LATVIAN JOURNAL OF PHYSICS
AND TECHNICAL SCIENCES
2018, N 4

DOI: 10.2478/lpts-2018-0030

APPLIED PHYSICS

CALCULATION POSSIBILITIES OF 3D PARAMETERS FOR SURFACES WITH IRREGULAR ROUGHNESS

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In the scientific research, calculations of roughness parameters are carried out, with the aim of comparing measured values of roughness parameters with the calculated ones by normal random field equations. First of all, roughness measurement experiments for surfaces with irregular roughness are carried out to determine the roughness parameters and the ordinate distribution histograms using modern measuring equipment Taylor Hobson Talysurf Intra 50. Using the obtained experimental data, Pearson criterion calculations are made in order to check the compliance of surface ordinate distribution function to normal Gaussian distribution law. The obtained results showed that for all investigated samples the surface ordinate distribution function complies with normal Gaussian distribution law. The next step is the calculation of several 3D roughness parameters (from the standard ISO 25178-2). According to the obtained results it is concluded that the calculated values of surface roughness parameters Sa, Sp, Spc, Sdq, Sdr are quite close to the values obtained by measuring equipment Taylor Hobson. The acquired formulas may be applicable for determination of 3D roughness parameters.

Keywords: distribution function, 3D roughness parameters, Pearson criterion, surface texture

1. INTRODUCTION

Nowadays, special attention is devoted to solution of engineering tasks – determination of wear, surface contact area, the coefficient of friction and surface contact deformations. Surface roughness parameters, which define surface quality and exploitation characteristics of components, play a considerable role in these types of tasks.

Today calculations of 3D surface roughness parameters have been little studied, and scientists rely on results obtained by measuring equipment. Everyone knows how the 3D surface roughness determination is implemented by profilometers, in turn, the equations used for texture parameter calculations by software are not specifically known. There are general formulas intended for integral calculating within the definition area. In turn, there are the theoretical formulas for calculation of 3D surface roughness parameters, which are suitable for surfaces, whose ordinates are distributed according to the normal Gaussian distribution law.

Particular attention is paid to surfaces treated with abrasive tools and electroerosion, which are widely applied in the field of engineering and mechatronics. It is important to note that all of these types of surfaces are characterised by irregular distribution of microirregularities over the surface. For all such types of surfaces, roughness is often modelled by the normal Gaussian random field of two parameters *X, Y*, for which the following conditions are typical [1]:

- Symmetrical arrangement of random variable in relation to its average value. It means that roughness parameter *Ssk* – skewness of ordinate distribution function – has to be equal to "0".
- Kurtosis of roughness ordinate distribution function, which is characterised by roughness parameter *Sku*, has to be equal to "3".
- The probability that surface ordinate values will be grouped in interval from -3σ to $+3\sigma$ has to be equal to 99.7% , where σ is a root mean square deviation of distribution function.
- Correlation function and its derivatives are continuous.

In further research, the following activities will be performed:

1. Check of roughness ordinate distribution function compliance to the normal Gaussian distribution law.
2. Calculation of 3D roughness parameters, comparing the measured and calculated values of roughness parameters.

2. SURFACE ORDINATE DISTRIBUTION

In the present research, five different types of surfaces: flat grinded, cylindrically grinded, treated with sand blasting, electro-erosion and shot peening have been investigated. The measurement experiments have been carried out on a sample series "Rugotest". Three surfaces have been measured for each sample. The obtained results of surface roughness measurements will be shown in the tables below.

Surface ordinate distribution compliance with the normal Gaussian distribution law as mentioned above is determined using the distribution function asymmetry indicator – *Ssk*, kurtosis *Sku* and Pearson criterion.

The parameter *Ssk* characterises the asymmetry of surface ordinate distribution function. Depending on the shape and location of roughness microirregularities in relation to the mean plane, this parameter can have either positive or negative values. The given parameter is described by the following equation [2]:

$$Ssk = \frac{1}{Sq^3}\left[\frac{1}{A}\iint_A z^3(x,y)dxdy\right], \tag{1}$$

where Sq – a root mean square height of the scale-limited surface, μm

A – a definition area, mm²

The parameter *Sku* characterises the curvature of surface ordinate distribution function. Depending on how densely the surface microirregularities are distributed over the surface, *Sku* values may be higher or lower than 3. The greater the distance between microirregularities is, the greater the values of parameter *Sku* will be. The given parameter is described by equation [2]:

$$Ssk = \frac{1}{Sq^4}\left[\frac{1}{A}\iint_A z^4(x,y)dxdy\right] \tag{2}$$

The present research analyses χ^2 distribution, which makes it possible to evaluate the compliance degree of theoretical and statistical distribution [3], [4]. There are special tables for χ^2 distribution, according to which the probability P can be determined for each χ^2 value at a certain number of degrees of freedom. Using the tabulated χ^2 values, it is possible to make the conclusions about probability, with which the hypothesis that a particular size *X* is divided by the normal Gaussian distribution law can be accepted.

Table 1

Conformity Assessment of Surface Ordinate Distribution to Normal Gaussian Distribution Law

Type of mechanical treatment	Ordinal No./ Surface No.	*Sa,* [μm]	Pearson criterion			Ssk	Sku
			Probability	$\chi^2_{critical}$	$\chi^2_{calculated}$		
1. Flat Grinding (Rugotest 104)	1 - No.2	0.042	0.95	8.67	0.675	-0.129	2.970
	2 - No.7	1.420			1.347	-0.277	3.000
	3 - No.8	3.120			4.819	-0.473	3.300
2. Cylindrical Grinding (Rugotest 105)	4 - No.2	0.044	0.95	8.67	0.427	-0.124	2.920
	5 - No.4	0.102			8.331	-0.746	4.660
	6 - No.7	1.140			1.239	-0.136	2.580
3. Electro-erosion (Rugotest 107)	7 - No.6	0.736	0.95	8.67	2.059	-0.328	2.930
	8 - No.7	1.200			0.644	-0.096	2.76
	9 - No.8	2.920			0.327	-0.073	2.900
4. Sand Blasting (Rugotest 3)	10 - No.6	0.500	0.95	8.67	2.003	-0.253	3.100
	11 - No.7	1.070			0.924	-0.213	3.18
	12 - No.8	2.3			4.560	-0.267	3.300
5. Shot Peening (Rugotest 3)	13 -No.6	0.487	0.95	8.67	0.275	-0.024	2.990
	14 -No.7	1.270			0.222	-0.021	2.910
	15 -No.8	3.460			1.280	-0.249	2.960

The calculated χ^2 values for surfaces with irregular roughness are shown in Table 1. For chosen probability p = 0.95, tabulated value of Pearson criterion χ^2 is 8.67. For all explored surfaces, the calculated values of Pearson criterion are lower than the tabulated ones.

The next step is to check the compliance of values of roughness parameters *Ssk* and *Sku* with standard values of Gauss distribution, where skewness of surface ordinate distribution function *Ssk*=0 and kurotsis *Sku*=3.

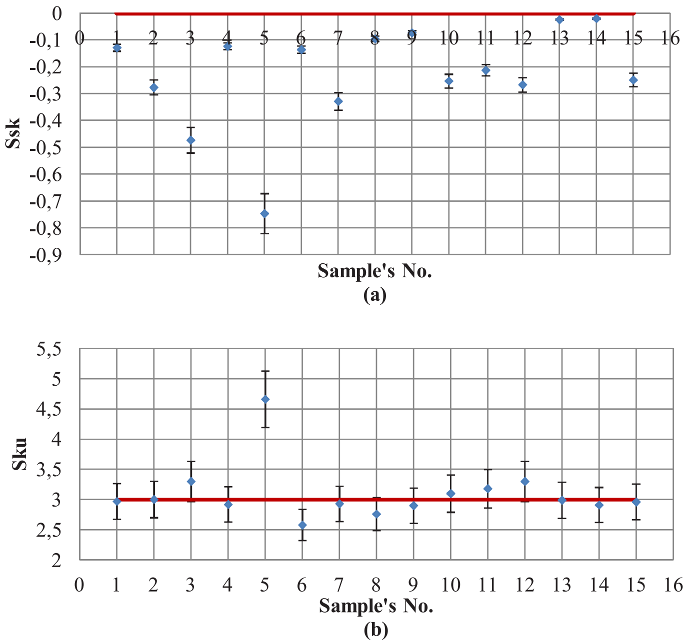

Fig. 1. Comparison of surface roughness parameters *Ssk* (a) and *Sku* (b) with standard values for the normal Gaussian distribution law.

The values of the given parameters are compared with standard values using graphical method, assuming that the values of measured parameters *Ssk* and *Sku* may vary within ±10 %. Figure 1 shows that the values of parameter *Sku* for several surfaces match with the standard values, while the value of parameter *Ssk* only for two surfaces matches with a standard value. *Ssk* and *Sku* values differ for cylindrically grinded surface No. 5, for which the calculated value of Pearson criterion is also greater than for all other surfaces.

Nevertheless, data from Table 1 shows that distribution function of surface ordinates correspond to the normal Gaussian distribution law with probability $p\geq$ 0.95 for all investigated samples.

3. CALCULATION OF 3D SURFACE ROUGHNESS PARAMETERS

Solving engineering tasks, for example, wear, surface contact area, coefficient of friction, surface contact deformations, it is important to understand the connection between the modelled surface and the experimental data. Irregular surface roughness is very often modelled by the normal random field of two parameters *X, Y*. The present paragraph describes the compliance of parameters of normal random field with experimental results.

The first group of roughness parameters is amplitude parameters. As mentioned above, the surface roughness is mainly characterised by height parameter *Sa*, which is directly related to the root mean square deviation *Sq*. Knowing *Sq* value, parameter *Sa* can be calculated using the following equation [1]:

$$E\{Sa\} \approx Sq \cdot \sqrt{\frac{2}{\pi}} \tag{3}$$

where *Sa* – an arithmetical mean height of the scale limited surface, [μm];
Sq – a root mean square height of the scale-limited surface, [μm].

Table 2

Comparison of Calculated and Measured Values for Parameter *Sa*

Type of mechanical treatment	Ordinal No./ Surface No.	$Sa_{calculated}$, [μm]	$Sa_{measured}$, [μm]	ΔSa, %
1. Flat Grinding (Rugotest 104)	1 - No.2	0.042	0.042	0
	2 - No.7	1.420	1.42	0
	3 - No.8	3.176	3.12	1.79
2. Cylindrical Grinding (Rugotest 105)	4 - No.2	0.043	0.043	0
	5 - No.4	0.107	0.102	4.90
	6 - No.7	1.117	1.14	-2.01
3. Electroerosion (Rugotest 107)	7 - No.6	0.728	0.736	-1.08
	8 - No.7	1.180	1.200	-1.66
	9 - No.8	2.905	2.920	-0.51
4. Sand Blasting (Rugotest 3)	10 - No.6	0.501	0.500	0.20
	11 - No.7	1.085	1.070	1.40
	12 - No.8	2.330	2.300	1.30
5. Shot Peening (Rugotest 3)	13 - No.6	0.488	0.487	0.20
	14 - No.7	1.268	1.270	-0.15
	15 - No.8	3.455	3.460	-0.14

Table 2 shows that all calculated values of parameter *Sa* are very close to the measured ones and lie within the range ± 10 %. It can be concluded that deviations of surface ordinate distribution practically do not change the relationship between basic parameters *Sa* and *Sq*.

The next roughness parameter is *Sp* – the maximum peak height subtracted from the mean plane [5]. The parameter *Sp* may find application in sliding contact issues. The given parameter can be calculated by the following formula [1]:

$$E\{Sp\} \approx 2 \cdot Sq \cdot \sqrt{\ln\left[E\{N_{01}\} \cdot \sqrt{Str}\right]}\ , \tag{4}$$

where $E\{N_{01}\}$ – the number of intersections with a mean line;
Str – a texture aspect ratio.

Consequently, to calculate this parameter it is necessary to know anisotropy coefficient and number of zeros. In [6], it is substantiated that anisotropy coefficient can be replaced by 3D roughness parameter *Str* – a texture aspect ratio. The number of zeros can be determined by profile diagrams. In this case, the number of zeros is calculated as the arithmetic mean of three profile diagrams.

Table 3

Comparison of the Calculated and Measured Values for Parameter *Sp*

Type of mechanical treatment	Ordinal No./ Surface No.	$Sp_{calculated}$, [μm]	$Sp_{measured}$, [μm]	ΔSp, %
1. Flat Grinding (Rugotest 104)	1 - No.2	0.147	0.154	-4.55
	2 - No.7	5.51	6.09	-9.52
	3 - No.8	11.97	12.9	-7.21
2. Cylindrical Grinding (Rugotest 105)	4 - No.2	0.165	0.178	-7.30
	5 - No.4	0.387	0.447	-13.42
	6 - No.7	4.23	4.18	1.20
3. Electroerosion (Rugotest 107)	7 - No.6	3.59	2.81	27.76
	8 - No.7	5.97	4.85	23.09
	9 - No.8	15.16	13.8	9.86
4. Sand Blasting (Rugotest 3)	10 - No.6	2.38	2.47	-3.64
	11 - No.7	4.89	4.99	-2.00
	12 - No.8	10.95	9.61	13.94
5. Shot Peening (Rugotest 3)	13 - No.6	2.29	2.44	-6.15
	14 - No.7	5.81	5.86	-0.85
	15 - No.8	15.17	13.8	9.93

From Table 3, it can be concluded that the values of parameter Sp obtained by Taylor Hobson are close to the calculated ones, only for four samples Sp values fall outside the acceptable ± 10 %.

The next group of 3D roughness parameters is feature parameters. This group includes arithmetic mean peak curvature Spc [5]. This parameter can be applicable to contacting surfaces working in friction and wear conditions. Spc can help determine microirregularity ability of deforming plastically or elastically under the load. The appropriate surface intersection level γ needs to be selected for Spc calculations. The researchers have determined that theoretical and measured values of peak number start to coincide at levels above $\gamma = 2$ [1], which is why in the given calculations values of Spc are checked at three levels: $\gamma = 2$; 2,5; 3. Calculation formula for parameter Spc is the following [1]:

$$E\{Spc\} \approx \frac{1}{2} \cdot \pi^2 \cdot Sq \cdot \left(\frac{2}{RSm_1}\right)^2 \cdot (1 + Str^2)\gamma, \tag{5}$$

where RSm_1 – the mean spacing of profile irregularities in direction perpendicular to processing traces, [mm]; *RSm1* is determined as an arithmetic mean of three profile diagrams.

γ – a relative surface height section, which is calculated by the formula (6):

$$\gamma = \frac{u}{\sigma}, \tag{6}$$

where u – the height subtracted from the mean plane; u=1σ, 2σ, 3σ eth.

σ – the root mean square height, [μm].

Table 4

Comparison of the Calculated and Measured Values for Parameter *Spc*

Type of mechanical treatment	Ordinal No./ Surface No.	$Spc_{calculated}$, for γ=2, [1/μm]	$Spc_{calculated}$, for γ=2,5, [1/μm]	$Spc_{calculated}$, for γ=3, [1/μm]	$Spc_{measured}$, [1/μm]	ΔSpc, %
1. Flat Grinding (Rugotest 104)	1 - No.2	0.00034	0.00042	0.00051	0.00024	41.67 (γ=2)
	2 - No.7	0.00343	0.00429	0.00515	0.00593	-8.09 (γ=3)
	3 - No.8	0.00342	0.00428	0.00514	0.00441	-2.95 (γ=2,5)
2.Cylindrical Grinding (Rugotest 105)	4 - No.2	0.00127	0.00159	0.00191	0.00310	-38.39 (γ=3)
	5 - No.4	0.00056	0.00070	0.00084	0.00061	-8.20 (γ=2)
	6 - No.7	0.00623	0.00779	0.00935	0.00472	31.99 (γ=2)
3.Electro-erosion (Rugotest 107)	7 - No.6	0.02067	0.02580	0.03100	0.02090	-1.10 (γ=2)
	8 - No.7	0.01725	0.02150	0.02580	0.01070	61.21 (γ=2)
	9 - No.8	0.00780	0.00980	0.01180	0.00830	-6.02 (γ=2)
4.Sand Blasting (Rugotest 3)	10 - No.6	0.00740	0.00930	0.01110	0.00620	19.35 (γ=2)
	11 - No.7	0.01030	001290	0.01550	0.01110	-7.21(γ=2)
	12 - No.8	0.01350	0.01690	0.02030	0.00920	46.74 (γ=2)
5. Shot Peening (Rugotest 3)	13 - No.6	0.00590	0.00740	0.00880	0.00600	-1.67 (γ=2)
	14 - No.7	0.00888	0.01111	0.01333	0.0108	2.87 (γ=2,5)
	15 - No.8	0.00627	0.00784	0.00940	0.00612	2.45 (γ=2)

Table 4 represents the values of parameter *Spc* at different levels γ. In the present research, the smallest value from three γ levels is determined for ΔSpc. From Table 4, it can be concluded that the measured *Spc* values mainly correspond to the calculated ones at level γ = 2.

The third group of roughness parameters is hybrid parameters, one of which is a parameter *Sdq* – a root mean square gradient. The given parameter can be applicable for evaluation of sealing, in theory of light and electromagnetic beam reflectance, as well as for determination of a surface wetting degree by various fluids.

The given parameter is calculated by the following formula [1]:

$$E\{Sdq\} \approx \frac{\pi}{2} \cdot Sq \cdot \frac{2}{RSm_1} \cdot \sqrt{\pi \cdot (1+Str^2)} \cdot \quad (7)$$

Table 5

Comparison of the Calculated and Measured Values for Parameter *Sdq*

Type of mechanical treatment	Ordinal No./ Surface No.	$Sdq_{calculated}$, *[μm/μm]*	$Sdq_{measured}$, *[μm/μm]*	ΔSdq, %
1. Flat Grinding (Rugotest 104)	1 - No.2	0.0037	0.0035	5.71
	2 - No.7	0.0693	0.0964	-28.11
	3 - No.8	0.1034	0.132	-21.67
2.Cylindrical Grinding (Rugotest 105)	4 - No.2	0.0110	0.0107	2.80
	5 - No.4	0.0077	0.0085	-9.41
	6 - No.7	0.0827	0.0822	0.61
3.Electroerosion (Rugotest 107)	7 - No.6	0.1290	0.1420	-9.15
	8 - No.7	0.1420	0.1200	18.33
	9 - No.8	0.1501	0.1530	-1.90
4.Sand Blasting (Rugotest 3)	10 - No.6	0.0641	0.0681	-5.87
	11 - No.7	0.1120	0.1280	-12.50
	12 - No.8	0.1763	0.1700	3.71
5. Shot Peening (Rugotest 3)	13 - No.6	0.0538	0.0595	-9.58
	14 - No.7	0.1100	0.1270	-13.39
	15 - No.8	0.1460	0.1430	2.10

Data from Table 5 indicate that *Sdq* parameter values are very close to the calculated ones, and only for five samples this parameter values do not lie within ± 10 %.

The last parameter, which has been analysed in the present research, is the developed interfacial area ratio *Sdr* [5] that defines the relationship between the real and nominal surface area. Values of this parameter are important particularly in case of surface adhesion. The greater the developed surface area is, the greater the number of links is between the substrate and coating. *Sdr* parameter can be calculated using the following equation [1]:

$$E\{Sdr\} \approx \frac{\pi^2}{2} \cdot Sq^2 \cdot \left(\frac{2}{RSm_1}\right)^2 \cdot (1+Str^2) * 100\% \cdot \quad (8)$$

Table 6

Comparison of the Calculated and Measured Values for Parameter *Sdr*

Type of mechanical treatment	Ordinal No./ Surface No.	$Sdr_{calculated}$, %	$Sdr_{measured}$, %	ΔSdr, %
1. Flat Grinding (Rugotest 104)	1 - No.2	0.0009	0.0006	50.00
	2 - No.7	0.3059	0.4610	-33.64
	3 - No.8	0.6822	0.8570	-20.40
2. Cylindrical Grinding (Rugotest 105)	4 - No.2	0.0034	0.0057	-40.35
	5 - No.4	0.0038	0.0036	5.56
	6 - No.7	0.4364	0.3360	29.88
3. Electroerosion (Rugotest 107)	7 - No.6	0.9436	1.0100	-6.57
	8 - No.7	1.2855	0.7200	78.54
	9 - No.8	1.4350	1.1600	23.71
4. Sand Blasting (Rugotest 3)	10 - No.6	0.2338	0.2320	0.78
	11 - No.7	0.7427	0.8210	-9.54
	12 - No.8	1.9814	1.4300	38.56
5. Shot Peening (Rugotest 3)	13 - No.6	0.1810	0.1770	2.26
	14 - No.7	0.7266	0.8030	-9.51
	15 - No.8	1.3579	1.0100	34.45

According to the data from Table 6, it can be seen that only for six surfaces the measured values of *Sdr* fall within the range ± 10 %, which may be explained by the insufficient number of measurements.

4. CONCLUSIONS

In the present scientific research, the possibility of applicability of calculation formulas for 3D roughness parameters has been checked and compliance of roughness ordinate distribution function with the normal Gaussian distribution law has been determined. It has been established that values of roughness parameters *Sa, Sp, Sdq, Sdr, Spc* obtained by the measuring equipment Taylor Hobson are quite close to the calculated ones. Incomplete coincidence of the measured and calculated values can be explained by surface ordinate distribution, for which *Ssk* and *Sku* values for some investigated surfaces do not fall within the deviation zone ± 10 %, without taking into account that the Pearson criterion value with probability > 95 % indicates that the ordinate distribution function conforms to the normal Gaussian distribution law. In addition, these results may be affected by the limited number of experiments. It has been concluded that equations analysed in the research can be applied for calculation of 3D roughness parameters and solution of global engineering tasks.

REFERENCES

1. Rudzitis, J. (2007). *Contact mechanics of surface, the second part*. Riga: RTU.
2. ISO. (2012). LVS EN ISO 25178-2 standard "Geometrical product specifications (GPS) - Surface texture: Areal - Part 2: Terms, definitions and surface texture parameters".
3. Pugachev, V.S. (1984). *Probability theory and mathematical statistics for engineers*. United Kingdom: Pergamon press.
4. Ventcel, E.S. (1969). *Probability Theory.* Moscow: Nauka.
5. Stout, K.J., Sullivan, P.J., Dong, W.P., Mainsah, E., Mathia, N.T., & Zahouani, H. (2000). *Development of methods for characterization of roughness in three dimensions*. London: Penton Press.
6. Bulaha, N., & Rudzitis, J. (2017). Analysis of model and anisotropy of surface with irregular roughness. In 16th International Scientific Conference "Engineering for Rural Development", 24–26 May 2017 (pp. 1123–1130). Jelgava, Latvia: Latvia University of Agriculture Faculty of Engineering.

3D PARAMETRU APRĒĶINU IESPĒJAS VIRSMĀM AR NEREGULĀRU RAUPJUMU

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K o p s a v i l k u m s

Dotajā zinātniskajā darbā tika veikti raupjuma parametru aprēķini, ar mērķi salīdzināt ar mēraparātu iegūtas raupjuma parametru vērtības ar aprēķinātām. Pirmajām kārtam, tika veikti virsmas raupjuma mērīšanas eksperimenti virsmām ar neregulāru raupjumu: slīpētām, apstrādātām ar elektroeroziju, smilšstrūklu un apšaudītām ar skrotīm, lai noteiktu raupjuma parametrus un virsmas ordinātu histogrammas, izmantojot moderno mērīšanas tehniku Taylor Hobson Talysurf Intra 50. Izmantojot iegūtos eksperimentālos datus, tika veikti Pirsona kritērija eksperimenti, lai pārbaudītu virsmas ordinātu sadalījuma sakritību ar normālo Gausa sadalījuma likumu. Pēc aprēķiniem tika noteikts, ka normālais Gausa sadalījuma likums ir raksturīgs visām pētāmām virsmām; tas, galvenokārt, tika pamatots ar Pirsona kritēriju, kura aprēķinātas un tabulētas vērtības sakrīt pie varbūtības 95%. Nākamais solis bija dažādu 3D raupjuma parametru (pēc standarta ISO 25178-2) aprēķini, izmantojot normālā gadījuma lauka formulas, ar mērķi noteikt sakarības starp eksperimentāliem datiem un modelētas virsmas parametriem. Parametru Sa, Sp, Spc, Sdq un Sdr vērtības bija salīdzinātas ar nomērītām. Pēc iegūtiem rezultātiem tika secināts, ka virsmas raupjuma aprēķinātas vērtības ir ļoti tuvas eksperimentālām, iegūtām ar Taylor Hobson mērīšanas tehniku. Taču dažiem paraugiem starpība sastādīja vairāk par ±10%, kas varētu būt izskaidrojams ar limitēto eksperimentu skaitu vai iespējamiem virsmas defektiem. Neskatoties uz to, iegūtas formulas var pielietot 3D raupjuma parametru noteikšanai.

27.03.2018.