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THE CHARACTERISTICS OF FUNCTIONAL PROPERTIES OF THE MACHINED SURFACE BASED ON THE NON-PARAMETRIC AND PARAMETRIC DESCRIPTIONS OF THE TOPOGRAPHY

CHARAKTERYSTYKA WŁAŚCIWOŚCI FUNKCJONALNYCH POWIERZCHNI OBROBIONEJ NA PODSTAWIE NIEPARAMETRYCZNEGO I PARAMETRYCZNEGO OPISU TOPOGRAFII

Key words: surface topography, non-parametric description, parametric description, functional properties.

Abstract The shaping of the functional properties of the surface of an object in a technological process plays a key role in the later operation of this object. The paper presents the results of the tests performed on the surface topography of objects made of a selected hard-to-machine material, i.e., titanium alloy. Two measuring devices were used in the research, an interference microscope, and a scanning electron microscope, which enabled the comprehensive (non-parametric and parametric) description of surface topography obtained for three different finishing parameters. It was noted that, in addition to material properties, in the evaluation of the functional properties of a surface, it is important to carry out not only the qualitative, but also quantitative analysis of the machined surface topography.

Słowa kluczowe: topografia powierzchni, opis nieparametryczny, opis parametryczny, właściwości funkcjonalne.

Streszczenie Kształtowanie właściwości funkcjonalnych powierzchni przedmiotu w procesie technologicznym odgrywa kluczową rolę w późniejszym procesie eksploatacji tego przedmiotu. W pracy przedstawiono wyniki badań topografii powierzchni przedmiotów wykonanych z wybranego materiału trudnoskrawalnego – stopu tytanu. W badaniach wykorzystano dwa urządzenia pomiarowe – mikroskop interferencyjny i skaningowy mikroskop elektronowy, co pozwoliło na kompleksowy (nieparametryczny i parametryczny) opis topografii powierzchni obrobionej otrzymanej dla trzech zabiegów ściernej obróbki wykończeniowej. Zauważono, że poza własnościami materiałowymi, w ocenie właściwości funkcjonalnych powierzchni istotna jest analiza topografii powierzchni obrobionej zarówno pod względem jakościowym, jak i ilościowym.

INTRODUCTION

The comprehensive tests of the surface layer require the use of various methods and measuring devices **[L. 1, 2]**. The obtained test results allow for the prediction and optimization of the functional properties of the manufactured surface which is the outcome of a technological process. The relationships between the technological process, the technological surface layer, and the functional properties (tribological properties) of the manufactured object are shown in **Fig. 1**.

The technological process is associated with the adoption of surface shaping technology resulting from design assumptions, related to the selection of appropriate machining tools and parameters **[L. 1, 3–5]**. The choice of surface shaping technology has an influence on the formation of the technological surface layer, including the giving of specific functional properties to the surface **[L. 6, 7]**. The functional properties of a surface are described on the basis of the adopted test methodology (measurement method and result analysis).

The characteristics of the technological surface layer have a significant impact on contact, including friction and accompanying friction processes (lubrication and wear) **[L. 1, 8–15]**. Therefore, surface functional properties should be analysed, based both on the parametric and non-parametric descriptions of surface

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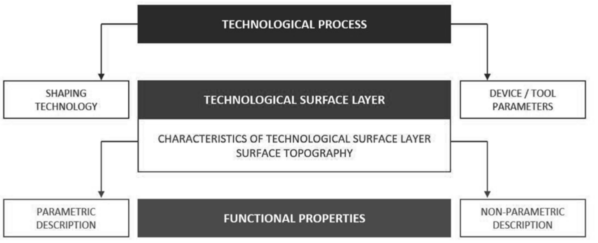


Fig. 1. The relationship between technological process, technological surface layer, and functional properties [L. 1]

Rys. 1. Powiązanie między procesem technologicznym, technologiczną warstwą wierzchnią oraz właściwościami funkcjonalnymi **[L. 1]**

finish **[L. 1]**. The non-parametric description consists in the analysis of the surface images of an examined object (photography, surface morphology, contour map, isometric image), captured with the use of various contact (contact profilometer) and contactless measuring methods (optical microscope, scanning electron microscope, interference microscope). If several different surfaces are compared and it is necessary to check whether the requirements imposed by the constructors have been satisfied, the non-parametric description should be supported by the parametric description. The parametric description requires the quantities to be assigned to the topography of the surface layer of an object **[L. 16]**, which is possible thanks to the developed features of surface texture including functions (e.g., the bearing curve, and the material ratio curve) and parameters (e.g., height, frequency, and hybrid ones).

The purpose of this article is to characterize the surface topography of an object made of a difficult-to-machine material, i.e. titanium alloy, based on the non-parametric and parametric descriptions of surface texture. This will enable the determination of the potential functional properties of manufactured surfaces intended for use in the polymer-titanium alloy friction pair.

RESEARCH SUBJECT AND METHODOLOGY

The subject of the research were cuboid elements measuring 36x16x6 mm, made of titanium alloy (TA designation) Ti-6.5Al-1,3Si-2Zr which, owning to its properties (including ρ = 4.43 g/cm^3, E = 114 GPa, σ_z = 900 MPa), belongs to the group of difficult-to--machine materials.

The technological process required the use of appropriate finishing operations, which included grinding and polishing **[L. 1, 5, 6]**. The latter one involved three treatments (processing parameters are given in the diagram), in which diamond micro grains ASM 3/1 and ASM 1/0 served as tools. As a result of the finishing treatment, three different surface topographies were produced, marked as TA1, TA2, and TA3, which were subsequently examined and analysed. The research methodology is shown schematically in **Fig. 2**.

The research on surface topography was conducted using two different measuring devices: white light

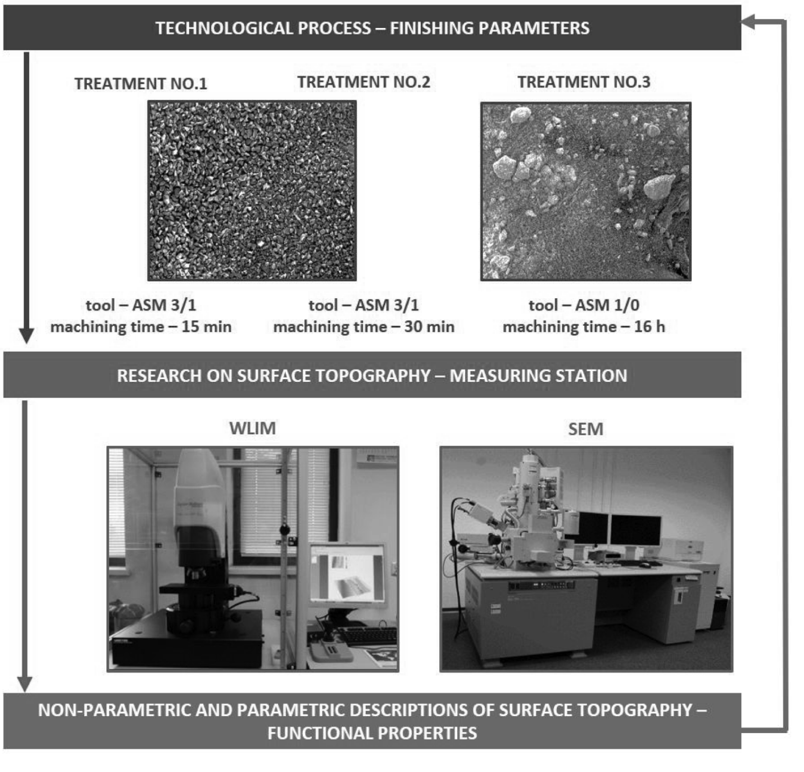


Fig. 2. Research methodology – technological process, measuring methods, surface topography description

Rys. 2. Metodyka badań – proces technologiczny, techniki pomiaru i opis topografii powierzchni interference microscope (WLIM) and scanning electron microscope (SEM). On the basis of the obtained results and non-parametric (photo-simulation, contour map, morphology) and parametric (bearing curve and parameters – *Sk, Spk, Svk,* Smr_1*,* Smr_2 *and Sq, Ssk, Sku, Sp, Sv, Spc, Vm, Vv*) descriptions, conclusions regarding the functional properties of machined surfaces were drawn.

RESEARCH RESULTS

The results of the research on the texture of the technological surface layer for the three processed objects (TA1, TA2, and TA3) obtained using WLIM are shown in **Figs. 3–5** displaying a surface photo (photo-simulation), a contour map, and a bearing curve, respectively. A qualitative analysis was carried out on the basis of the first two items (a and b), while the bearing curve (c), in addition to the visual image, was described by parameters from the Sk group (*Sk, Spk, Svk,* Smr_1*,* Smr_2).

Table 1 presents the selected (enlarged) fragments of the surfaces along with valleys characterizing each of the tested surfaces TA1, TA2, and TA3. **Table 2** presents a set of chosen parameters which enable the quantitative description of the topography of the machined surfaces. In addition to the investigation of surface texture, **Fig. 6** shows the results obtained using SEM (surface morphology), which are the real images of the examined surfaces.

The analysis of photo-simulation of machined surfaces indicates a clear differentiation of these surfaces. With each operation, the number of valleys characterizing the surfaces of the objects made of titanium alloy decreased. During machining, small valleys visible in TA1 **(Fig. 3a)**, as a result of the impact of diamond micro-grains**,** joined together in subsequent treatments, creating larger cavities (TA2 – **Fig. 4a**) or even leading to their gradual elimination (TA3 – **Fig. 5a**).

A similar tendency in shaping the examined surfaces can be observed in contour maps; however, in this case, one can additionally draw conclusions on the characteristic dimensions of the valleys. The scale analysis shows that, while smaller cavities with a depth of 0.5 µm (TA1 – **Fig. 3b**) clumped together, valleys with a higher surface area were created, but their depth decreased to respectively 0.4 µm for TA2 (**Fig. 4b**) and 0.3 µm for

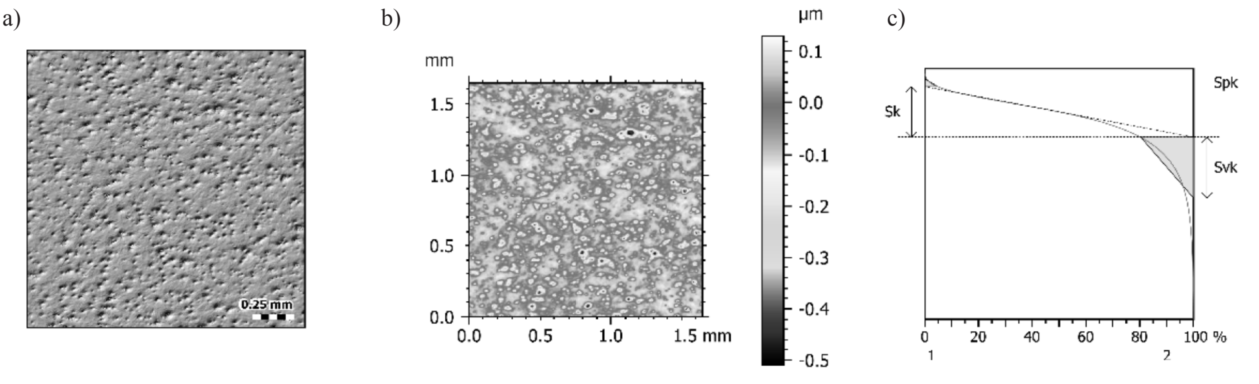


Fig. 3. Results of research on TA1 surface, obtained using WLIM: a) photo-simulation, b) contour map, c) bearing curve
Rys. 3. Wyniki badań powierzchni TA1 otrzymane z wykorzystaniem WLIM: a) fotosymulacja, b) mapa konturowa, c) krzywa nośności

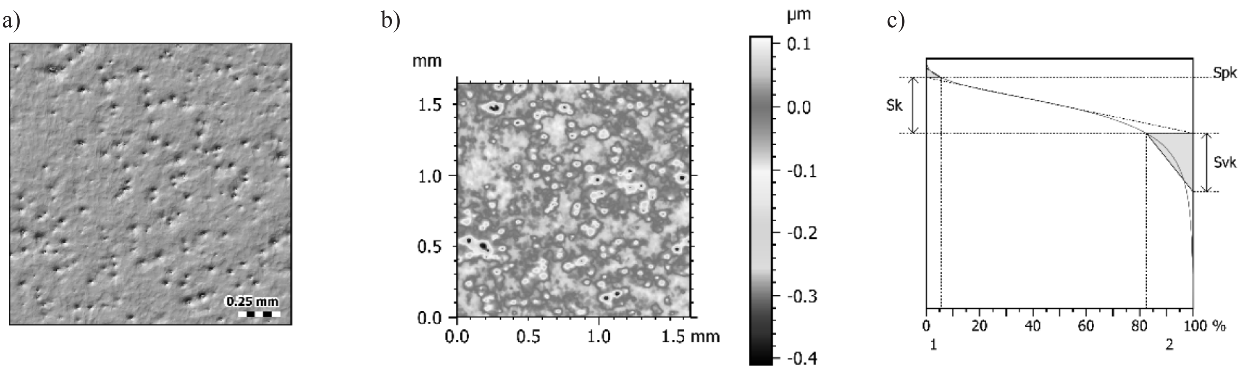


Fig. 4. Results of research on TA2, obtained using WLIM: a) photo-simulation, b) contour map, c) bearing curve
Rys. 4. Wyniki badań powierzchni TA2 otrzymane z wykorzystaniem WLIM: a) fotosymulacja, b) mapa konturowa, c) krzywa nośności

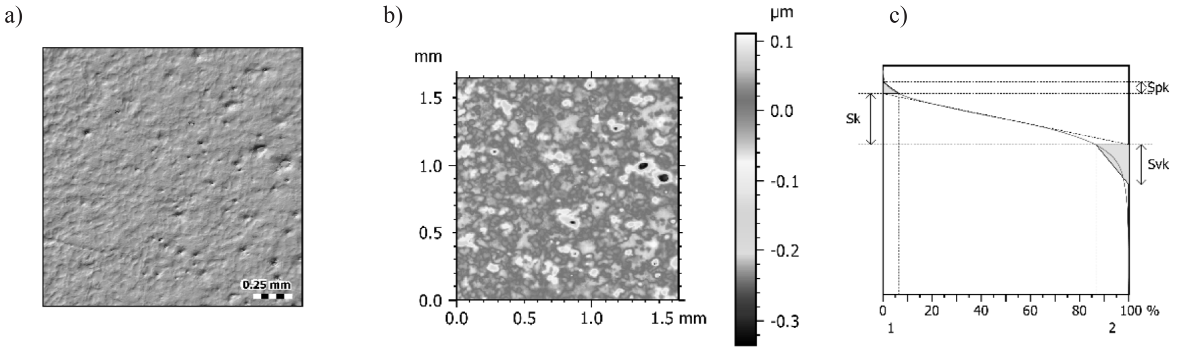


Fig. 5. Results of research on TA3, obtained using WLIM: a) photo-simulation, b) contour map, c) bearing curve
Rys. 5. Wyniki badań powierzchni TA3 otrzymane z wykorzystaniem WLIM: a) fotosymulacja, b) mapa konturowa, c) krzywa nośności

TA3 (**Fig. 5b**). The selected surface fragments containing characteristic cavities are presented in **Table 1.**

From the graphs displaying the bearing curve (TA1 – **Fig. 3c**, TA2 – **Fig. 4c**, TA3 – **Fig. 5c**) and from the analysis of parameters describing it (*Sk, Spk, Svk,* Smr_1, Smr_2) – **Table 2**, it can be inferred that the shape of hills and valleys underwent significant changes. It should be emphasized that the both mentioned features of surface topography play a key role in the operation process; therefore, they characterize the potential functional properties of the surface.

Table 1. Selected fragments of examined surfaces – characteristics of valleys
Tabela 1. Wybrane fragmenty badanych powierzchni – charakterystyka wgłębień

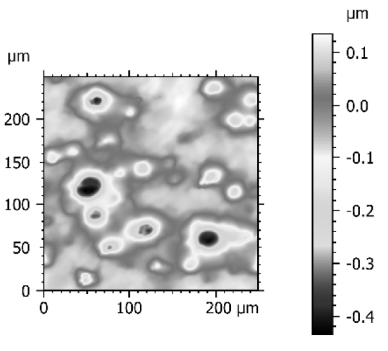
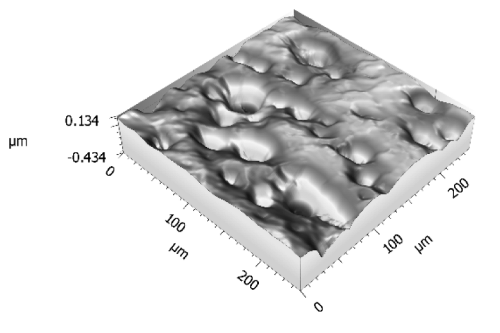
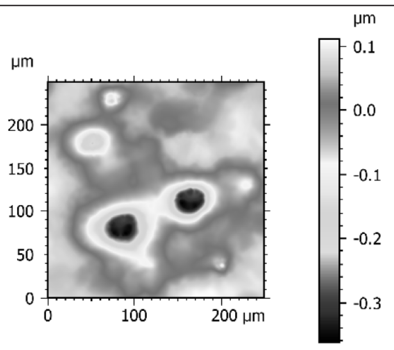
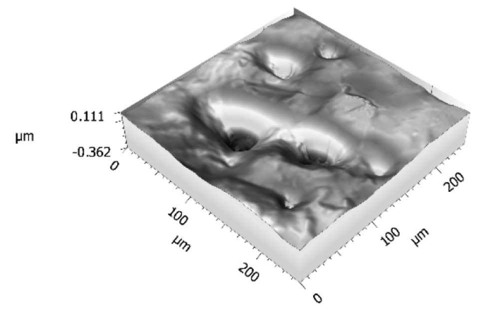
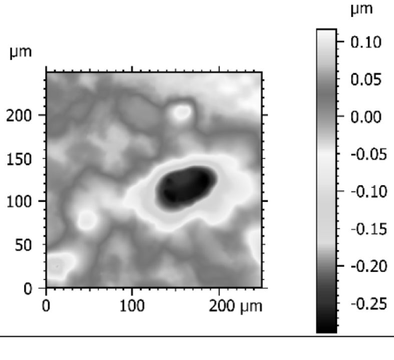
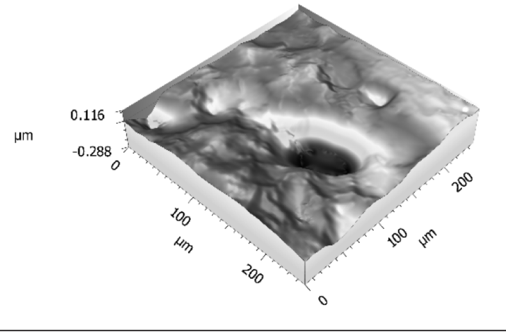
	Contour map	*Isometric image*
TA1		
TA2		
TA3		

Table 2. A set of surface topography parameters
Tabela 2. Zestawienie parametrów topografii powierzchni

Sq [μm]	*Ssk* [–]	*Sku* [–]	*Sz* [μm]	*Spc* [1/mm]	*Vm* [mm^3/mm^2]	*Vv* [mm^3/mm^2]	*Sk* [μm]	*Spk* [μm]	*Svk* [μm]	Smr_1 [%]	Smr_2 [%]
0.076	–1.83	7.83	0.638	2.76	1.29e–006	7.35e–005	0.129	0.017	0.155	4.81	19.6
0.063	–1.74	7.86	0.522	0.597	1.25e–006	6.37e–005	0.116	0.019	0.123	5.56	17.6
0.045	–1.50	8.51	0.446	0.488	1.29e–006	5.07e–005	0.099	0.025	0.078	6.57	13.5

The parametric description of the surface formed in the subsequent operations of finishing shows that the parameters were affected differently. It was noted that values of the parameters Ssk, Sku, Spk, and Smr_1 increased, while the values of *Sq, Sz, Spc, Vv, Sk, Svk,* and Smr_2 were reduced. In the case of *Vm*, its values for the tested surfaces TA1, TA2, and TA3 were comparable. It is understandable that the value of *Sq* went down due to the longer impact of the tool on the surface of the workpiece. A negative value of *Ssk* indicates the plateau-like structure of the surface and the occurrence of deep and small cavities on it. An increase in this parameter towards 0 not so much points to a small change in the plateau-like surface texture as to the transition of small valleys into larger ones, and shallower at the same time. The values of the *Sku* parameter indicate the occurrence of cavities and other anomalies on the surface. The higher the value of this parameter, the more uneven is the distribution of valleys, as confirmed by previous analyses. The change in the value of the *Sz* parameter indicates that the distance between the lowest and the highest points on the surface is decreasing, thus improving the surface quality. The *Spc* parameter makes it possible to analyse the shape of hills. The results presented in the table show that the *arithmetic mean* peak *curvature* significantly decreased, resulting in a modification of the rounding angle of these peaks, which translates into functional properties (in the operation process, hills with sharp peaks cause wear by micro-cutting, whereas hills with rounded peaks result in wear by micro-chipping). It was noticed that the value of the *Vm* parameter which describes the material volume between treatments did not practically change, but this is not the case of the *Vv* parameter which characterizes dale void volume. The values of *Vv* differ considerably, which has to do with a reduction in the number and size of valleys occurring on the surfaces of the workpiece made of titanium alloy. The valleys can play a dual role. On the one hand, they can be positive if they are the places where the lubricant accumulates; on the other hand, they can be negative if they are the places where the wear products are gathered. The parameters describing the bearing curve show the differences in the height of the protruding peaks (*Spk*) and the depth of the valleys (*Svk*). These differences (small in the case of peaks, larger in the case of valleys) can significantly affect the operation process. In addition, it should be noted that similar changes take place in the peak material ratio Smr_1 (increases in the next treatment) and the valley material ratio Smr_2 (decreases in subsequent operations).

The parametric and non-parametric descriptions of the test results produced by WLIM are supported by the results obtained from SEM – **Fig. 6**. The morphology of the treated surfaces TA1, TA2, and TA3 is a real reflection of the surfaces of the examined objects.

Looking at the SEM pictures, one can notice a similar description of the results presented in **Figs. 3–5** (photo-simulation and contour map). SEM images were taken on a much smaller surface of the tested objects. They mainly depict material features. On TA2 and

a) b) c)

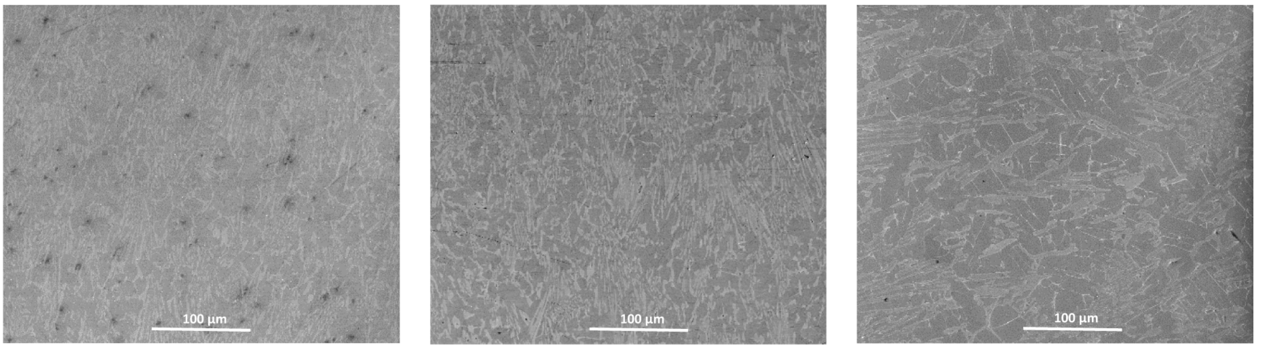


Fig. 6. Results of research on surfaces, obtained using SEM – surface morphology: a) TA1, b) TA2, c) TA3
Rys. 6. Wyniki badań powierzchni otrzymane z wykorzystaniem SEM – morfologia powierzchni: a) TA1, b) TA2, c) TA3

TA3 surfaces, practically no details such as valleys characterizing the examined surfaces can be visible. Despite this, supplementary research using SEM is beneficial, because it shows a real picture of the tested surfaces.

CONCLUSIONS

Non-parametric (qualitative) description was based on the results of surface morphology (SEM), contour maps (WLIM), and partially on the bearing curve (WLIM), while the parametric (quantitative) description was made on the basis of 12 selected surface topography parameters (*Sq, Ssk, Sku , Sz, Spc, Vm, Vv, Sk, Spk, Svk,* Smr_1*,* Smr_2).

The analysis of surface topography obtained from abrasive machining, based on a non-parametric description, shows the influence of technological process parameters (tool and time) on the texture of the manufactured surface, and thus on its functional properties.

An increase in the values of the parameters *Ssk, Sku, Spk,* and Smr_1 and a decrease in the values of the parameters *Sq, Sz, Spc, Vv, Sk, Svk,* and Smr_2 were noted. In the case of *Vm*, the values for the tested surfaces TA1, TA2, and TA3 were comparable.

Based on the description of surface topography, it was determined that the texture of the examined surfaces, regardless of the applied treatment, was plateau-like. Differences in the number and sizes of valleys, in the shape of the bearing curve, and the peak curvature were observed.

Defects (anomalies) in the form of valleys visible on the surfaces can play a positive or negative role. They can be the places where the lubricant accumulates (thus positively affecting friction and the wear mechanism), or places where wear products accumulate and pile up (thus causing destruction going deep into the surface layer).

When planning the technological process of an object with the view of shaping functional properties, the costs of its manufacture should be taken into account. It is worth thinking if it makes much sense to strive for the best quality of the machined surface, which is not necessarily going to work during the operation process.

Conducting research on surface topography, related to technological process, is therefore important and necessary not only because of the impact that the surface texture has on functional properties in the operation process, but also because of manufacturing costs.

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