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Surface Texture Parameters Application for Nanocoatings

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***Abstract* – surface roughness is a quality indicator of the surface. Due to the introduction of the new standard ISO 25178-2:2012 nanocoating surface has begun to be explored in volume rather than through the profiles, as it was done previously. In this work surface 3D topography parameters of different coatings on the basis of TiAl were analysed in order to determine the highest quality coatings.**

***Keywords* – Nanocoatings, surface texture, roughness, topography, wear**

I . INTRODUCTION

Surface roughness is one of the main surface quality geometric parameters that strongly affect the operating indicator of parts, because mainly machine element surfaces are exposed to external influence. During the exploitation, parts' surfaces receive different types of loads, interaction of which leads to microcracks and fracture site, surfaces come into frictional contact, which causes the surface wear and they lose their primary characteristics. There is no perfectly smooth surface, even the particularly accurate machined surfaces have minimal roughness, which determines the quality of the parts and respectively their application. Roughness determines the surface texture, which characterizes the orientation of roughness; it means the location of peaks and valleys on the surface.

II. DEVELOPMENT OF ROUGHNESS PARAMETERS' STANDARDIZATION

Any surface topography is characterized by roughness parameters which determine the height of microirregularities, depth of the valleys, the distances between adjacent irregularities, etc.

Originally, surfaces were investigated along the profiles; it means irregularities were measured in a plane defining the profile point coordinates (Xi, Yi). In one of the first surface roughness parameters' standards – GOST 2789-73 [1] only six roughness parameters were mentioned: Ra, Rz, Rmax, Sm, S, Tp, which were not even divided into separate groups [10].

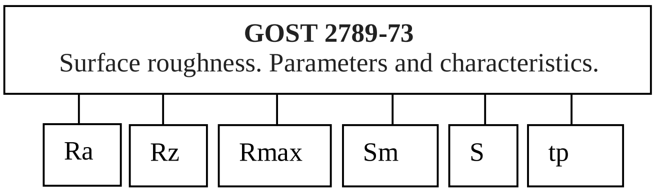

Fig.1. Profile's roughness parameters of Standard GOST 2789-73 [1]

In turn, standard ISO 4287:2000 [2] included 14 roughness parameters, divided into the following groups: height, height distribution, spacing, and hybrid parameters.

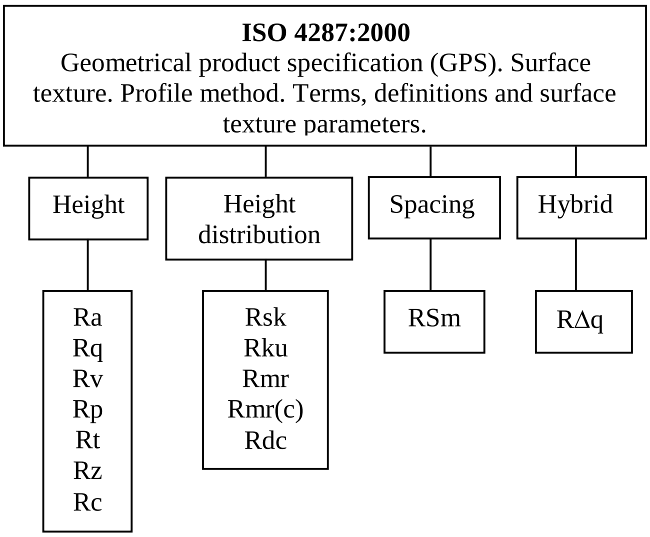

Fig.2. Profile's roughness parameters of Standard ISO 4287:2000 [2]

The Fig.3 shows a surface profilogram, where in directions X and Y valleys were noted, which form the roughness.

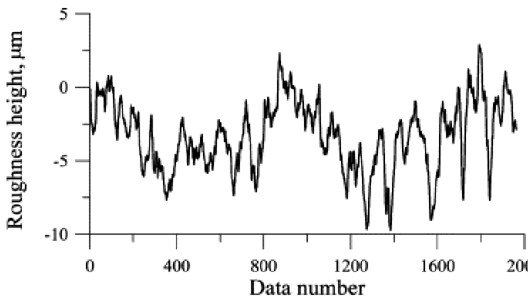

Fig.3. Surface profilogram [3]

The parameters mentioned above describe concrete profiles of surface, but they do not give a complete notion of the entire surface.

In parts two and tree of ISO 13565:2000 Standard [4] the surface with stratified functional properties (surface with extremely deep valleys under the fine processed plateau zone with a relatively small undulation) is characterized by the following parameters: Rpk, Rk, Rvk, Mr_1, Mr_2, Rpq, Rvq, Rmq.

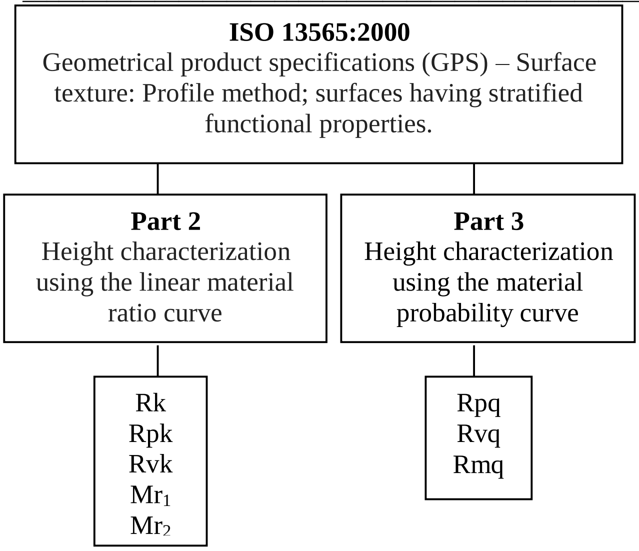

Fig.4. Profile's roughness parameters of Standard ISO 13565:2000 [4]

On August 30, 2012, ISO standard 25178-2:2012 [5] "Geometrical product specifications (GPS). Surface texture: Areal - Part 2: Terms, definitions and surface texture parameters" was introduced. This standard includes surface texture parameters, which are divided into several groups: height, spatial, functional (square, void volume, material volume, fractal and miscellaneous parameters), feature parameters, however, the group of spacing parameters doesn't exist in the new standard.

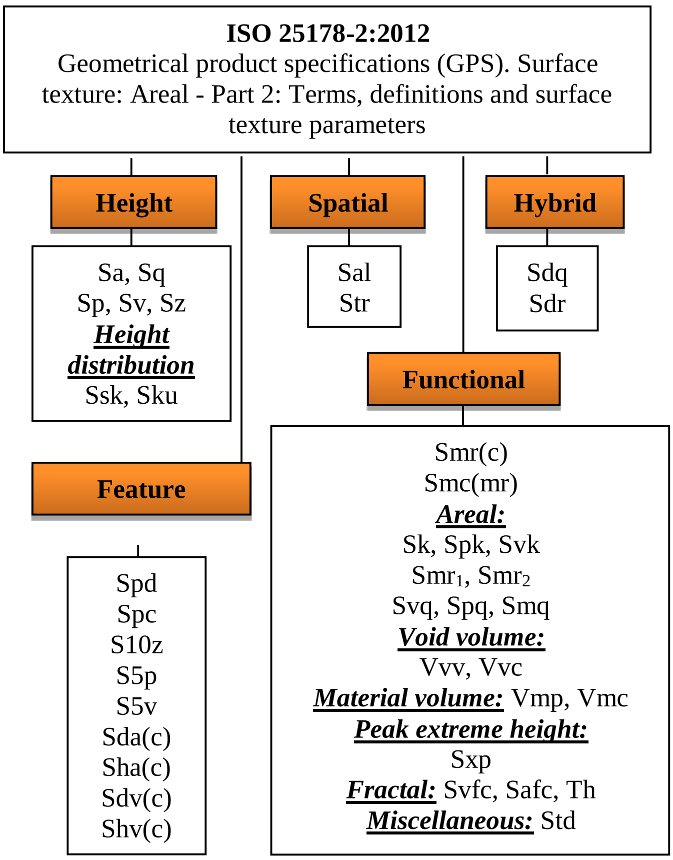

Fig.5. Texture roughness parameters of Standard ISO 25178-2:2012 [5]

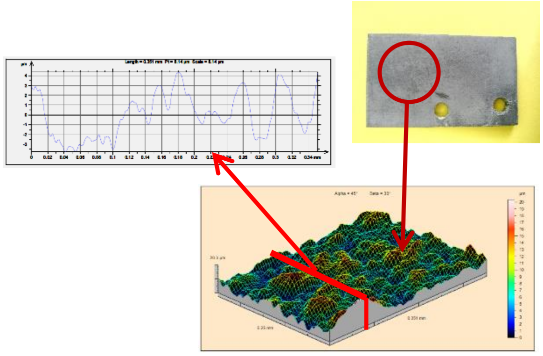

Fig.6. 2D and 3D roughness depiction of the sample surface

III. Comparison of 2D and 3D Parameters

In the standard ISO 25178-2:2012 several parameters (20 parameters) are analogous to the old standard's 2D parameters because essentially they determine the same surface characteristics:

TABLE I

ANALOGICAL 2D AND 3D PARAMETERS OF SURFACE

2D parameters	3D parameters
Ra	*Sa*
Rq	*Sq*
Rv	*Sv*
Rp	*Sp*
Rz	*Sz*
Rsk	*Ssk*
Rku	*Sku*
Rmr	*Smr*
Rmr(c)	*Smr(c)*
Rk	*Sk*
Rpk	*Spk*
Rvk	*Svk*
Rpq	*Spq*
Rvq	*Svq*
Rmq	*Smq*

Fig.7. shows that the parameters of two surface profiles, *Ra* [9]– arithmetical mean deviation of the profile and *Rq* – mean squared height, are equal in size, but these surfaces have completely different characteristics and functional properties.

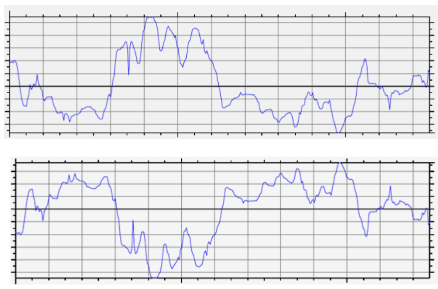

Fig.7. Profilograms of two different surfaces with the same Ra=1,07 μm and Rq=1,26 μm

Conversely, Fig.8 shows analogical texture parameters *Sa* and *Sq*, which characterize the texture of the surface. Here totally different surfaces also have the same *Sa* and *Sq* values, but the surface topography shows that the first surface is characterized by a large number of valleys, but the second – by a large number of peaks. *Sa* and *Sq* parameters can be used to indicate significant deviations in texture characteristics. *Sq* is commonly used to describe the optical surface and *Sa* – the mechanical surface.

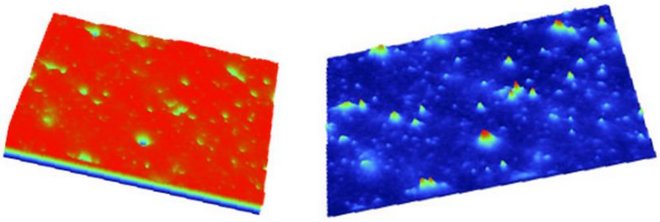

Fig.8. Two different topographies of the surfaces with the same Ra and Rq values [6]

IV. Measurements Of Nanocoatings 3D Parameters

The surface while being measured is divided into parallel profiles, which are at the same distance Δy from one another, whereas each profile is measured with step Δx. In this way the surface is characterized by a number of profile points Nx and profile number Ny. Each point of the surface has a relevant height Z, respectively the point is indicated by coordinates X, Y, Z. Steps Δx and Δy depend on radius value of the measuring needle.

Coatings' roughness depends on the roughness of the base material and to get an accurate coating it is necessary to machine the surface qualitatively, choosing an appropriate finish machining operations. Due to the fact that the coating particles collide with the base material and flatten, forming thin flakes, which are attached to a rough surface, it can be concluded that the coating roughness to a large extent repeats the machined surface roughness. Of course, in the spraying process covering modes such as deposition rate, time pressure, working gas supply also play a significant role, in turn, selecting the most efficient modes it isn't possible to get a perfectly smooth coating.

Within the framework of the scientific project special nanocoatings were produced and deposited on samples, shown in Table II:

TABLE II
List of measured nanocoatings

Nr.	Nanocoating materials
75	GTE* blade with nanocoating (TiAl)
76	GTE blade with nanocoating ((TiAl)+N)
77	GTE blade with nanocoating (TiAl)N
103	Metal with nanocoating ((TiAl)+O)
47	Glass sample with nanocoating ((TiAl)+N)
5	Modified nanocoating on Ti basis

* Gas turbine engine

The measuring process was carried out on the modern equipment "Form Taylorsurf Intra" (Taylor Hobson), and some samples for measuring are shown in Fig.9.

Fig.9. Coated samples for measuring

3D roughness parameters of the coatings were measured, as well as 2D profile roughness parameters in X and Y directions, surface and profile support curves and the vertex distribution histograms were formed, the coating surface after levelling, truncated form, undulation and 3D roughness were shown as well.

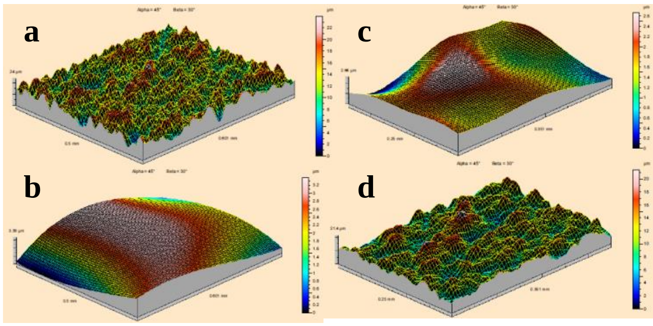

Fig.10. Nanocoating surface after levelling (a), truncated form (b), undulation (c), the surface roughness (d)

Looking at the surface texture and profile peaks histogram (Fig.11), it can be concluded that vertex distribution of a separate profile is chaotic and the maximum value of the peaks is 12.8 μm, while the texture vertex histogram shows a normal distribution of peaks with the maximum value – 21.4 μm, it again points to the fact that the profile measurements do not give the full picture about the surface state.

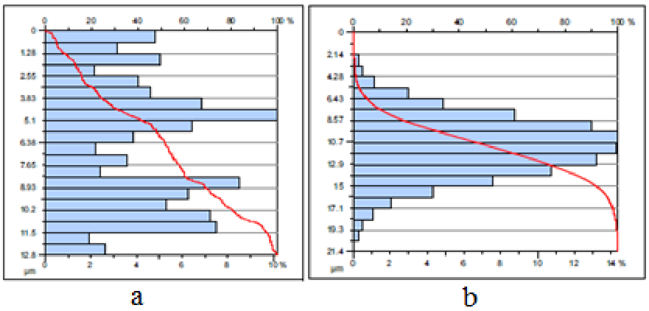

Fig.11. Histograms of nanocoating profile (a) and texture (b)

From the list of 3D texture parameters the most important parameters were chosen, which give the information about the surface properties and applications.

[6] The first parameter "*Sds*" – number of peaks, is the key parameter for the surfaces of bearings, electronic contacts and sealings. The manner in which surface peaks are elastically and plastically deformed under load is attributed to the parameter *Sds.* Depending on the application, a small *Sds* parameter values can cause bigger localized contact stress and as a result – pitting corrosion. If the surface sliding properties are the most important, the number of peaks is needful to prevent optical contact in retention period of loads distribution.

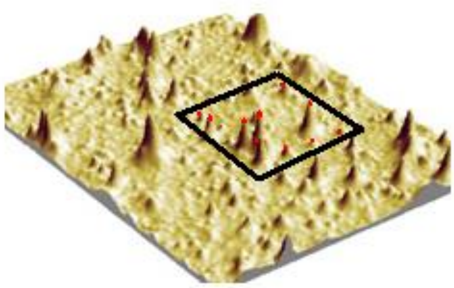

Fig.12. Depiction of the surface texture parameter Sds [6]

Sds parameter represents the number of peaks per unit area. Peak is defined as the highest point among the nearest 8 points. In addition, it is accepted that the peaks are points, located above the threshold, which is 5% of *Sz* above the midline.

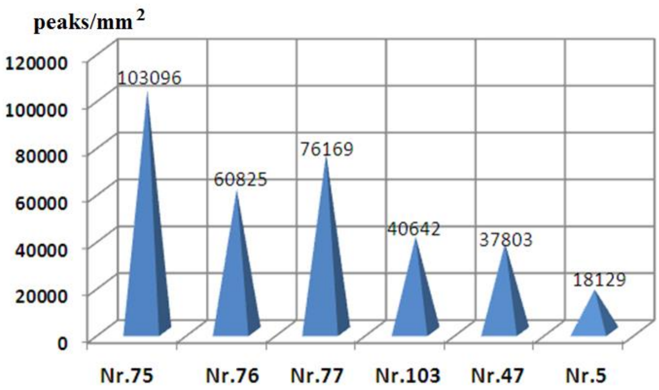

Fig.13. Graph of Sds values of the coated samples.

Fig.13 shows the number of peaks per unit area of comparable nanocoatings. Extreme peak number is typical for coating TiAl (sample Nr.75), while sample Nr.5 has a minimal number of peaks, which is almost 6 times smaller.

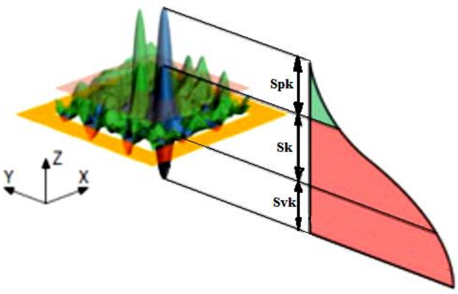

Fig.14. Depiction of surface texture parameters Sk, Spk, Svk [7]

The next important parameters are field parameters – *Sk, Spk, Svk* (Fig.14). [6] *Sk* is the base roughness (core roughness) depth, which is measured from the surface core roughness with the predominant peaks and valleys removal. It represents a surface core roughness, over which the load may be distributed by contacting the surface. Also *Sk* as a nominal roughness can be used to replace the parameter *Sz*, when the anomalous peaks or depressions may adversely affect the measurements.

Spk is the reduced peak height, which is measured from the peaks height above the core roughness. Great *Spk* value characterizes the surface, consisting of high peaks, providing a small initial contact area, and thus contact stress large areas when the surface is in contact. So *Spk* can represent nominal material height, which may be removed during the contact. According to *Spk* values, Smr_1 represents the percentage of the surface which can be removed while contacting.

Svk is the reduced valley depth, which is measured under the core roughness. The given parameter is a mayor of the valley depth below the nominal roughness and may be used for identifying oil retention.

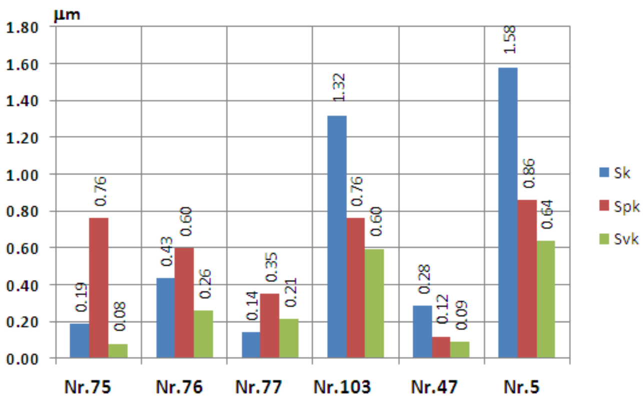

Fig.15. Graphs of Sk, Spk, Svk values of the coated samples.

Fig.15 shows that the modified coating on the Ti basis has the greatest core roughness (*Sk*) values. *Spk* parameter values of samples Nr. 75, 76, 103 and 5 remain at one level. Sample No.47 has the smallest *Spk* value.

Next parameter group is the height parameters *Sa*, *Sq*, which were mentioned above, as well as parameter *Sz* [6], which defines the maximum height of the surface, namely, the sum of the values of the highest peak and the deepest valley of the surface.

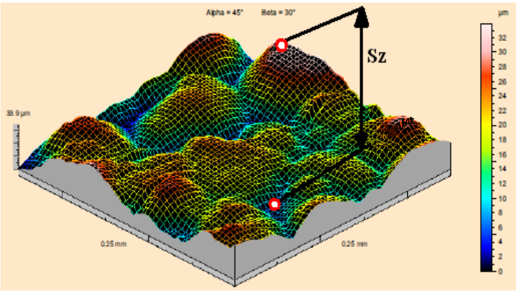

Fig.16. Depiction of the texture parameters Sz of the surface.

This parameter is dangerous to use for the surface analysis, because it is sensitive to isolated peaks and valleys, which may not be significant. However, *Sz* can be useful for surfaces, which have been filtered by low-pass filters (surfaces with expressed undulation) to describe undulation amplitude. In addition, the maximum height of the surface will help to find burrs on the surface, which point to the material's poor quality and inaccurate machining.

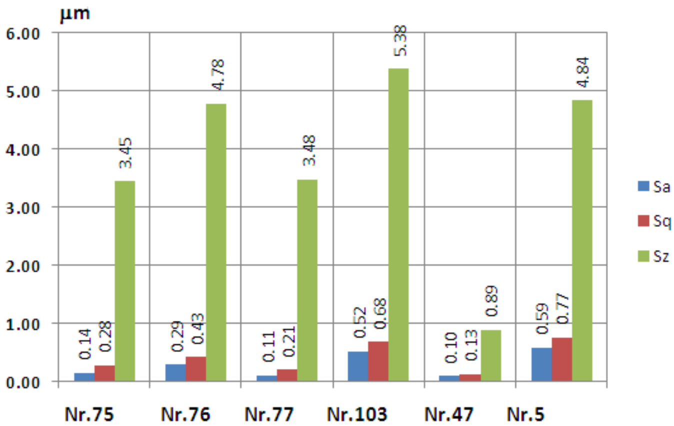

Fig.17. Graphs of Sa, Sq, Sz values of the coated samples

In Fig.17 significant differences in *Sa*, *Sq* and *Sz* parameters for different coatings can be noticed. The glass sample with the nanocoating ((TiAl)+N) (Nr.47) has the smallest surface roughness values, almost the same situation is with sample Nr.75 (TiAl). In turn, the coating, in which TiAl oxides (Nr.103) are dominant and sample Nr.5 have quite a large roughness in comparison with other sample surfaces.

Void volume parameters are also significant for coating analysis. [6] Parameter *Vvv* determines the void volume of the valleys, it is the amount of space, limited by the surface structure from the plane at height, corresponding to the level of *Mr* and the lowest valley "*p*". Default value of "*p*" is 80%, but this can be changed if necessary.

Parameter *Vvc* is the core void volume – amount of space, limited by the surface structure at heights, which correspond to *mr* values "*p*" and "*q*".

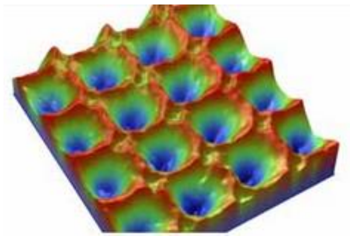

Fig.18. Depiction of the texture parameters Vvv and Vvc of the surface [6]

Both *Vvc* and *Vvv* parameters indicate the void volume mayor, which is expressed as a surface between different heights, fitted with material proportion values. In this way, the given parameters indicate how much fluid will fill the surface between the selected material ratio values.

Void volume parameters are useful in terms of fluid flows and coatings. The parameter *Vvc* can be used in determining how much core space is available after a single machining when the peaks heights are decreasing. The parameter *Vvv* can be used to determine the potential remaining void volume after the significant wear.

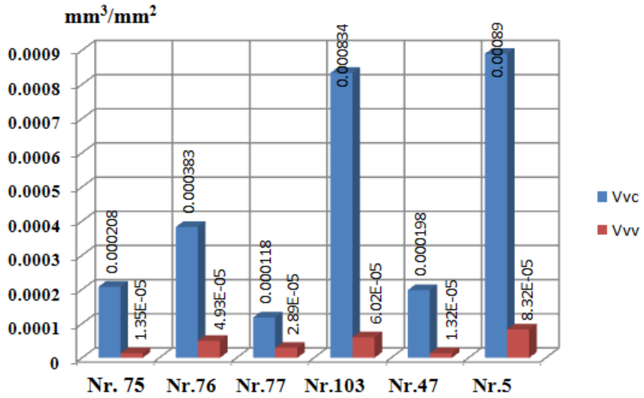

Fig.19. Graphs of Vvv and Vvc values of the coated samples

Fig.19 shows that the metal samples with the coating ((TiAl)+O) and modified coating on the Ti basis have the largest amounts of valley void volume, while the coating (TiAl)N has the lowest value of *Vvc*. The coatings TiAl and ((TiAl)+N) (Nr.76) also have small values of core void volume.

In turn, material volume parameters – *Vmp* and *Vmc*. should be also represented. [6] Parameter *Vmp* is the vertex material volume, which involves the surface from a height, which is appropriate to the material index level "*p*" to the highest peak. Level "*p*" is 10%, but may also be other (as needed).

Parameter *Vmc* – the core material volume describes a volume, which includes the surface between the peaks, corresponding to the material index values "*p*" and "*q*". By default, "*p*" value is 10% and the value of "*q*" is 80%.

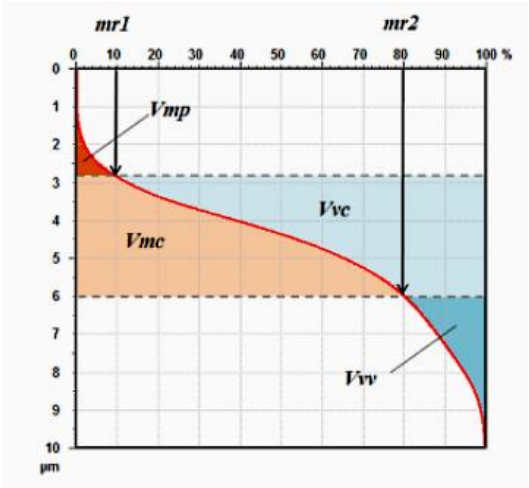

Fig.20. Depiction of the surface texture parameters Vvv and Vvc [8]

The given parameters determine the material mayor, which forms a surface at different heights below the highest peaks of the surface. The parameters *Vmc* and *Vmp* help to understand how much material may be worn at support curve at the given depth (*Vmp*), and how much material is available for load retention when the highest layers are worn (*Vmc*). In sealing operations *Vmp* parameter can give a notion of the material portion for sealing and parameter *Vvc* – the void volume for fluid blockage or leakage.

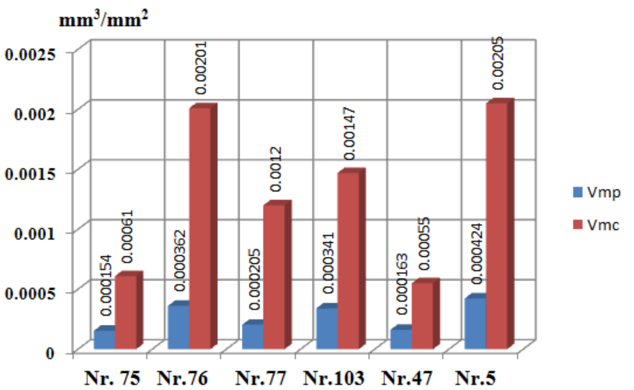

Fig.21. Graphs of Vmc and Vmp values of the coated samples

In Fig.21 sample roughness parameters *Vmp* and *Vmc* were compared. Samples Nr.76 ((TiAl)+N) and Nr.5 (modified nanocoating on Ti basis) have the largest values of these parameters, but the coatings TiAl and ((TiAl)+O) have the smallest values.

V. Conclusions

After the comparative analysis of texture roughness parameters of the investigated nanocoatings, it was determined that the most qualitative coating is nanocoating (TiAl) + N), deposited on a glass sample, because it has the lowest height of microirregularities and a small number of microprotrusions compared with other coatings and provides sealing capabilities and lubricant retention.

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Natālija Fiļipova. Jānis Rudzītis. Virsmas tekstūras parametru pielietojums nanopārklājumos.
Šajā rakstā tika izskatīti un analizēti nanopārklājumu tekstūras raupjuma parametri, lai noteiktu un identificētu kvalitatīvāku un funkcionālāku nanopārklājumu. Raupjuma parametru analīzes pamatā bija raupjuma parametru standartu izskatīšana gan atsevišķiem profiliem, gan visai virsmas tekstūrai. Tika atrasta analoģija starp 2D un 3D parametriem, kā arī identificēti pavisam jauni tekstūras raksturojumi, tādi kā tukšumu tilpums, materiāla tilpums pie konkrētā griezuma (nodiluma), un arī citi parametri, kas uzrādīti standarta ISO 25178-2:2012 tabulā. Darbā ir sniegts saraksts ar paraugiem, uz kuru virsmām tika uznesti nanopārklājumi, kuru pamatā ir tādi materiāli kā titāns un alumīnijs, un pēc tam, pētījumu procesā tika izmērīta to topogrāfija, izmantojot moderno mērīšanas tehniku. Analīzes rezultātā tika noteikts, ka kvalitatīvākais pārklājums ir nanopārklājums ((TiAl)+N), uznests uz stikla paraugu; Tam ir vismazākais mikronelīdzenumu augstums un pīķu skaits, kā arī tam ir blīvēšanas spējas un spēja noturēt smērvielas.

Наталия Филипова, Янис Рудзитис. Применение параметров текстуры поверхности для нанопокрытий.

В данной статье рассмотрены и проанализированы параметры шероховатости текстуры нанопокрытий, с целью определить и выявить наиболее качественное и функциональное нанопокрытие. В основу анализа параметров шероховатости легло рассмотрение стандартов параметров шероховатости как отдельных профилей, так и всей текстуры поверхности. Были найдены аналогии между 2D и 3D параметрами, а также выявлены совершенно новые характеристики текстуры, такие как объем пустот, объём материала при конкретном срезе (износе), а также другие параметры, указанные в таблице стандарта ИСО 25178-2:2012. В работе представлен список с образцами, на поверхности которых были нанесены нанопокрытия, в основу которых легли материалы титан и алюминий, а затем, в процессе исследований измерена их топография, с использованием современной измерительной техники. В результате анализа было установлено, что наиболее качественное покрытие – это нанопокрытие ((TiAl)+N), нанесенное на стеклянный образец, которое обладает наименьшей высотой микронеровностей и количеством вершин, а также обладает уплотнительными способностями и способностями к удержанию смазки.