.1, very small values, thus, for selecting the feed speed of 5 m/min or 15 m/min, the engineer has to introduce supplementary criteria, such as time to process, costs, technological system availability etc.

For grinded surfaces taken into account in this study, the ratio *Sy/Sa* is not as relevant as it was for the honed surfaces analyzed by Malburg [12], but the lowest values were found for the surfaces obtained with lower feed speed (5 m/min). The authors propose another set of parameters, related to the functional ones, as presented in Table 2. They introduced the sum of the functional parameters, *S=Svk+Sk+Spk*, and the the ratios obtained from each functional parameter and their sum *S*.
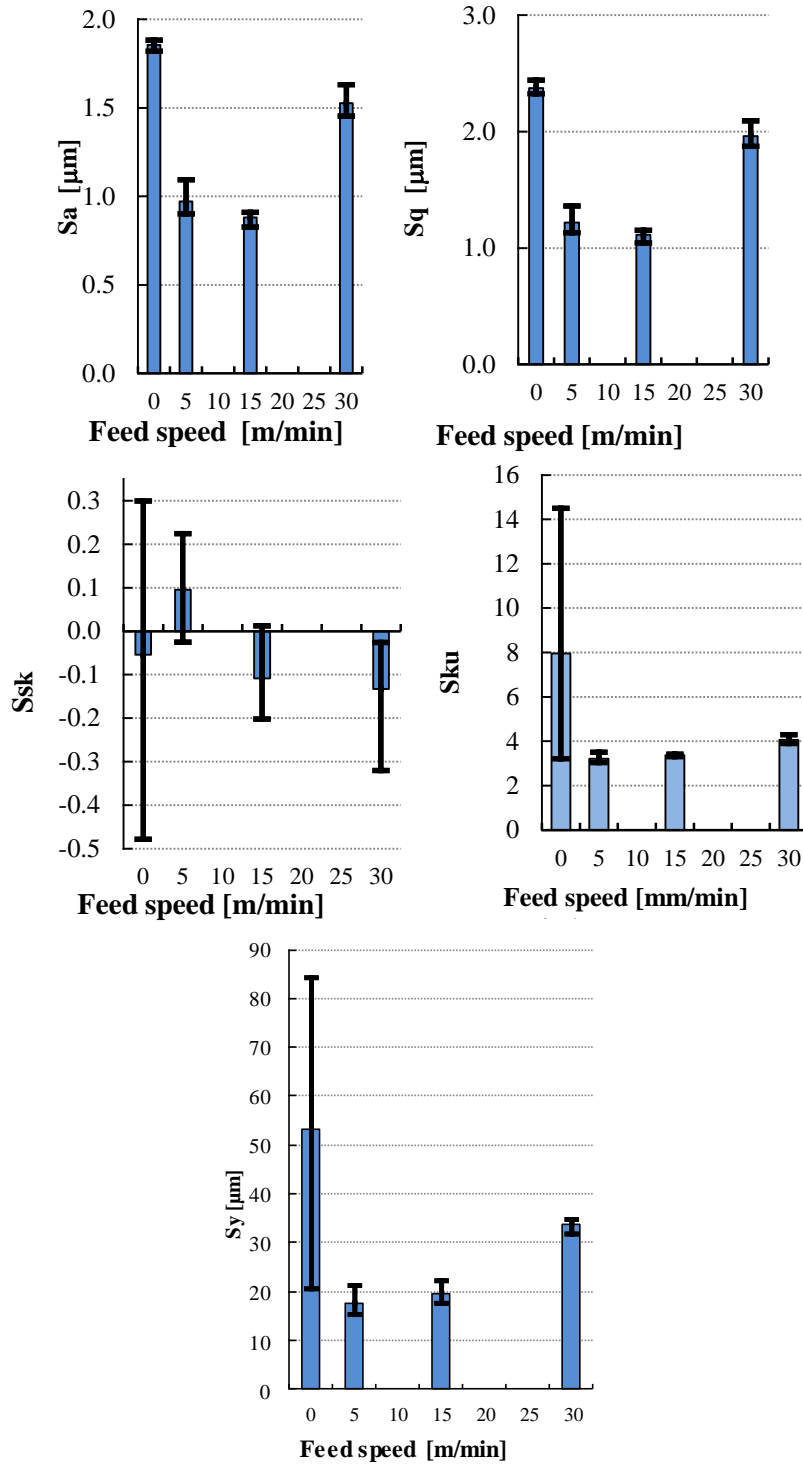
Fig. 1 The amplitude parameters for the investigated surfaces

Table 3. Ratios of functional parameters

| Parameter	Initial surface	Fine grinding	Medium grinding	Rough grinding
	Feed speed [m/min]			
	0	5	15	30
Sy/Sa	19.11	18.43	22.21	22.23
Svk	2.394	1.091	1.193	2.320
Sk	5.83	3.14	2.80	4.74
Spk	3.27	1.641	1.594	2.551
S=Svk+Sk+Spk	11.49	5.872	5.587	9.611
Svk/S	0.208	0.185	0.213	0.241
Sk/S	0.507	0.534	0.501	0.493
Spk/S	0.284	0.279	0.285	0.265
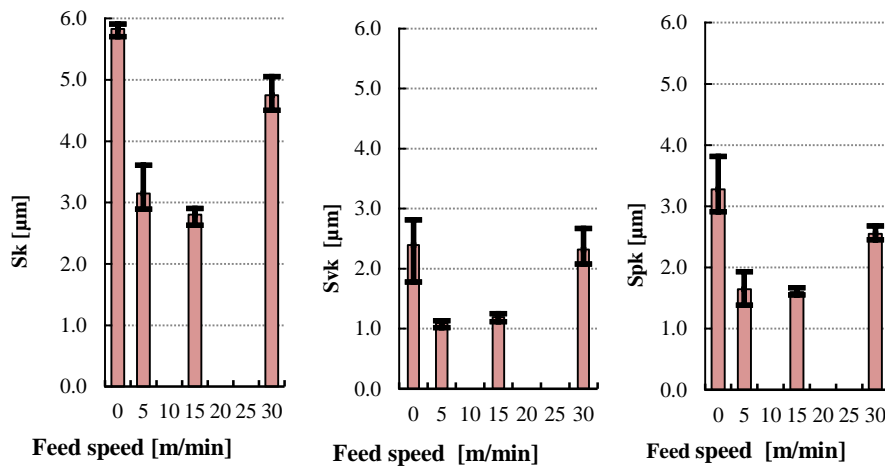
Fig. 2. Functional parameters characterizing the investigated surfaces

The values for Ssk and Sku have a greater scattering range for the initial surface. By grinding, the scattering ranges diminish at 30% as compared to the initial range for Ssk and at 10% as compared to the initial range for Sku. Also, the average value of Sku is diminishing to almost half the initial values. For larger feed speed (namely, 15 m/min and 30 m/min), Ssk becomes negative, meaning deep valleys due to the breaking process of some asperities.

Sa, Sq and Sy have similar evolutions (with a slight difference for Sy, see Fig. 1): the highest feed speed gave the higher values; thus, the average value of Sa is only 17.8% less than that characterizing the initial surface. But for the feed speed of 15 m/min, Sa is only 52% from the initial value and for 5 m/min, it represents 47.5%. The feed speeds of 5 m/min and 15 m/min gave very close results. For Sq, the average values represent 82.16% for rough grinding (the feed speed of 30 m/min), 46.8% for medium grinding and 51.05% for fine grinding, as refered to the initial average value of the same parameter. Sy has an average value of 63.3% for
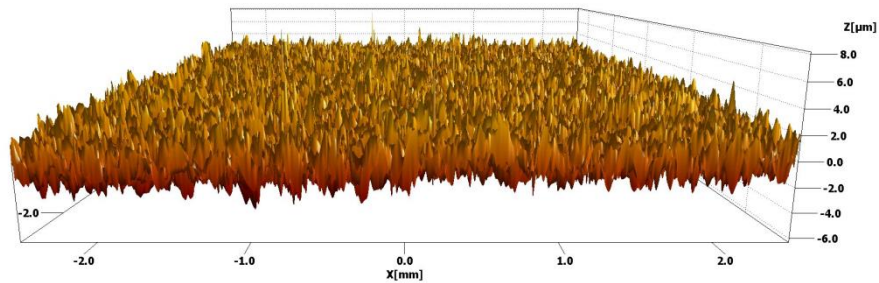
the rough grinding, 36.5% for medium grinding and 32.8% for fine grinding, as calculated from the initial value (before grinding).
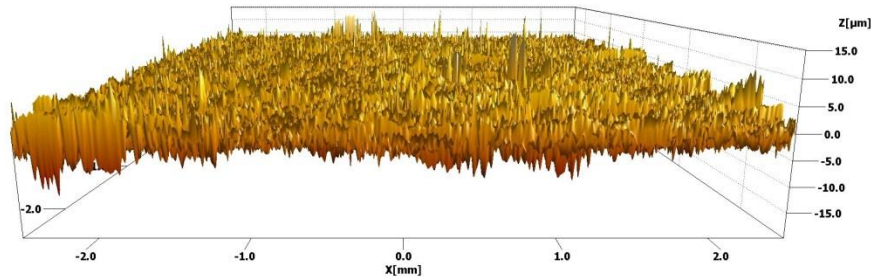
a) Rough grinding (feed speed of 30 m/min)
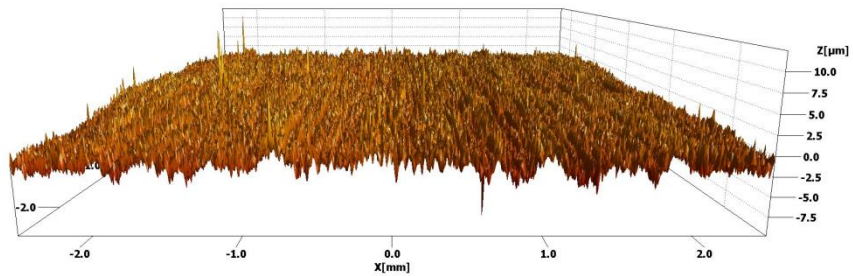
b) Medium grinding (feed speed of 15 m/min)

c) Fine grinding (feed speed of 5 m/min)

Fig. 3. Virtual reconstruction of three of the analyzed areas

Functional parameters present the same tendency, thus the feed speed of 30 m/min is too high for getting a well differentiated surface quality as compared to the initial one.

The average values for the functional parameters are close for the surfaces obtained with low feed speeds (5 m/min and 15 m/min), but for the highest feed speed analyzed in this study, their values are similar to the initial surface. The conclusion is that higher feed speed does not improve the bearing capacity of the surface, especially for tribological applications.

The participations of functional parameters to the sum $S=Spk+Sk+Svk$ is similar for all analyzed surfaces, including the initial one (before grinding). But the values of this sum are acceptable for low feed speeds of 5 m/min and 15 m/min. This means that the studied range for the feed speed implies spectacular changes of the processes taking place within the superficial layers for the lower feed speed of 5 m/min and 15 m/min. The highest feed speed of 30 m/min modifies the least the surface parameters, those being lower than the initial ones but too close to those initial ones in order to justify the costs of grinding process.

High values for *Spk* are not recommended in lubricated and loaded contacts as peaks, even less numerous and isolated, could be easily broken, locally modifying the stress distribution to generate plastic strain and also, they are the cause of disrupting the lubricating film. This could be one of those supplementary reasons not to select the high feed speed for grinding.

Conclusions

Analyzing the spread of the investigated parameters for all three grinding processes, the authors estimated that the process could be improved in order to reduce the parameter spread, especially for *Sku*, *Sy* and *Sk*. There are few peaks left after grinding (Fig. 3 and Table 2), but very high and narrow that could be eliminated by a better grinding, by changing the abrasive tool or even the method.

Investigating the spread of the values for the texture parameters and their dependence on the grinding process (here, the feed speed) will allow for optimizing the grinding technology and also the surface quality. Therefore, it is most likely that some kind of rule (similar to the 16%, as recommended in ISO 4288:1996 Geometrical Product Specifications (GPS). Surface texture: Profile method. Rules and procedures for the assessment of surface texture) is needed to take account of the deviations that occur within an engineering surface.

If one analyze only the amplitude parameters *Sa* and *Sq*, the conclusion does not reflect the actual quality of the investigated surfaces. These two parameters are spread in similar ranges for all three types of surfaces. References [2, 3, 14] give even a direct relation between these two parameters ($Rq \approx 1.16 \ Ra$). It is only possible to say that they have a trend to decrease for the low feed speeds, but for the feed speed of 30 m/min, these two parameters are only a little bit lower as compared to the average values obtained for the initial surface (without grinding).

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 very close to the reality when measuring 3D surface roughness.

This study is a good opportunity to make lobby in the favor of characterizing the surface quality by a set of parameters and not by the "classical" ones, such as *Sa* or *Sq*.

Nomenclature

The parameters involved in this study are defined and calculated taken into account [20] and for the functional parameters, see Fig. 4:

Sa – the 3D average roughness,

Sq – the root mean square,

Sku – the surface kurtosis,

Ssk – the surface skewness,

Sy – the peak-peak height (the height difference between the highest and lowest pixel in the image),

Spk – the reduced summit height,

Svk – the reduced Valley Depth,
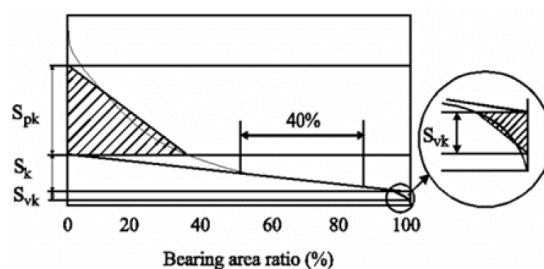
Sk – the core Roughness Depth.

Fig. 4. The functional parameters [20]

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