A 2D and 3D study of the texture of wear scars for soybean oil additivated with nano graphite

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Abstract. Based on studies on characterization of surface topography, the following conclusions can be drawn: surface texture analyses are statistical. There is no agreed methodology for characterizing both the texture of worn surfaces and those of new ones (unworn). The methodology depends on many factors: the shape and size of triboelements, the available equipment and software, the set of selected parameters, the user experience and ingenuity. Worn scars were obtained after tests on four ball machine (European conditions [30], at LubriTest laboratory of “Dunarea de Jos” University). The test parameters for each tested lubricant were: force at main shaft of the four ball machine - 100 N, 200 N and 300 N (± 5%), sliding speeds of 0.383 m/s, 0.537 m/s and 0.691 m/s, test time - 60 minutes (± 1%), the concentration of the additive is 0.25%, 0.50% and 1% (wt), respectively. Analysing the data from this study, it can be seen that for all measurements, St is higher than Rt, which means that the maximum values were not found on the axis of the ellipse perpendicular to the sliding direction. This is logical because in a circular or almost circular contact, the maximum contact pressure is towards the front of the contact. Thus, a 3D study will also include the area of maximum contact pressure that will most likely affect the surface texture quality to a greater extent. For some test regimes, i.e. (F=100 N, v=0.38 m/s), lower values were obtained than those obtained on the initial surfaces of the balls, which implies that the test regime acts as a running-in process, improving the surface quality Amplitude parameters and three functional parameters will be analysed in this paper.

1. Introduction
Based on studies on characterization of surface topography [1] [2], [3], [5], [7], [11], [17], [20], the following conclusions can be drawn:
- surface texture analyses are statistical,
- there is no agreed methodology for characterizing both the texture of worn surfaces and those of new ones (unworn),
- the methodology depends on many factors: the shape and size of triboelements, the available equipment and software, the set of selected parameters, the user experience and ingenuity.

Figure 1 underlines the requirement of studying a set of texture parameters and not only one [32] as different textures could have similar value for one parameter and they have different values for
parameters that the analyst would not know to add to his evaluation. This study examines the parameters of amplitude (Ra, Rq, Rt, Rsk, Rku) and the "homologues" 3D (Sa, Sq, St, Ssk, Sku) and the functional ones (Rpk, Rk, Rvk, Spk, Sk, Svk). Ra (or Sa) parameter is not sufficient for surface quality assessment because, in practice, there may be surfaces with the same values of Ra (or Sa) (Fig. 1), but with very different characteristics, which will significantly affect their dry or lubricated behavior.

For the analysis of worn surface quality, based on a recent documentation ([8], [9] [22], [10], [13], [14], [15], [16], [23], the following directions of investigation are outlined. Because there are few comparative studies for 2D and 3D analyses, a comparison will be done between the values obtained for 2D and 3D parameters and a method of sampling the 2D records and the 3D investigation areas will be detailed. The study should correlate the evolution of the texture parameters with the exploitation parameters of the system (working regime, tribological parameters, acoustic emission etc.).

Amplitude parameters and three functional parameters will be analysed in this paper. Worn scars were obtained after tests on four ball machine (European conditions [30], at LubriTest laboratory of "Dunarea de Jos" University). The test parameters for each tested lubricant were:
- force at main shaft of the four ball machine - 100 N, 200 N and 300 N (± 5%),
- sliding speeds of 0.383 m/s, 0.537 m/s and 0.691 m/s, corresponding to the spindle speeds of the four-ball machine 1000 rpm, 1400 rpm and 1800 rpm (± 6 rpm),
- test time - 60 minutes (± 1%),
- the concentration of the additive is 0.25%, 0.50% and 1% (wt), respectively.

![Fig. 1. Surface types and amplitude parameters](image)

a) Gaussian surface

b) Surface with deep and narrow valleys
c) Surface with tall and narrow peaks
d) Surface with valleys and wide peaks, with relatively high slope
e) Surface with peaks and rare valleys but with extreme values

2. **Amplitude parameters**

most commonly used. It was known in the form of AA (Arithmetic Average) in the United States, and CLA (Center Line Average) in the UK. If a height $z(x)$ of the profile, obtained by intersecting the measured surface with a reference plane, Ra is defined as the arithmetic mean of the absolute values of the ordinates $z(x)$, measured from the mean line, within a basic length:

$$Ra = \frac{1}{M} \sum_{i=1}^{M} |z(x_i)|$$  \hspace{1cm} (1)  

where $M$ is the number of points on the profile, by which it was meshed on the reference length, and $z(x_i)$ is the height of the rated profile, at any position ($x_i$), $i = 1...M$. 

2
For 3D records, the arithmetic mean of the absolute values of \( z(x, y) \) is defined within the limits of the measurement surface:

\[
Sa = \frac{1}{M \cdot N} \sum_{i=1}^{N} \sum_{j=1}^{M} |z(x_i, y_j)|
\]

(2)

where \( N \) is the number of profiles on the investigated surface, \( j=1...N \), and \( M \) are the number of recorded points on each line, \( i=1...M \).

The average square deviation of the profile/surface, \( Rq/Sq [\mu m] \), defined in [26], [28], as the quadratic mean of \( z(x) \) or \( z(x, y) \), ordinate values within the boundary of a base length or measuring surface and is a dispersion parameter of the height of the asperities. For parameter 2D, the calculation relation is:

\[
Rq = \sqrt{\frac{1}{M} \sum_{i=1}^{M} z^2(x_i)}
\]

(3)

Blunt defines the mean square deviation of the surface as being [2]:

\[
Sq = \sqrt{\frac{1}{M \cdot N} \sum_{j=1}^{N} \sum_{i=1}^{M} z^2(x_i, y_j)}
\]

(4)

where \( M \) is the number of points on a profile and \( N \) is the number of profiles on the investigated surface; \( z(x, y) \) is the set of gross state data obtained for the investigated surface.

The maximum profile/surface height, \( Rt/St \), is the distance between the highest peak and the deepest valley in the investigated area [2]. The maximum height of the profile or surface is denoted by \( Rz/Sz \) (according to ISO ([26], [27])), \( St \) (according to [31]) or \( Sy \).

If working with unfiltered raw profiles relative to a reference line/surface:

\[
Rt = (|Rp| + |Rv|)
\]

(5)

\[
St = (|Sp| + |Sv|)
\]

(6)

The asymmetry factor of the investigated profile/surface, or skewness, \( Rsk/Ssk \), is a measure of the profile/surface deviation asymmetry from the median plane (sharp features on the profile or investigated surface). It is strongly influenced by isolated peaks or voids.

\[
Rsk = \frac{1}{M \cdot Rq} \sum_{i=1}^{M} z^3(x_i)
\]

(7)

\[
Ssk = \frac{1}{M \cdot N \cdot Sq} \sum_{j=1}^{N} \sum_{i=1}^{M} z^3(x_i, y_j)
\]

(8)

The flattening factor of the assessed profile/surface (kurtosis), \( Rku/Sku \), is a measure of the curvature of the flattening or "sharpness" of the surface heights distribution curve. These parameters provide information about the shape of the profile or the surface.

\[
Rku = \frac{1}{M \cdot Rq} \sum_{i=1}^{M} z^4(x_i)
\]

(9)

\[
Sku = \frac{1}{M \cdot N \cdot Sq} \sum_{j=1}^{N} \sum_{i=1}^{M} z^4(x_i, y_j)
\]

(10)

For a Gaussian surface with uniformly distributed peaks and valleys, the value of 2D and 3D parameters is 3. Physically, kurtosis indicates the peaks on a surface.

### 3. Functional parameters

According to [2], [1], [24], [4], [5], [28], the functional parameters are defined by the load length curve (for 2D analysis) or the load area curve (for 3D analysis). These parameters are field parameters and must be taken into account that they are statistical ones.

The height of the peaks, \( Rpk/Spk \), estimates the small peaks above the main plane of the surface.
These peaks will be removed during the run-up period by deformation or removal as wear particles. In order to have as small as possible particles from the surface, a lower value for this parameter would be desirable. This parameter is used to evaluate the surface in the sense that small values mean unpeeled/unpeeling surfaces.

The relative height of the core of the surface, Rk/Sk, is the functional part of the surface. After the run-in period (after the peaks represented by Rpk/Spk are worn out), this part will take over the load during exploitation.

The reduced depth of the deepest valleys of the analyzed profile/area, Rvk/Svk, is an estimate of the valley depths that will retain the lubricant during exploitation.

Functional parameters

Regarding the functional parameters, Rpk, Rk and Rvk, respectively Spk, Sk and Svk, they were chosen for this analysis, considering that they could better reflect a correlation with the tribological parameters (coefficient of friction, wear and very probable acoustic emission), as shown in [2], [18], [24]. These parameters also have suggestive names: Rpk - "zone of asperity heights" or contact region (here, in the wearing process, peaks of are deformed and/or detached in contact with the conjugate surface), Rk - the "core" of the texture, "the load bearing core" in service, Rvk - "the valley area" or "the lubricant retention area".

4. A particular methodology for measuring texture of worn surfaces

For surface quality assessment, the NANOFOCUS μSCAN laser profile was used, from the "Ştefan cel Mare" University of Suceava. This is an optical non-contact profilometer for measurement of surface microtopography, with a measuring range of 150 mm x 200 mm, a vertical measurement range of 1.00 \( \mu \)m to 18 mm, a vertical resolution of 25 nm [29]. SPIP program 6.7.2 [25] was used to process the results.

The 3D parameters were calculated for each wear scar on the three fixed balls and the average, maximum value and minimum value were calculated. The measurement step is the same for 3D and 2D: 5 \( \mu \)m. Line spacing for 3D measurements is also 5 \( \mu \)m. 2D parameters are the average of three measurements, that is, three profile lines, perpendicular to the sliding direction, on each ball. The linear profiles must be perpendicular to the sliding direction, so they are one of the axes of the selected ellipse (the wear scar) 3D parameters are calculated for all z(x,y) values measured on the measuring area (wear scar).

The following notations were introduced to evaluate the scattering of measured values for a texture parameter [22], [15]. It will be exemplified by the roughness arithmetic parameter, Ra or Sa, depending on the measurement method (2D or 3D).

Each parameter on the measured area/line can be characterized by:
- the highest recorded value, \( Ra_{\text{max}} \) or \( Sa_{\text{max}} \);
- the minimum recorded value, \( Ra_{\text{min}} \) or \( Sa_{\text{min}} \);
- the average value of the parameter in several measurements, \( Ra_m \) or \( Sa_m \).
\[ Ra_m = \frac{1}{n} \sum_{i=1}^{n} Ra_i \]  \hspace{1cm} (11)
\[ Sa_m = \frac{1}{n} \sum_{i=1}^{n} Sa_i \]  \hspace{1cm} (12)

where \( Ra_i \) is the value of the parameter \( Ra \) for the measurement (line) \( i \), \( Sa_i \) is the value of the parameter \( Sa \) for the measurement \( i \) (on the investigated area), \( n \) being the number of measurements (in this study \( n = 3 \) for values 2D and \( n = 3 \) for those 3D);

- higher deviation above the calculated average for \( n \) measurements:
  \[ As = Ra_{max} - Ra_m \]  \hspace{1cm} (13)
- lower deviation from the average calculated for \( n \) measurements:
  \[ Ai = Ra_{min} - Ra_m \]  \hspace{1cm} (14)
- higher deviation above the calculated average, in percentage, for \( n \) measurements:
  \[ As(\%) = \frac{As}{Ra_m} \cdot 100 \% \]  \hspace{1cm} (15)
- lower deviation from the average calculated for \( n \) measurements:
  \[ Ai(\%) = \frac{Ai}{Ra_m} \cdot 100 \% \]  \hspace{1cm} (16)

The following case studies have been detailed in this chapter:
- a comparative study of the values obtained for the roughness parameters, 3D for the entire elliptical wear scar and 2D, for the longest line on the wear scar, perpendicular to the sliding direction,
- the study of the influence of graphite concentration and of test parameters (speed and force) on the 3D parameters of the wear scar surface, on the balls.

5. Comparative study of 2D and 3D parameters for worn surfaces of balls

Table 1 shows values of 3D amplitude and functional parameters for the non-worn (initial) surface of the ball and Figure 3 presents a typical Abbott-Firestone curve for the unbroken surface of the ball.

Table 1. Characteristic values for the surface of the balls

| Parameter | Value [\( \mu m \)] |
|-----------|---------------------|
| \( Sa \)  | 0.4739              |
| \( Sq \)  | 0.6676              |
| \( Ssk \) | 1.486               |
| \( Sku \) | 8.213               |
| \( St \)  | 7.378               |
| \( Spk \) | 1.367               |
| \( Sk \)  | 1.021               |
| \( Svk \) | 0.558               |

Taking into account the information in Figure 3 and Table 1, the characteristics of the surface texture of the balls are:
- very high asperities (\( St = 7 \ \mu m \)),
- fine finished surface (\( Sa = 0.47 \ \mu m \)),
- plateau with bumps resulting from the technological peculiarities of obtaining the surface of the balls (\( Ssk = 1.48 \), \( Sku = 8.21 \)),
- the Abbott-Firestone curve characteristic of fine-grained surfaces with low volume for retaining...
the lubricant ($S_vk=0.55 \text{ \mu m}$), with high volume of material in the core of the profile, responsible for contact resistance and low values for $Spk$ ($Spk=1.36 \text{ \mu m}$).

A value in table 2 is the average of values recorded for each of the three wear scars of the fixed ball, in one test. Analyzing the graphs in Figures 4 to 6 and Table 2, the following observations can be done:

- generally, the average value of the same parameter is greater for 3D evaluation as compared to the value obtained in a 2D analysis, and the scatter range is lower for 3D than for 2D,
- for the parameters $Ra$, $Sa$, $Rq$, $Sq$, $Rp$, $Sp$ and even $Rsk$, $Ssk$, there were obtained close average values, which means that these parameters are less sensitive to the measurement method,
- for the other analyzed amplitude parameters, the average 2D values are smaller than the 3D average values for the same parameter,
- the biggest difference was found between the mean values for $Rt$ and $St$.

Fig. 4. Comparison of 3D and 2D parameter values as average and spread intervals

Figures 4 to 6 shows comparisons of 2D and 3D parameters. The parameter set $(F, v)$ was chosen
only to give an example of the differences between the two types of wear measurements, after a test with soybean oil + 1% graphite. The rest of the graphs are given in [6].

It can be seen from average values of the amplitude parameters that the ratio between 3D and 2D is between 2.5...3.5. This difference can be explained in this way. The 2D profile, although equal in length to one of the axes of the contact ellipse or the wear scar, perpendicular to the sliding direction, is not likely to contain extreme values of asperities. A proof of this statement is the rebuilt image of the wear scar in Fig. 8, for F=300 N, where some micro-pits and heights are not in the 2D measuring line. According to the EHD theory [12], [21], the maximum pressure in a point-to-point contact is at the entrance of the lubricant in contact. On many photos taken at the optical microscope, it can be noticed that the rougher texture is not on the axis of wear scars perpendicular to the direction of sliding, but between this line and the entrance in contact. Another reason is that the 2D profiles are filtered with a reference length of 0.25 μm and the 3D profiles are analyzed on the raw profile only with a leveling of the worn surface.

As in tribology extreme values of asperities are important in both dry and lubricated contact, it results that 3D measurements better reflect the surface quality and how the surface will behave during work.

**Amplitude parameters**

Figure 5 shows a comparison between the average values and the scattering intervals obtained for the 2D and 3D parameters, Ra and Sa, for the worn surfaces of the balls.

![Graph](image1)

**Fig. 5.** Average values and scatter intervals obtained for 2D and 3D parameters

All these graphs reflect the influence of the sliding velocity on the amplitude parameters of the
surface texture. Considering the large number of data analyzed (Three 2D profiles, one on each wear scar and three wear scars on the 3 balls of a test set, for 3D parameters), it is considered that trends can be analyzed in the sense of comparing values and highlighting the benefits of 3D parameterization.

Qualitatively, the evolution trends of 2D and 3D parameters based on sliding speed are similar, but the values differ a lot. Generally, the average 3D parameter is higher, but the scatter range is lower.

Figure 5 shows the following:
- as the sliding speed increases, the quality of the used surface improves;
- from the point of view of the allocated calculation time, given the dedicated program, for the investigator, it takes longer to select lines and calculate the average;
- large differences occur for Rku-Sku, Rz-Sz, Rv-Sv, Rp-Sp; the values obtained for 3D parameters are higher (almost all of them are at least twice as large);
- spreading intervals are smaller for 3D parameters.

![Graph showing average values and scatter intervals obtained for 2D and 3D parameters](image)

Fig. 6. Average values and scatter intervals obtained for 2D and 3D parameters

Ra or Sa does not provide information about the spatial structure and does not differentiate the valleys and the topography of the texture. Malburg [Malburg, 2008] also appreciated the surface quality with the ratio

$$\frac{R_t}{R_a} = \frac{R_t}{R_a}$$

for honed surfaces. This ratio will be considered in this study for worn surfaces. A small value can indicate good surface quality and a continued operation of the system in good condition. A high value characterizes a surface with peaks and/or valleys (rare or not), but very high, which implies
an aggressive wear process, at least in the area of the existence of the singular maximum. In this study, the author analyzed the Rt/Ra ratios and St/Sa ones, calculated with the average values obtained according to the methodology described above.

Table 2 shows the average value, the lower and upper deviation values, respectively, for each analyzed 3D and 2D parameter, for soybean oil + 1% graphite. This lubricant has been chosen for studying these wear scars because the tribological behavior of this lubricant was better as compared to other formulated lubricants in [6].

Table 2. Average values and spread intervals for 2D/3D amplitude parameters, for balls tested with soybean oil + 1% graphite

| Parameter | F = 100 N | F = 200 N | F = 300 N | v = 0.38 m/s | Parameter | F = 100 N | F = 200 N | F = 300 N |
|-----------|-----------|-----------|-----------|--------------|-----------|-----------|-----------|
| Ra        | 0.19       | 0.56      | 0.42      | 0.65         | Sa        | 0.79      | 0.87      | 0.79      |
| Rq        | 0.28       | 0.72      | 0.53      | 0.75         | Sq        | 0.96      | 1.08      | 0.96      |
| Rt        | 1.58       | 3.62      | 2.75      | 6.20         | St        | 7.26      | 7.90      | 7.26      |
| Rsk       | 0.84       | 0.85      | 0.23      | 0.13         | Ssk       | 0.23      | 0.41      | 0.23      |
| Ru        | 6.37       | 3.81      | 3.28      | 2.58         | Sku       | 2.90      | 3.26      | 2.90      |
| Rpk       | 0.05       | 0.39      | 0.71      | 0.92         | Spk       | 1.04      | 1.47      | 1.04      |
| Rk        | 1.58       | 3.62      | 1.29      | 2.28         | Sk        | 2.47      | 2.95      | 2.47      |
| Rvk       | 1.07       | 0.001     | 0.44      | 0.26         | Svk       | 0.55      | 0.59      | 0.55      |
| Rt/Ra     | 8.15       | 6.38      | 6.52      | -            | St/Sa     | 9.53      | 9.07      | 9.17      |

| Parameter | F = 100 N | F = 200 N | F = 300 N | v = 0.53 m/s | Parameter | F = 100 N | F = 200 N | F = 300 N |
|-----------|-----------|-----------|-----------|--------------|-----------|-----------|-----------|
| Ra        | 0.22       | 0.37      | 0.47      | 0.53         | Sa        | 1.04      | 1.69      | 1.04      |
| Rq        | 0.28       | 0.48      | 0.59      | 0.63         | Sq        | 1.26      | 0.83      | 1.26      |
| Rt        | 1.29       | 2.19      | 2.59      | 4.07         | St        | 9.63      | 6.60      | 9.63      |
| Rsk       | 0.53       | 0.58      | 0.60      | 0.16         | Ssk       | 0.36      | 0.38      | 0.36      |
| Ru        | 3.61       | 3.25      | 2.99      | 2.61         | Sku       | 3.43      | 3.22      | 3.43      |
| Rpk       | 0.03       | 0.31      | 0.85      | 0.73         | Spk       | 1.42      | 0.99      | 1.42      |
| Rk        | 129        | 1.72      | 1.41      | 1.93         | Sk        | 3.58      | 2.39      | 3.58      |
| Rvk       | 0.001      | 0.04      | 0.17      | 0.23         | Svk       | 0.53      | 0.38      | 0.53      |
| Rt/Ra     | 5.7        | 5.81      | 5.52      | -            | St/Sa     | 9.52      | 7.63      | 9.52      |
For the sampling method used in this study, the St/Sa ratio is two to three times higher than Rt/Ra (Tables 2). It follows that 3D surface quality evaluation can highlight the existence of
extreme values with greater probability. There is a decrease in this ratio with increased speed, more pronounced for St/Sa. At higher speeds, worn surfaces are of better quality than those obtained for lower test speeds (v=0.38 m/s), which a designer is interested in when selecting the working system, especially in the case of a regime with repeated starts and stops.

To highlight the importance of studies based on a set of texture parameters, Figure 9 schematically presents different profiles, characterized by the set (Rq, Rsk, Rku). Therefore, in this study, the values of these amplitude parameters are analyzed only for 3D (Sq, Ssk, Sku).

In international standards, it is recommended for well-processed surfaces that these deviations are within ± 16% for 2D parameters, but these are worn surfaces. The values in Table 2 show that this range would only be met for a few 3D parameters (Sa, Sq and St - except for the original surface).

\[ Rq = 0.27 \mu m, \ Rsk = -0.32, \ Rku = 6.08, \ F = 100 N \]  
\[ Rq = 0.39 \mu m, \ Rsk = 0.6, \ Rku = 3.48, \ F = 300 N \]

Fig. 8. Wear scars for v = 0.69 m/s. 3D virtual images are reconstituted from data measurements and their cross sections, (for 3D images, Z scale is in microns, 200:1), 2D profiles are taken on the scar axis perpendicular to the sliding direction.

**Conclusions**

Analyzing the values for the pair (Rsk, Rku) or (Ssk, Sku), it is observed that Rsk (and Sku) are positive and Rku has values in the range 2 ... 3. It results that the vast majority of wear scars are surfaces with tall and narrow peaks, resulting from abrasive wear, the traces being visible also on the images obtained with the optical microscope and on the virtual images that reconstruct the surface with the help of the profilometer software [SPIP 6.7.2].

Figures 7 and 8 exemplify these conclusions only for one wear scar of a tested ball, but they are supported by the data in Table 2. Analyzing the data from Tables 2, it can be seen that for all measurements, St is higher than Rt, which means that the maximum values were not found on the axis of the ellipse perpendicular to the sliding direction. This is logical because in a circular or almost circular contact, the maximum contact pressure is towards the front of the contact. Thus, a 3D study will also include the area of maximum contact pressure that will most likely affect the surface texture quality to a greater extent. For some test regimes, i.e. (F=100 N, v=0.38 m/s), lower values were obtained than those
obtained on the initial surfaces of the balls, which implies that the test regime acts as a running-in process, improving the surface quality.

References
[1] Blateyron, F., (2008). 3D parameters and new filtration techniques. www.digitalsurf.fr/pressreleases/2008-06-unn-prize.pdf.
[2] Blunt, L., Jiang, X. (2003). Advanced techniques for assessment surface topography, London, Butterworth-Heinemann.
[3] Blunt, L., Jiang, X., Leach, R., Harris, P., Scott, P. (2008). The development of user-friendly software measurement standards for surface topography software assessment, Wear, 264, pp. 389-393.
[4] Botan, M., Pirvu, C., Georgescu, C., Deleanu L. (2013). Influence of Feed Speed on Surface Quality of Several Building Stones, paper 777, Proceedings from 5th World Tribology Congress (WTC 2013), p. 1958, Torino, Italy, 8-13 September 2013, Curran Associates, Inc.
[5] Cotell, C.M., Sprague, J.A., Smidt, F. A. Jr. (2002). ASM Handbook volume 5 – Surface Engineering, ASM International, USA.
[6] Cristea G C 2017 Tribological characterization of soybean oil additivated with nano materials based on carbon (black carbon, graphite and graphene) (PhD thesis: “Dunarea de Jos” University of Galati)
[7] Davim, J. P., Mata, F. (2004). Influence of cutting parameters on surface roughness in turning glass-fibre-reinforced plastics using statistical analysis, Industrial Lubrication and Tribology, 56(5), pp. 270-274.
[8] Deleanu, L., Cantaragiui, A., Birsan, I. G., Podaru, G., Georgescu, C. (2011). Evaluation of the spread range of 3D parameters for coated surfaces. Tribology in Industry, 33(2), pp. 72-78.
[9] Deleanu, L., Cantaragiui, A., Georgescu, C., Botan, M. (2011). Influence of measured samples on 3D roughness parameters, Mechanical Testing and Diagnosis, 1, pp. 42-53.
[10] Demkin, N. B., Izmailov, V. V. (2010). The relation between the friction contact performance and the microgeometry of contacting surfaces, Journal of Friction and Wear, 31(1), pp. 48-55.
[11] Dong W.P., Sullivan, P.J., Stout K. J. (1994). Comprehensive study of parameters for characterising three-dimensional surface topography. III: Parameters for characterising amplitude and some functional properties, Wear, 178(1-2), pp. 29-43.
[12] Dowson, D., Higginson, G., R. (1977). elasto-hydrodynamic lubrication, Oxford, Pergamon Press.
[13] Scurtu, I.C., Manufacturing and design of the offshore structure Froude scale model related to basin restrictions, (2015) IOP Conference Series: Materials Science and Engineering, 95 (1), art. no. 012068, DOI: 10.1088/1757-899X/95/1/012068
[14] Georgescu, C. (2015). Utilizarea uleiurilor vegetale pentru obținerea lubrifianților ecologici, raport postdoctorat, Universitatea “Dunărea de Jos”. Galați.
[15] Georgescu, C., (2012). Stratul superficial în procesele de frecare și țură ale unor materiale compozite cu matrice de polibutilentereftalat, teză de doctorat, Universitatea “Dunărea de Jos”. Galați.
[16] Georgescu, C., Cristea, G. C., Dima, C., Deleanu, L. (2017). Evaluating lubricating capacity of vegetal oils using AbbottFirestone curve, 13th International Conference on Tribology, ROTRIB'16 IOP Publishing IOP Conf. Series: Materials Science and Engineering 174 012057, http://iopscience.iop.org/article/10.1088/1757-899X/174/1/012057/pdf
[17] Leach, R. (2011). Optical measurement of surface topography, Berlin, Heidelberg, Springer.
[18] Malburg, M. C. (2002). Cylinder Bore Surface Texture Analysis, Digital Metrology Solutions Inc., http://www.digitalmetrology.com/Papers/CylinderBoreNoBkgd.pdf
[19] Martin, J. M., Ohmae, N., (2008), Nanolubricants. Tribology Series, Wiley.
[20] McCormick, H., Duho, K. (2004). A brief history of the development of 2-d surface finish characterization and more recent developments in 3-d surface finish characterization, Contract
DAAE07-C-L130 issued by the U.S. Army TACOM, Warren, MI., http://www.c-kengineering.com/images/pdf/product/surface%20finish/see%203di/3-D%20Surface%20Measurement.pdf

[21] Olaru, D. (2002). Fundamente de lubrificaţie, Iaşi, Editura Gh. Asachi.

[22] Pirvu C., Maftei L., Georgescu C., Deleanu L. (2017). Maps of 3D Parameters for Worn Surfaces of Composites PA + Glass Beads Sliding on Steel, *Industrial Lubrication and Tribology*, 69(1), pp. 42-51.

[23] Stachowiak, G.W., Batchelor, A.W. (2005). *Engineering tribology*, Butterworth-Heinemann, Team Lrn.

[24] Stout, K. J., Sullivan, P. J., Dong, W. P., Mainsah, E., Luo, N., Mathia, T., Zahouani, H. (1994). The development of methods for the characterisation of roughness in three dimensions, Publication no. EUR 15178 EN of the Commission of the European Communities: Brussels-Luxembourg.

[25] ***SPIP The Scanning Probe Image Processor SPIP™, Version 6.7.2 (2017), disponibil on-line: http://www.imagemet.com/WebHelp/spip.htm.

[26] *** SR EN ISO 4287 (2003). Specificaţii geometrice pentru produse (GPS). Starea suprafeţei: Metoda profilului. Termeni, definiţii şi parametri de stare ai profilului

[27] *** SR EN ISO 4288 (2002). Specificaţii geometrice pentru produse (GPS). Starea suprafeţei. Metoda profilului. Reguli şi proceduri pentru evaluarea stării suprafeţei

[28] *** SR EN ISO 25178-2 (2012). Specificaţii geometrice pentru produse (GPS). Starea suprafeţei: Areal. Partea 2: Termeni, definiţii şi parametri de stare a suprafeţei

[29] *** NanoFocus AG μScan® – Instruction Manual.

[30] *** EN ISO 20623 (2003). Petroleum and related products. Determination of the extreme-pressure and anti-wear properties of fluids. Four ball method (European conditions)

[31] *** ASME B46.1: 2009 Surface Texture (Surface Roughness, Waviness, and Lay)

[32] *** ASME B46 Committee – Surface Texture – Panel Discussion