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A COMPARISON BETWEEN 2D AND 3D SURFACE PARAMETERS FOR EVALUATING THE QUALITY OF SURFACES

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ABSTRACT

This paper presents a comparison of the results for roughness parameters obtained with the help of two methods of evaluating the quality of the finished surfaces: 2D profilometry and 3D profilometry. There were investigated square areas from finished steel rings and polymeric blocks, these elements being used for tests on a block-on-ring tribotester. There were calculated the average values of the 3D parameters characterizing three square areas on each part and the average values of nine 2D profiles extracted from the already investigated square areas. There were also discussed the scattering ranges for the roughness parameters as given by each of the two methods. When evaluating the worn surfaces, the parameters Ssk, Sku, Sy, Sp are Sv, are more relevant, as the high peaks affect the tribological parameters, especially when dealing with polymeric composites.

KEYWORDS: 3D roughness parameters, 2D roughness parameters, finished surface

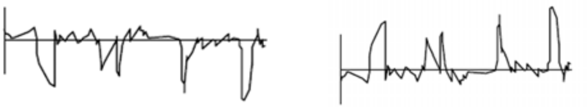
1. INTRODUCTION

From recent specialized literature concerning the characterization of the surface texture [1-3, 7, 9-12, 14, 17, 21, 22], the authors concluded that the existing studies generally have a statistical character and that there is no general methodology for characterizing the surfaces (new ones but especially the worn ones). When the specialists adopt a methodology for measuring and characterizing the surface, this one depends on factors, such as the shape and the dimensions of the triboelements, the available equipment and soft ware(s), the set of the selected parameters and not the least, the experience and the imagination of those who design the methodology.

In order to evaluate the surface quality, as previously suggested by Blunt, [2], this study will point out the importance of evaluating a set of parameters and not only one. Figure 1 shows five profiles characterized by the parameter set (*Rq*, *Rsk*, *Rku*) [29]. But what happens when we investigate the same set of parameters, but related to 3D measurements (*Sq*, *Ssk*, *Sku*)? The authors will try give to give an answer to that question.

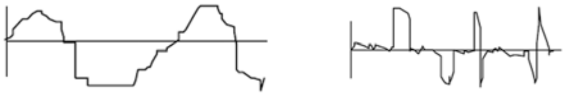
The aim of this paper is to make a comparative study between the same set of parameters, ones as resulted from 2D measurements and the other ones as given by 3D investigations. In order to emphasis the advantages of 3D investigations, the authors proposed a methodology for sampling the profiles and zones on non-worn and worn surfaces.

Gaussian surface: ***Rq=3, Rsk = 0, Rku=3***



Rq=12, Rsk= -1 Rku=8
Surface with deep and narrow valleys

Rq=12, Rsk=1, Rku=8
Surface with high and sharp peaks



Rq=4 Rsk = 0 Rku=1.5
Surface with large peaks and valleys, with relatively big slopes

Rq=4, Rsk=0, Rku=10
Surface with rare peaks and valleys, but having extreme values

Fig. 1. *Types of surfaces and the corresponding set of parameters (Rq, Rsk, Rku) (adapted from [29])*

The interest in evaluating surface quality with the help of 3D parameters is pointed out by the development of performant and more miniatural equipment by adequate and focused research [11, 13, 18, 19], but also by the fast development in standardization of these parameters. This year were published ISO 25178-2:2012 Geometrical product specifications (GPS). Surface texture: Areal. Part 2. Terms, definitions and surface texture parameters, a revised version of the one from 2010 [24]. This study uses the term and definitions given in [2, 26, 27], also related to ISO 25178:2010 and to other norms for a 2D evaluation [23, 25, 28, 29].

2. MEASURING METHODOLOGY FOR EVALUATING THE SURFACE QUALITY WITH THE HELP OF TEXTURE PARAMETERS

In order to do this comparative study, the profilometer Laser NANOFOCUS µSCAN [26], from "Ştefan 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, a vertical resolution of 25 nm. For parameters' calculation it was used the soft SPIP 5.1.11 [27].

Measurements were done for blocks of polymeric material (PBT + 10% glass beads) and for the external rings of tapered rolling bearings, both elements being involved in block-on-ring tests [4, 8, 13], for both non-worn and worn surfaces.

Figure 1 presents a wear track as it was rebuilt with the help of the profilometer soft; 1, 2 and 3 are the investigated zones.

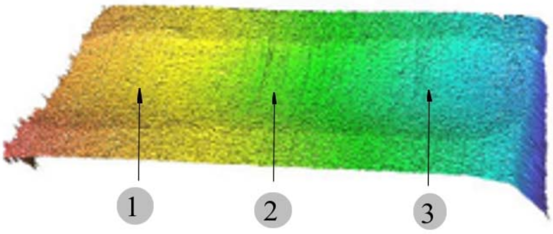


Fig. 2. *An example of investigated surfaces for analyzing texture parameters; the wear track on a block made of composite PBT+10% glass beads, test conditions: normal load F=5 N, sliding speed v=0.75 m/s and the sliding distance L=7500 m; the initial scanned surface was of 5 mm x 2.5 mm*

For evaluating the 3D parameters involved in this study, there were selected three zones, each of 500 µm x 500 µm for the polymeric blocks and of 100 µm x 100 µm for the metallic rings, these being reduced for reason of the surface curvature. All 2D and 3D measurements were done with a step of 5 µm. The distance between lines for 3D measurements was also 5 µm.

The value of a 2D parameter was calculated as the average of nine line profiles, three on each zone. The direction of the selected profiles was perpendicular to the sliding direction. For the blocks, these three profiles were selected one at the middle of the investigated zone of 500 µm x 500 µm, and the other two at a distance of 125 µm from the first one. For the rings, one profile was at the middle of the investigated zone and the other two were very close to the limits of the investigated zone. It results that the value of one parameter for a 2D profile involves 100 peak measurements for the blocks and 20 data for the rings. Thus, when calculating the 2D parameters with the following method, it implies using 300 values for $z(x,y)$, less than those involved for evaluating a 3D parameter; a value of a 3D parameter was evaluated using all recorded values for $z(x,y)$, that is 10 000 data on one investigated zone.

Based on the studied documentation [1-3, 5-7, 9-12, 20-23] and on the authors' experience, there were introduced the following notations for evaluating the scattering of the measured/calculated values for each texture parameter for the profiles or the zones. The explanations are given only for one parameter, the arithmetic average of absolute values, *Ra* for 2D evaluation and *Sa* for 3D evaluation, depending on the type of investigation:

- the maximum recorded values from nine 2D measurements (profiles), Ra_{max}, and from three zones for the 3D parameters, Sa_{max},
- the minimum recorded values from nine 2D measurements (profiles), Ra_{min}, and from three zones for the 3D parameters, Sa_{min},
- the average value of the parameter, Ra_m or Sa_m:

$$Ra_m = \frac{1}{n}\sum_{i=1}^{n} Ra_i \tag{1}$$

$$Sa_m = \frac{1}{n}\sum_{i=1}^{n} Sa_i \tag{2}$$

where Ra_i is the value of the parameter *Ra* for the *i*-th measurement (line), Sa_i is the value of the parameter *Sa* for the *i*-th measurement (the investigated zone *i*-th), n being the number of measurements (in this study $i=9$ for 2D measurements and $n=3$ for the 3D ones),

- the superior deviation related to the average value as calculated for *n* measurements:

$$As= Ra_{max}- Ra_m \tag{3}$$

- the inferior deviation related to the average value as calculated for *n* measurements:

$$As= Ra_{min}- Ra_m \tag{4}$$

- the superior deviation as a percentage of the average value as calculated for *n* measurements:

$$As(\%) = \frac{As \cdot 100}{Ra_m} \quad [\%] \tag{5}$$

- the inferior deviation as a percentage of the average value as calculated for *n* measurements:

$$Ai(\%)=\frac{Ai\cdot 100}{Ra_m}\quad[\%] \tag{6}$$

Taking into account these notations, a texture parameter could be expressed as $Ra_{m\,Ai(\%)}^{\;As(\%)}$ in the following tables.

The symbols for the texture parameters are given in the soft help and also in [2, 26, 27].

There are discussed the 2D amplitude parameters *Ra* (arithmetic average of absolute values), *Rq* (root mean squared), *Rsk* (skewness or a measure of the asymmetry of the probability distribution of asperities’ hight), *Rku* (kurtosis), *Rv* (maximum valley depth), *Rp* (maximum peak height), *Rz* (maximum height of the asperities) and their 3D "homologs": *Sa*, *Sq*, *Ssk*, *Sku*, *Sv*, *Sp*, *Sy,* the 2D functional parameters *Rpk*, *Rk*, *Rvk*, and the 3D ones, *Spk*, *Sk*, *Svk*, respectively. Why taking into account only the well-known parameter *Ra* (or *Sa*) is not enough for evaluating the surface quality? Because, in practice, different surfaces could have the same values for *Ra* (or *Sa*), and the differences in the topography structure significantly affect the tribological behavior, especially in dry regime of elements made of composites [2, 4-6, 8, 21]. *Ra* and *Sa* do not offer information on the spatial arrangement and do not differentiate the shape and the distribution of peaks and valleys. Thus, more useful could be a set of parameters, evaluating a given surface as a whole. Malburg [16] appreciated the surface quality with the help of the ratio:

$$Rz\,/\,Ra=\frac{Rz}{Ra} \tag{7}$$

for honed surfaces that have o very good finishing. The authors estimate that this ratio is also useful in studying the worn surfaces. A low value of this parameter could indicate a good quality of the worn surface and the tribosystem may continue to function in good conditions. A high value characterizes a surface with high peaks or/and deep valleys that, even rare, would initiate damaging processes (debris detach, micro-cracks and, in a vicious circle, abrasive wear, locally high temperature, modifications of the structures of the materials in contact, etc. When one or both triboelements are made of polymeric composites, the resulted very high asperities indicate the presence of hard component, left within the superficial layers as result of the preferential removal of the polymer (the softer component) [15]. In this study, the ratios of *Rz/Ra* and *Sz/Sa* were calculated with the average values obtained by the described methodology. The ratio involving the 3D parameters is:

$$Sz\,/\,Sa=\frac{Sz}{Sa} \tag{8}$$

3. CASE STUDY. AN ANALYSIS OF 2D AND 3D PARAMETERS FOR NON-WORN AND WORN SURFACES

3.1. The Amplitude Parameters

Figure 3 presents a virtual image, rebuilt, of the investigated zone with the help of [27].

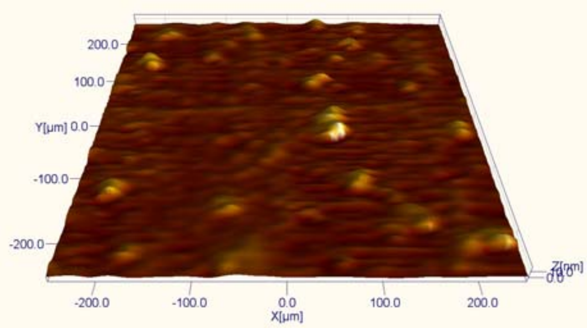


Fig. 3. *A virtual image of the non-worn surface of the composite PBT+10% glass beads*

Figure 4 presents a suggestive comparison of 2D and 3D parameters for the non-worn surface of the block made of the composite PBT+10% glass beads.

Analyzing the graphs in Figures 4 and 5, the following observations could be done:

- generally, the average value of an amplitude parameter is greater, but the scattering interval is narrower for the 3D evaluation as compared to the 2D one;

- for the parameters *Ra*, *Sa*, *Rq* and *Sq*, even for *Rku* and *Sku*, their average values are close, meaning that these parameters are less sensible to the evaluation method;

- the bigger difference was noticed for the average values of *Rz* and *Sz*, and for *Rv* and *Sv*. The values of *Rp* and *Sp* were similar, both for the average values and the scattering ranges, maybe because of a uniform dispersion of the hard component at the surface of the blocks.

Figure 4 presents a comparison between the 2D and 3D amplitude parameters, for the average values and the scattering ranges, characterizing the non-worn and worn surfaces of the blocks made of the composite PBT+10% glass beads, tested at *F*=5 N and a sliding distance of *L*=7500 m, in dry regime. These graphs also point out the influence of the sliding speed on the amplitude parameters. Taking into account the great number of analyzed data (9 profiles 2D) and 3 zones for 3D parameters, the authors consider that the 2D and 3D values could be compared in order to emphasise the advantages of 3D investigation of the surface texture.

The evolution tendencies of the 2D and 3D amplitude parameters depending on the sliding speed are qualitatively similar, but the obtained values for each method differ quite a lot. Generally, in this study, the average values of the 3D parameters are greater and the scattering range smaller as compared to those obtained for the 2D parameters. For instance, the average of *Ra* is 15...20% smaller than the values for *Sa*.

Analyzing Figure 5, it results the following:

- As the sliding speed increases, the quality of the worn surface becomes better (lower values of the average parameter values and narrower scattering ranges).
- Taking into account the time and the soft allocated for this study, are more time-consuming the lines’ selections and the average calculation for the 2D investigations.
- For the parameters *Ra*-*Sa*, *Rq*-*Sq*, *Rsk*-*Ssk*, the average values are close, but all 3D values are greater by 5...15%.
- Greater differences appear for the pairs *Rku*-*Sku*, *Ry*-*Sy*, *Rv*-*Sv*, *Rp*-*Sp*; (the 3D ones are almost twice the value obtained for their 2D homologs).
- The scattering ranges for the 3D parameters are narrower.

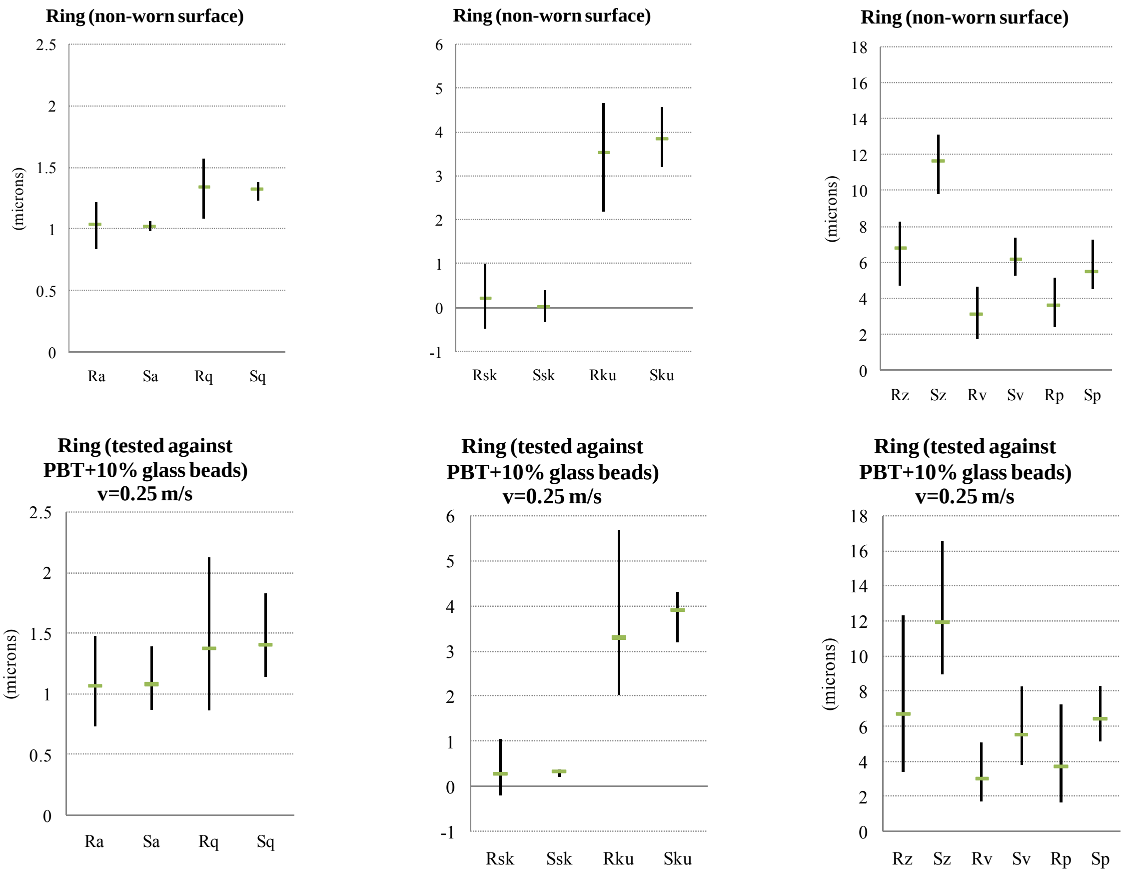
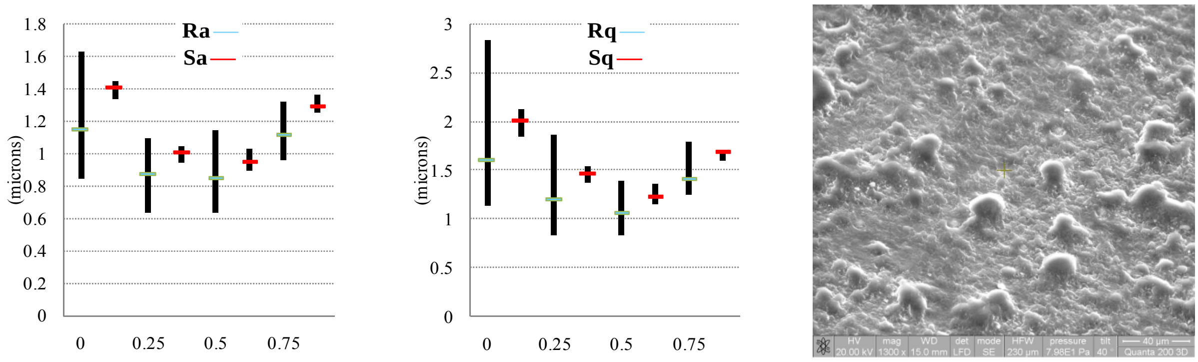


Fig. 4. *The 2D and 3D amplitude parameters for the metallic rings: the non-worn surface (up), the worn surface (down) for F=5 N, v=0.25 m/s and L=7500 m*



v=0 m/s

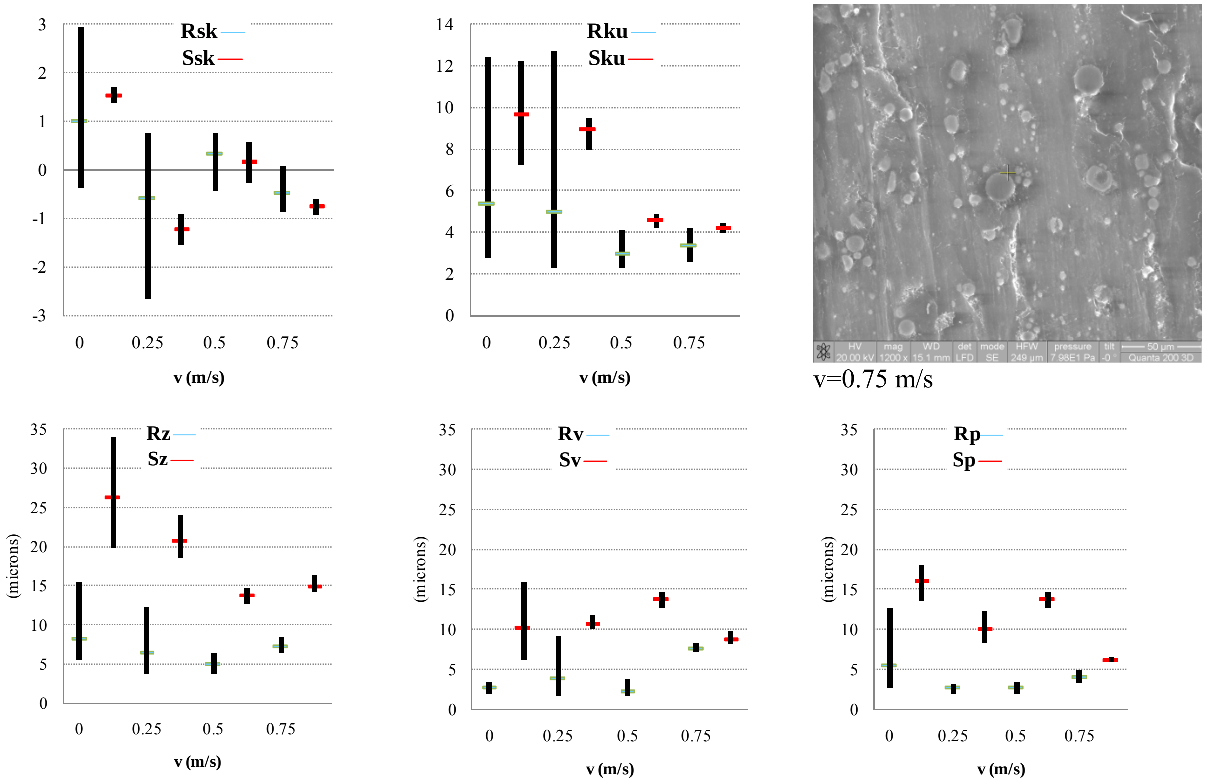


Fig. 5. *The average values and the scattering ranges for 2D and 3D amplitude parameters (non-worn surface of the block made of composite PBT+10% glass beads is given at v=0.0 m/s), tests at F=5 N and sliding distance L=7500 m)*

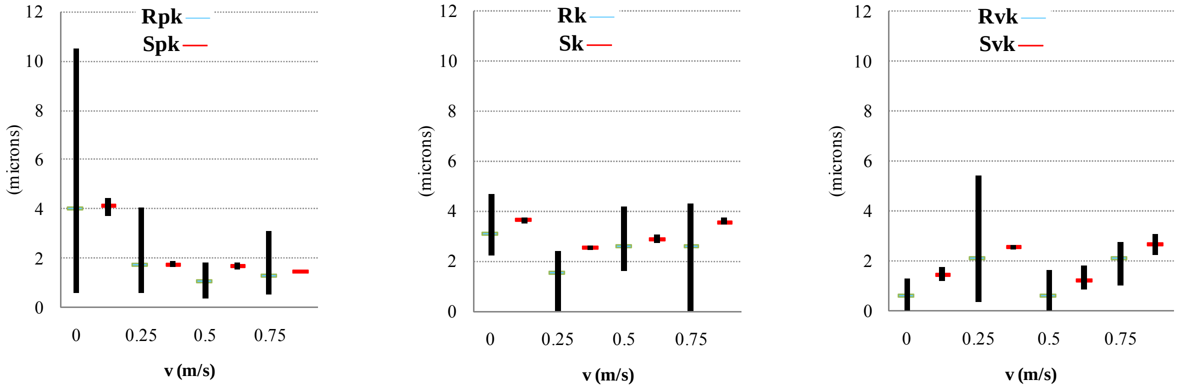


Fig. 6. *The average values and the scattering ranges for 2D and 3D functional parameters (non-worn surfaces is given at v=0.0 m/s), tests at the normal force F=5N and the sliding distance L=7500 m)*

Tables 1 and 2 present the average values and the deviations around them for the amplitude parameters, as obtained for the blocks made of PBT+10% glass beads (in percentage of the average value). For very good finished surfaces (non-worn), an international standard [25] recommends 2D parameters to be in a range of ±16% to the imposed as average value. From Tables 1 to 4, one may notice that this range of ±16% was obtained only for several 3D parameters (*Sa*, *Sq* and *Sy* – the last except the non-worn surface). From Tables 1 and 2, one may notice that the sampling method for evaluating the surface quality, the 3D parameters could be of more interest for tribologists because they reveal better the singularities of the surfaces (rare but extreme values for peaks and valleys). The ratio *Sz/Sa* is almost twice the value obtained for *Rz/Ra*. A 3D investigation has a higher probability of pointing out the extreme values as compared to a 2D one. The authors noticed a more accentuated decrease of the ratio *Sy/Sa* when the sliding speed was increased. It results that when testes at higher speeds, the worn surface has a better quality as compared to surfaces resulted after being tested at a lower speed (here *v=0.25 m/s*). The designer is interested in that aspect and will select the functioning regime that gives a better surface quality, especially when the tribosystem functions with repeated stops.

For the rolling bearing rings (Tables 3 and 4), the non-worn surfaces are characterized by a ratio

Sz/Sa$\approx$*11* and it does not modify too much after testing, being around this value.

This could be a supplementary argument in sustaining the affirmation that PBT and the PBT-based materials do not have an intense transfer process and adhesion on the counterface of metallic nature, at least for the block-on-ring tests with the commanding parameters: *F=5 N*, *v=0.25 m/s*,..., *0.75 m/s*.

Table 1. *The average values and the deviations of the 2D parameters, characterizing the composite blocks*

Parameter	Non-worn surface	v=0.25 m/s	v=0.50 m/s	v=0.75 m/s
Ra	$1.152^{+41.4\%}_{-26.7\%}$	$0.870^{+25.4\%}_{-26.7\%}$	$0.852^{+33.9\%}_{-25.2\%}$	$1.114^{+18.5\%}_{-13.8\%}$
Rq	$1.610^{+75.8\%}_{-29.2\%}$	$1.199^{+54.9\%}_{-30.6\%}$	$1.061^{+31.4\%}_{-21.6\%}$	$1.417^{+13.0\%}_{-12.0\%}$
Rsk	$0.989^{+196.2\%}_{-138.1\%}$	$-0.590^{+230.9\%}_{-348.2\%}$	$0.329^{+135.1\%}_{-231.2\%}$	$0.461^{+114.5\%}_{-87.6\%}$
Rku	$5.399^{+129.9\%}_{-49.3\%}$	$5.009^{+153.5\%}_{-53.9\%}$	$2.939^{+40.3\%}_{-21.4\%}$	$3.380^{+22.6\%}_{-23.9\%}$
Ry	$8.307^{+87.2\%}_{-33.1\%}$	$6.499^{+87.9\%}_{-41.2\%}$	$5.002^{+26.2\%}_{-23.7\%}$	$7.214^{+16.7\%}_{-10.8\%}$
Rv	$2.81^{+26.1\%}_{-30.9\%}$	$3.831^{+137.0\%}_{-56.5\%}$	$2.270^{+65.7\%}_{-26.7\%}$	$3.980^{+24.86\%}_{-28.9\%}$
Rp	$5.499^{+132.5\%}_{-50.8\%}$	$2.667^{+17.3\%}_{-25.3\%}$	$2.731^{+28.5\%}_{-28.1\%}$	$3.233^{+15.3\%}_{-12.1\%}$
Rz/Ra	***7.210***	***7.470***	***5.870***	***6.475***

Table 2. *The average values and the deviations of the 3D parameters, characterizing the composite blocks*

Parameter	Non-worn surface	v=0.25 m/s	v=0.50 m/s	v=0.75 m/s
Sa	$1.404^{+3.0\%}_{-5.0\%}$	$1.010^{+3.2\%}_{-5.9\%}$	$0.946^{+8.6\%}_{-5.1\%}$	$1.293^{+5.5\%}_{-3.1\%}$
Sq	$2.007^{+6.0\%}_{-8.1\%}$	$1.473^{+5.2\%}_{-6.8\%}$	$1.234^{+10.4\%}_{-6.5\%}$	$1.697^{+6.0\%}_{-4.3\%}$
Ssk	$1.541^{+11.0\%}_{-9.8\%}$	$1.228^{+26.2\%}_{-25.1\%}$	$0.157^{+263.5\%}_{-267.3\%}$	$-0.754^{+20.7\%}_{-22.7\%}$
Sku	$9.643^{+26.5\%}_{-25.0\%}$	$8.917^{+6.1\%}_{-10.6\%}$	$4.606^{+5.4\%}_{-7.9\%}$	$4.205^{+4.6\%}_{-5.3\%}$
Sy	$26.204^{+29.9\%}_{-24.4\%}$	$20.713^{+16.3\%}_{-10.1\%}$	$13.694^{+7.1\%}_{-6.8\%}$	$14.948^{+9.4\%}_{-5.5\%}$
Sv	$10.229^{+55.4\%}_{-39.0\%}$	$10.742^{+9.7\%}_{-5.3\%}$	$7.675^{+9.3\%}_{-7.1\%}$	$8.788^{+12.3\%}_{-6.5\%}$
Sp	$15.974^{+13.6\%}_{-15.1\%}$	$9.971^{+23.4\%}_{-16.3\%}$	$6.019^{+4.2\%}_{-6.4\%}$	$6.159^{+5.2\%}_{-4.0\%}$
Sz/Sa	***18.663***	***20.507***	***14.475***	***11.560***

Table 3. *Average values and scattering ranges for 2D parameters, for the metallic rings*

Parameter	Non-worn surface	*v*=0.25 m/s
2D amplitude parameter		
Ra	$1.035^{+17.7\%}_{-19.0\%}$	$1.068^{+38.1\%}_{-31.0\%}$
Rq	$1.339^{+16.8\%}_{-19.2\%}$	$1.374^{+54.6\%}_{-37.0\%}$
Rsk	$0.227^{+345.2\%}_{-309.8\%}$	$0.270^{+289.7\%}_{-167.2\%}$
Rku	$3.530^{+31.8\%}_{-38.2\%}$	$3.302^{+71.9\%}_{-38.5\%}$
Rz	$6.797^{+21.2\%}_{-30.6\%}$	$6.736^{+82.7\%}_{-49.4\%}$
Rv	$3.144^{+48.2\%}_{-44.5\%}$	$3.024^{+68.6\%}_{-41.8\%}$
Rp	$3.653^{+41.5\%}_{-34.6\%}$	$3.712^{+94.2\%}_{-55.7\%}$
Rz/Ra	***6.56***	***6.30***

Table 4. *Average values and scattering ranges for 3D parameters, for the metallic rings*

Parameter	Non-worn surface	*v*=0.25 m/s
3D amplitude parameter		
Sa	$1.021^{+3.5\%}_{-4.1\%}$	$1.081^{+28.3}_{-19.6\%}$
Sq	$1.323^{+4,0\%}_{-6.7\%}$	$1.401^{+30,2\%}_{-18.5\%}$
Ssk	$1.020^{+1766,7\%}_{-1703.1\%}$	$0.325^{+16,6\%}_{-30,8\%}$
Sku	$3.836^{+18.5\%}_{-16.4\%}$	$3.914^{+9.5\%}_{-18.4\%}$
Rz	$11.676^{+12.3\%}_{-16.2\%}$	$11.050^{+38.3\%}_{-25.2\%}$
Sv	$6.194^{+19.6\%}_{-14.6\%}$	$5.519^{+49.6\%}_{-31.3\%}$
Sp	$5.482^{+32,0\%}_{-17.9\%}$	$6.431^{+28.7\%}_{-20.0\%}$
Sz/Sa	***11.43***	***11.05***

2D functional parameters		
Rpk	$3.092^{+114.5\%}_{-85.5\%}$	$1.871^{+71.9\%}_{-88.3\%}$
Rk	$3.456^{+34.3\%}_{-21.8\%}$	$2.813^{+31.2\%}_{-21.5\%}$
Rvk	$1.399^{+84.2\%}_{-91.5\%}$	$1.190^{+92.2\%}_{-100.0\%}$

3D functional parameters		
Spk	$1.427^{+21.5\%}_{-18.6\%}$	$1.967^{+27,0\%}_{-20.9\%}$
Sk	$3.102^{+1.7\%}_{-0.9\%}$	$3.268^{+24.0\%}_{-19.2\%}$
Svk	$1.633^{+31.3\%}_{-16.0\%}$	$1.236^{+48.2\%}_{-34.9\%}$

3.2. Functional Parameters

For a 2D analysis, the three functional parameters, *Rpk* (the first region of the contact), *Rk* (the "working" region of the contact or the core height) and *Rvk* (the lubricant retention region or the "valley" depth), selected for evaluating the topography are presented in Fig. 7, as they are extracted from the bearing curve for a 2D profile [29].

The scattering ranges are greater for the 2D investigations, the average values being smaller but closer to those obtained from the 3D investigations (Fig. 8).

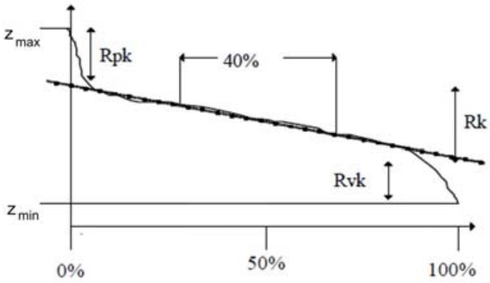


Fig. 7. *The set of functional parameters Rpk, Rk and Rvk [29]*

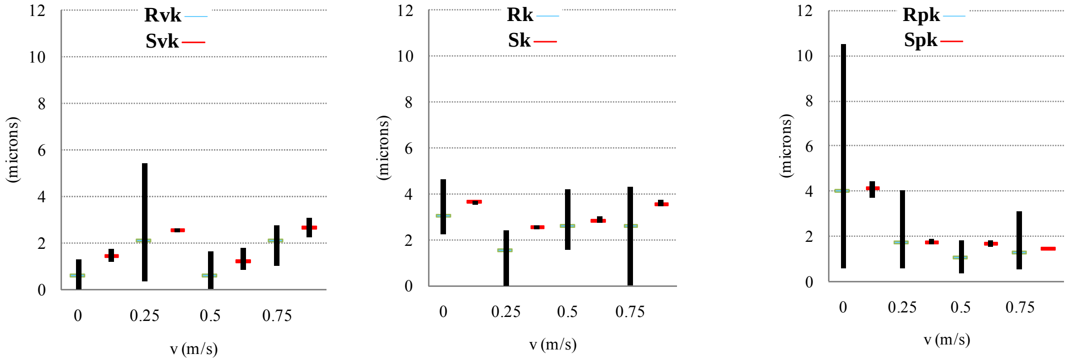
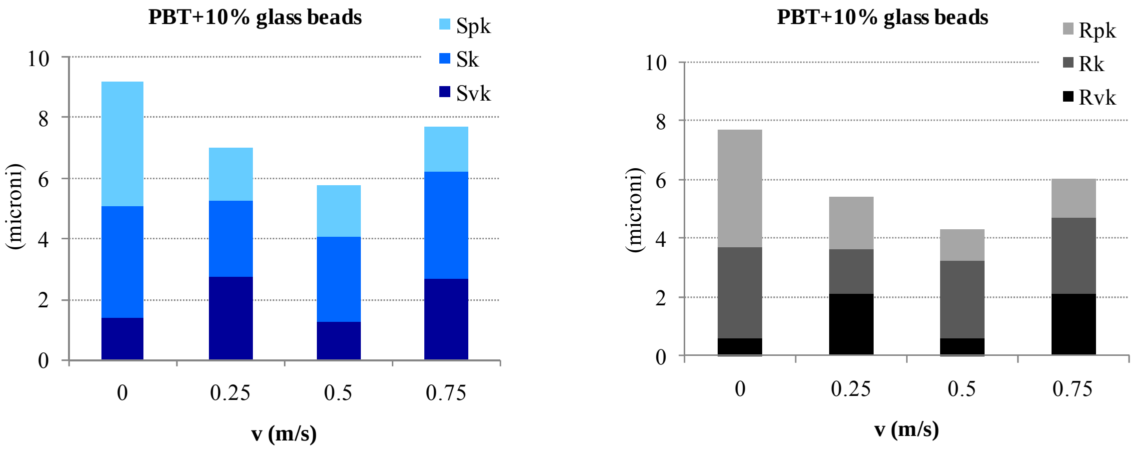


Fig. 8. *The functional parameters; average values and scattering ranges for the blocks made of PBT + 10% glass beads, a function of sliding speed (v=0 m/s for the non-worn surface as resulted from the moulding process); test conditions F=5 N and L=7500 m*



a) 3D

b) 2D

Fig. 9. *The average values of the functional parameters characterizing the wear tracks of the blocks made of PBT+ 10% glass beads (tests done at F=5 N and L=7500 m)*

The authors consider that the 3D functional parameters could reflect better a possible correlation with the tribological characteristics (the friction coefficient, the wear parameters and even the acoustic emission).

Figure 9 suggestively presents the average values of the 2D and 3D functional parameters, for the blocks made of PBT + 10% glass beads. One may notice that the 3D values are greater for all parameters.

Presenting the sum (*Rpk+Rk+Pvk*) and (*Spk+Sk+Svk*), respectively, as given in Fig. 9, is more adequate for pointing out the material distribution within the surface topography. The decrease of the values of *Rk* or *Sk* indicates a decrease of the texture resistance when bearing the loads in contact and greater values for *Rpk* or *Spk* suggest a higher probability for the material in that zone to be worn (detached, plastically deformed, etc.) as the asperities have higher and narrow shapes in this region.

3. CONCLUSIONS

The evaluation of the quality of both non-worn and worn surfaces with the help of 3D parameters reflects better the topography reality when the measuring pitch is smaller and the investigation zone is larger or the sampling methodology is proved to give acceptable results. This study pointed out that three 3D measurements on both non-worn and worn surfaces have characterized in a good manner the quality of the investigated surfaces.

In tribology, the extreme values are important, both for the dry contact and the lubricated one. Thus, this study underlines that a 3D investigation will be more appropriate for evaluating the surface quality and it reflects better the nature of the topography.

As for the worn surfaces, the specialists would be more interested in values of the amplitude parameters *Ssk*, *Sku*, Sy, *Sp* and *Sv*, because the high peaks affect the tribological parameters, especially when dealing with polymeric composites with hard particles and their possible non-uniform distribution.

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