SURFACE TEXTURE PARAMETERS INFLUENCE ON TRIBOLOGICAL PROPERTIES OF FUNCTIONAL COATINGS

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Abstract. The aim of the paper is to investigate the influence of the surface texture parameters on the tribological properties of functional coatings. The object of the investigation is the Ti-TiN erosion-resistant PVD coating sprayed on the surface of the compressor blade of the aircraft gas turbine (base material: Incoloy 800). Surface texture parameters were recently standardized, but the effectiveness and necessity for using such parameters in science and industry are still not fully proven. Thus, the relationship between concrete diapasons of values of selected texture parameters and tribological properties, as well as selection of most appropriate texture parameters for characterization of contact surfaces still is under discussion. Hence, the aim of presented paper is highly actual. The comparative study on the influence of the surface texture parameters on the friction coefficient was done. For evaluation of the coating surface quality as well with the goal to evaluate the adequacy of ordinary (2D) and new (3D) approaches the 2D description approach was applied. The achieved results prove the ascendancy of surface texture parameters. Recommendations for choosing such parameters for contact surfaces (including amplitude, spacing, functional and hybrid parameters) were elaborated and offered.

Keywords: coating, surface texture, friction.

Introduction

Increasing the wear resistance of the responsible parts and components is an urgent task in Mechanical and Transport Engineering. Thus, for improving the heat and erosion resistance of compressor blades of the aircraft gas turbine 2-layer Ti-TiN erosion-resistant PVD coatings were offered [1]. Fragment of the compressor of the aircraft gas turbine and the view of the coated and uncoated compressor blade of a helicopter gas turbine engine are given in Fig. 1.
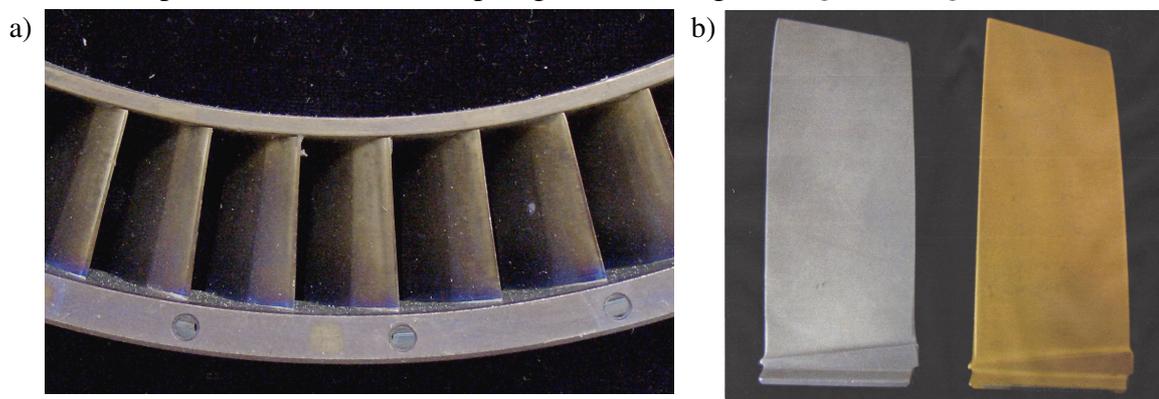

Fig. 1. **Compressor of the aircraft gas turbine:** a – fragment's view and the view of the coated (on the right side); b – uncoated (on the left side) compressor blade of a gas turbine engine [1]

On the other hand, nowadays in the field of evaluation of the surface quality the transition from the 2D roughness parameters to the 3D texture parameters, defined according to the EN ISO 25178-2:2012 "Surface texture: Areal - Part 2: Terms, definitions and surface texture parameters", occurs [2-5]. Many researches pointed that applying of 3D texture parameters is more preferable for surface characterization, especially for surfaces of the parts of tribological units, due to more adequate and precise description of the surfaces of 3D objects [3; 5-8] and as economically feasible approach for microtopographical research [5; 7]. For example, in [7] after experimental investigation of the 2D roughness parameter Ra and 3D texture parameter Sa the following conclusion was done: the 3D parameter is more stable than the 2D parameter with less relative error (up to 5 %). At that the relative error has a trend to decreasing when the measuring area is increasing. The relative error of the 2D roughness parameter is greater than 5 % and it is not depending on the measuring trace length. Besides, the number of the necessary measurements for defining the 3D parameters is significantly lower than for defining the 2D parameters, as shown in Fig. 2.
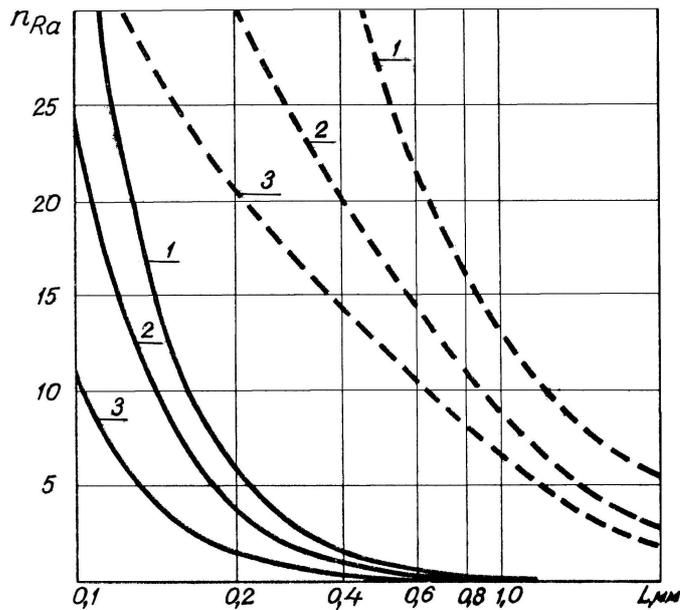
Fig. 2. **Number of measurements nRa depending on the measuring trace length L:** 1- Ra (Sa)
2.51 µм; 2 - Ra (Sa) 0.98 µм; 3 - Ra (Sa) 0.56 µм (- - - - for profile; _____ for surface) [7]

The aim of this paper is to investigate the influence of the surface texture parameters on the tribological properties of functional coatings. Despite of some published results of investigations in the field [1; 5-10] the effectiveness and necessity for using such parameters in science and industry are still not fully proven. Thus, the relationship between concrete diapasons of values of selected texture parameters and tribological properties, as well as selection of most appropriate texture parameters for characterization of contact surfaces still is under discussion. Hence, the aim of presented paper is highly actual.

Materials and methods

The base material of the compressor blade was Incoloy 800: Cr – 10.5…12.0 %; C – 0.10 …0.16 %; Cu ≤ 0.30; Mn ≤ 0.60 %; Mo - 0.35…0.50 %; Ni - 1.5…1.8 %; P ≤ 0.30 %; S ≤ 0.025 %; Si ≤ 0.60 %; V - 0.18…0.30 %; W - 1.60…2.0 %. Both the uncoated and coated samples (with 2-layer Ti-TiN erosion-resistant PVD coatings) were investigated.

For metrological study the 3D measurement system "Form Talysurf Intra 50" ("Taylor Hobson Ltd", UK) was used. This system supports 2D and 3D measurements with stylus instrument (by basic "stepping" method) and data processing by computer. For tribological study the TRN (CSM Instruments, Switzerland) tribometer was used. The ball-on-disc tests were performed without lubrication under the force of 1 N with a sliding distance of 1 m, linear velocity 0.05 m/s, material of the ball 100Cr6 (DIN EN ISO 683-17), diameter of the ball 6 mm. Testing conforms to the following standards DIN 50324 "Tribology; testing of friction and wear model test for sliding friction of solids (ball-on-disc system)", ASTM G99 "Standard test method for wear testing with a pin-on-disk apparatus" and ASTM G133 "Standard test method for linear reciprocating Ball-on-flat sliding wear". The views of the used equipment are shown in Fig. 3.

Since 2D roughness parameters still used for characterization of the surface quality (especially in industry) the following parameters (according to ISO 4287 "Surface texture: Profile method - Terms, definitions and surface texture parameters") were measured: Ra – arithmetic mean roughness, Rz – maximum height of profile, RSm – mean width of the roughness profile elements and Rdq – root mean square slope. Such selection of roughness parameters is generally accepted in the industry for a long time period [3; 7; 11]. Thus, the necessity of supplementation the amplitude parameters with spacing and hybrid parameters is based on the fact, that only amplitude parameters do not give any information about the shape of asperities (Fig. 4).
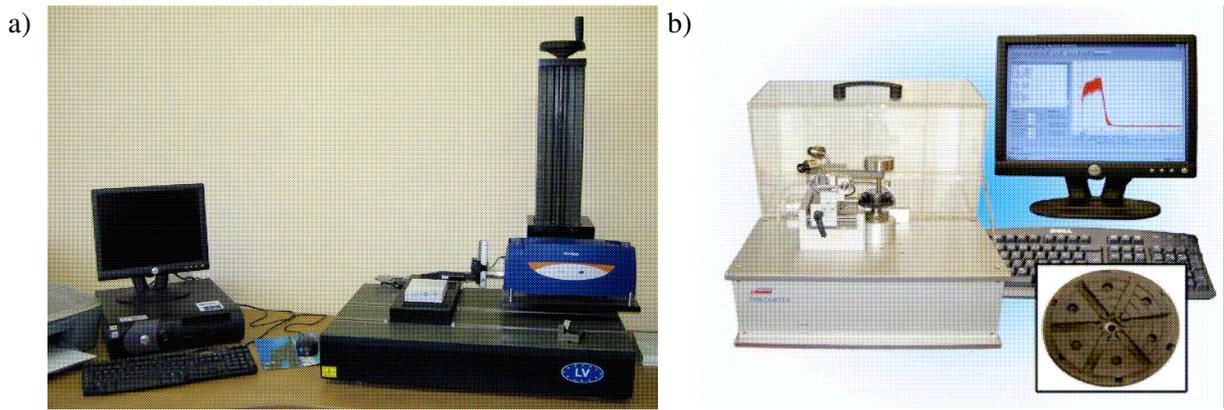
a)

b)

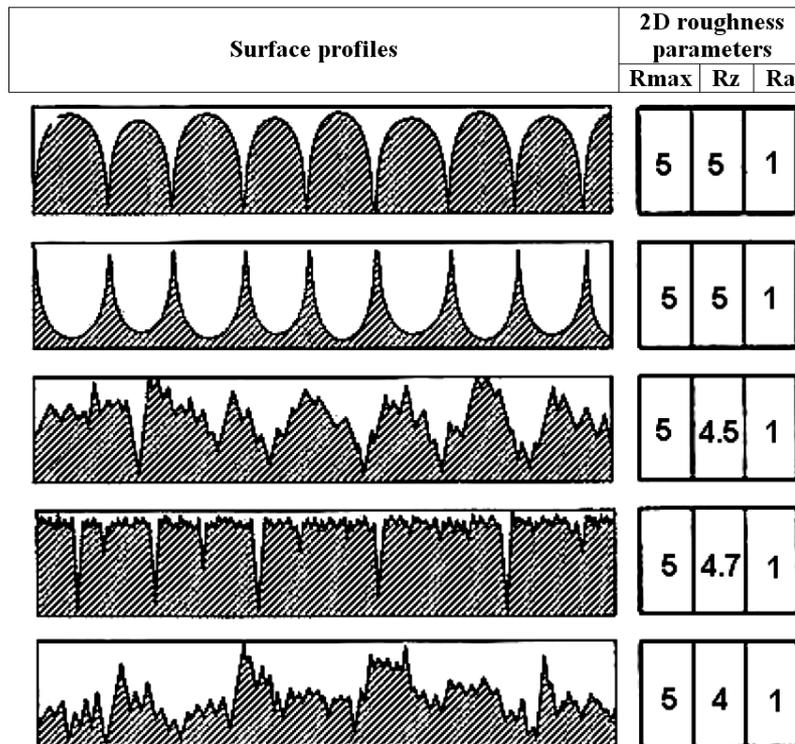Fig. 3. **3D roughness measurement system "Form Talysurf Intra 50" (a) and tribometer TRN (b)**

Fig. 4. **Examples of different surface profiles with the same values of the amplitude roughness parameters Ra and Rmax [11]**

The following 3D texture parameters according to the EN ISO 25178-2:2012 "Surface texture: Areal - Part 2: Terms, definitions and surface texture parameters" were measured and analyzed: 1) amplitude parameters: Sa, Ssk; 2) spatial parameter: Str, 3) functional (material volume) parameter: Vmc, and 4) hybrid parameter: Sfd. These texture parameters were chosen due to their significance for friction surfaces of the tribological parts because of their essence: Sa – arithmetic mean of the deviations from the mean plane, represents an overall measure of the texture comprising the surface; Ssk – skewness of the scale-limited surface, represents the degree of symmetry of the surface heights about the mean plane; Str – texture aspect ratio of the surface, measures the isotropy of the surface; Vmc – core material volume of the scale-limited surface, indicates a measure of the material forming the surface between various heights; Sfd – fractal dimension of the surface (complexity of the surface), smaller value specifies the more periodical surface (different from the random surface).

Results and discussion

Comparison of the 2D amplitude and spacing roughness parameters of the surface of compressor blades of a gas turbine engine with coating and without it is given in Table 1. The profiles of the uncoated and coated samples are given in Fig. 5.

Table 1

Comparison of 2D amplitude and spacing roughness parameters

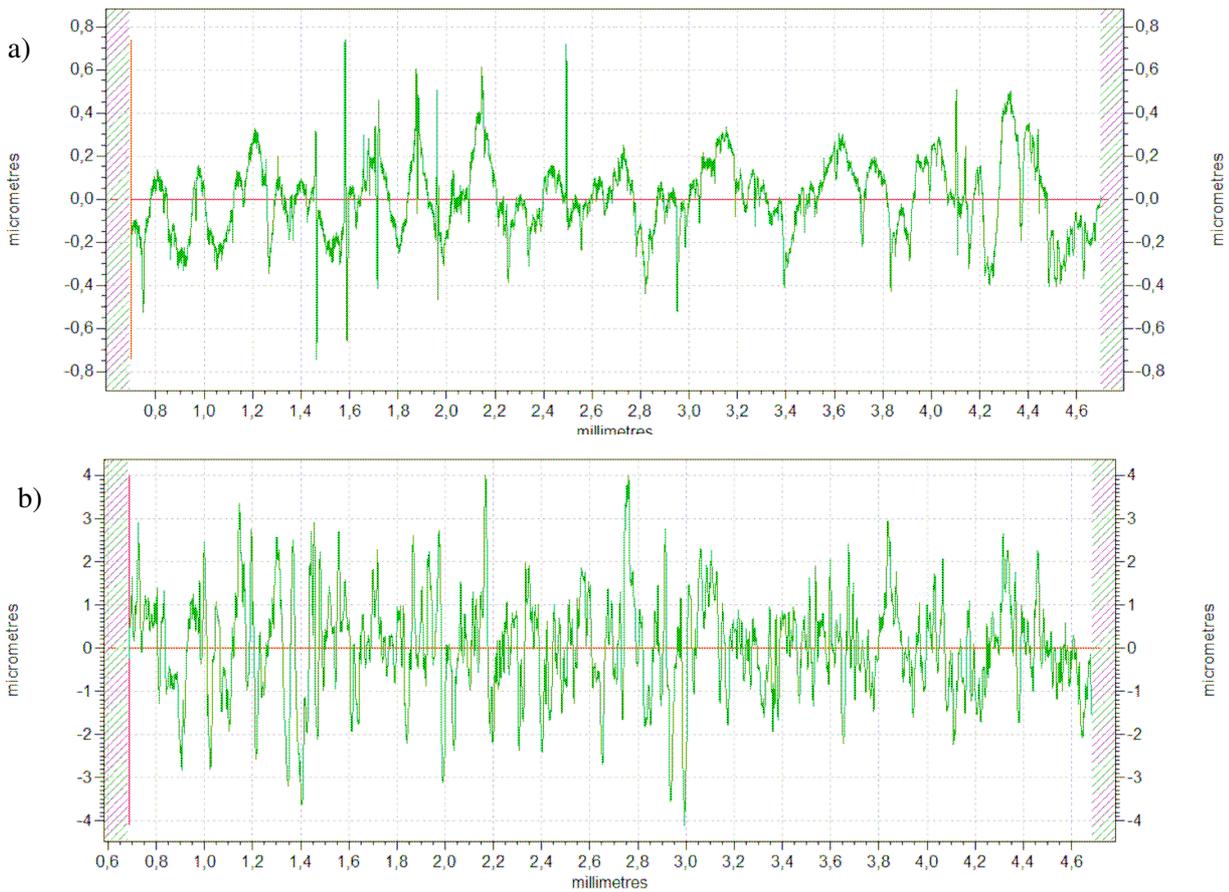| Samples:	Amplitude parameters		Spacing parameter	Hybrid parameter
	Ra, µm	Rz, µm	RSm, mm	Rdq, °
Uncoated	0.128	1.185	0.449	2.09
Coated	0.806	6.327	0.099	11.98

Fig. 5. **Profile of the turbine blade:** a – uncoated; b – coated

As shown in Table 1, the 2D roughness parameter values significantly change after the PVD process. The spacing parameter RSm has the lowest value after the coating process, but the amplitude parameters Ra and Rz – the highest values. That can be explained by the fact that the plasma coating deposition process tends to create isotropic and peaky surface texture due to Ti and TiN droplet condensation on relatively smooth substrate. The hybrid parameter Rdq for the coated surface is higher than for uncoated. This parameter is useful in assessing such properties of the engineering surfaces as crushability of the surface during contact and friction: it is considered, that the higher value of the Rdq means the higher friction shown by the surface. So, the analysis of the 2D roughness parameters exhibited that the tribological properties of the achieved coating are under the question.

As mentioned in Introduction, recently many scientists assume that surface texture metrology gives a better understanding of the surface in its functional state since in practical applications surface roughness of the machine parts behaves as a 3D object. That is why it was decided to evaluate the adequacy of the ordinary (2D) and new (3D) approaches. The achieved 3D surface images and photo simulation of the surfaces of samples without coating and with coating are given in Figure 6. The comparison of the measured 3D texture parameters of the surfaces of uncoated and coated samples is given in Table 2.
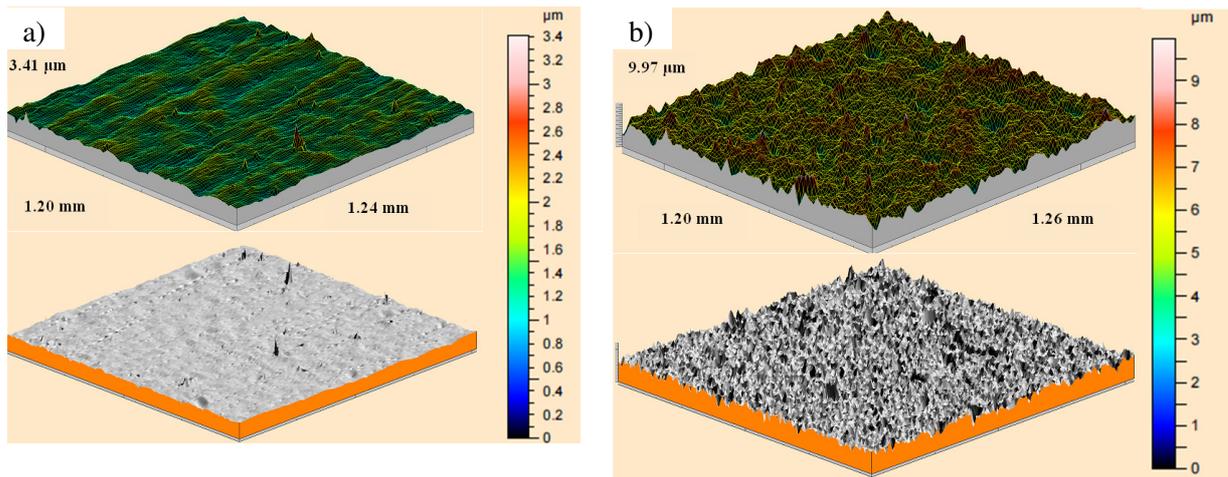
Fig. 6. **Turbine blade 3D surface image and photo simulation:** a – uncoated; b – coated

Table 2

Comparison of 3D texture parameters

Samples:	Amplitude parameters		Spatial parameter	Functional parameter	Hybrid parameter
	Sa, µm	Ssk	Str	Vmc, mm^3·mm^{-2}	Sfd
Uncoated	0.116	0.140	0.125	0.00102	2.33
Coated	0.659	-0.679	0.701	0.00400	2.42

As shown in Table 2, similar to 2D amplitude roughness parameters the 3D texture amplitude parameter Sa for the coated sample is higher in comparison with the uncoated sample. At the same time another amplitude parameter Ssk has negative value for the sample with coating and positive value for the uncoated sample. The positive skewness indicates the appropriateness of surfaces to plating etc., but the negative skeweness of the coated surface confirms good lubricant retention ability and bearing ability, which is significant in tribological application. As distinct from the 2D amplitude roughness parameters the 3D texture amplitude parameters show that the coated surface would probably be more adequate choice for a bearing surface, which has only few high asperities in combination with the strong core. After the mentioned asperities will wear away the core they will still have good bearing ability that is important in tribological application as well. Additionally, the spatial parameter Str for the coated sample is closer to 1 (maximal value of Str) than Str for the uncoated sample. It can be assumed, that the coated surface is much more isotropic than before coating. The higher value of the functional parameter Vmc (core material volume) for the coated sample proves better bearing ability of the surface due to greater core material volume in contact during normal exploitation time (after wear-in). The high values of the hybrid parameter Sfd (close to 3 – maximum value of Sfd) confirm more random character for the surfaces of both (coated and uncoated) samples.

Thus, as distinct from the 2D roughness parameters the 3D texture parameters confirm that coated surface is applicable for tribological application. The complex testing on the influence of the 2-layer Ti-TiN erosion-resistant PVD coatings on the adhesion strength, heat resistance, erosion resistance and coefficient of friction, offered in [1], confirms the appropriateness of coated parts for tribological application, in particular as an erosion-resistant coating for compressor blades of the aircraft gas turbine. For instance, the average value of the coefficient of friction for Ti-TiN coated sample is $f = 0.24$, but for uncoated Incoloy 800 sample is $f = 0.27$. The visual examination of the surfaces of the samples shows that during testing the standard friction process occurs, because no any traces of wear or plastic deformation of the surface were found.

Hence, at least for the surfaces described above, the surface texture metrology gives more adequate description of the surface and prognosis about the surface ability, for example, for tribological application, when the obvious 2D approach cannot guarantee adequate characterization. From standardized texture parameters we recommend to measure and analyse the following set of

parameters for contact surfaces: 1) amplitude parameters: Sa, Ssk; 2) spatial parameter: Str, 3) functional (material volume) parameter: Vmc, and 4) hybrid parameter: Sfd.

Conclusions

The investigation of the surface quality of the compressor blades of the aircraft gas turbine coated by the 2-layer Ti-TiN erosion-resistant PVD coatings in comparison with the uncoated samples was done. The surface quality was evaluated using the ordinary (2D) and new (3D) approaches. The achieved results prove the ascendancy of the surface texture parameters. Thus, the analysis of the 2D roughness parameters shows that the tribological ability of the coated samples is questionable. On the contrary, the analysis of the texture parameters allows predicting good lubricant retention ability and bearing ability. Such conclusions were done after analysing of the appointed set of texture parameters: 1) amplitude parameters: Sa, Ssk; 2) spatial parameter: Str, 3) functional (material volume) parameter: Vmc, and 4) hybrid parameter: Sfd. Predicted acceptable wear resistance and durability were proved, for instance, by evaluation of the coefficient of friction for the coated and uncoated samples, which is for Ti-TiN coated sample is $f = 0.24$, but for uncoated Incoloy 800 sample is $f = 0.27$. Hence, it could be assumed that the 3D metrology is more suitable for exploring functional surfaces than the 2D metrology.

Acknowledgements

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