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IMPROVING THE QUALITY OF TECHNOLOGICAL SURFACES OF MACHINES OF COMPOSITE COATINGS

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Abstract

Nickel matrix coatings were sprayed by the Casto-Dyn 8000 torch on a steel substrate, and then subjected to straight turning. Determining of the optimum geometry of indexing is now synonymous with the selection of the optimum shape and dimensions of the insert and of an appropriate holder. According to cutting board, it was selected square, triangular, trigon inserts, made of carbide and of cubic boron nitride (borazon). Machining of nickel-based coatings was carried out for the cutting speed $v_c = 214$ m/min in the case of treatment with borazon inserts, $v_c = 107$ m/min in case of plates treated with tungsten carbide cutting, using the feed $f = 0.06$ mm/rev and the depth of cut $a_p = 0.3$ mm. Metal cutting the surface of steel samples coated with a composite coating containing 15% Al_2O_3 based on nickel, conducted for the cutting speed $v_c = 157$ m/min when machining with borazon inserts and for $v_c = 83$ m/min inserts with tungsten carbide for feed $f = 0.06$ mm/rev and depth of cut $a_p = 0.3$ mm. Highly precise finishing of flame spraying composite and alloy coatings was carried out using turning by tool with borazon inserts. Flank (VB) and attack (KB) of turning tool wear while maintaining a constant length of spiral cutting (L_{SC}) were determined. The effect of the shape and grade of inserts upon the geometric structure of the composite coatings and is considered in the paper. The article can determine the shape and grade of inserts is necessary to obtain sufficient quality of the shaft of centrifugal pumps with a composite coating.

***Keywords**: composite coatings, flame spraying, surface finishing, technological quality*

1. Introduction

Metal matrix composite are used in fields of technology, such as aerospace, electronics, energy, industry, defence, automotive, aviation, shipbuilding, and more. Composite materials are characterized by high resistance to tribological wear. Composite coatings obtained by flame spraying have a large surface roughness. Therefore, these coatings must be subjected to finishing most commonly used after-machining (e.g., machine cutting, grinding). Flame sprayed coatings are applied taking into account the allowance for finishing. Machining should ensure not only the thickness of coatings related to the nominal dimension of the object, but also to obtain the required surface roughness and waviness. Choosing parameters (feed rate, depth, cutting speed) machining coatings, it must be remembered that the tool does not always cut sprayed particles, but may cause them breaking the surface. This occurs primarily in coatings of high porosity. On ships, there are outboard water systems (e.g., a central cooling system), often used in centrifugal pumps. In the case of pump shafts, the most common disability its wear of the shaft neck (corrosion and friction) at the location of installation seals (stuffing box). Currently, the primary method of regeneration is the shaft bushing. As an alternative to the method used to repair worn shafts neck of centrifugal pumps the flame spraying was proposed. The flame sprayed technology is inexpensive and easy to implement. Therefore, it can be successfully used for regeneration of machine parts by the crew of ship engine room. Flame sprayed coatings are characterized by porosities, oxide inclusions and the presence of a strongly developed surface float. In order to obtain a suitable surface texture coatings finishing must be used. For this purpose, turning and grinding can be applied. The paper proposes finish turning for the flame sprayed coatings. Alloy coatings Ni-5%Al and composite Ni-5%Al-15%Al_2O_3 were investigated, which substantial powders have been obtained by flame spraying using the "Casto-Dyn 8000" torch delivered by Messer Eutectic Castolin company. In practice, the thermally sprayed coatings are machined using the same tool as for machined surface. For example, a company Messer Eutectic Castolin proposed multi tool with a square or cylindrical inserts. Cutting knives, cutting elements should be made of cubic boron nitride or diamond. In addition, the insert tool made of tungsten carbide is allowed [7]. During the turning of alloy and composite coatings, the durability of the insert is usually short. It is therefore important to determine the length of spiral cutting. This is the length cutting, which are chosen for recommended cutting, thus allowing for a reliable process. Length of spiral cutting is dependent on the insert geometry and grade, depth of cut and material that shall be subject machined [8].

The processes of production and regeneration of products with applied metal matrix composite coating are recognized among engineers, technologists, because of the possibility of increasing the performance characteristics of the surface layer (strength, tribological and corrosion resistance and decorative aspect). Metal matrix composite and metal alloy and coatings containing in-metal matrix dispersion inclusions of non-metallic phase is characterized by high resistance to tribological and corrosion wear [1, 3, 5, 6, 12-14]. Metal matrix composite are used in such fields of technology, such as aerospace, electronics, energy, industry, defence, automotive, aviation, shipbuilding, and more. Based on a literature review, in the study it has been considered composite coatings based on nickel with aluminum [4, 9, 10, 11, 15].

2. The research methodology

Alloy and composite coatings were applied for degreased samples stainless steel. Coatings on nickel-based alloy was flame sprayed powder material 21021 ProXon company “Castolin”, where the percentage share of the mass was: Ni – 93.45%, Al – 5%, B – 0.8%, Fe – 0.34% , Cr – 0.18%, Si – 0.15%, C – 0.08%. Coatings for metal matrix composite MMC, were sprayed with a mixture of powdered ProXon 21021 and MetaCeram 28020 (Al_2O_3 – 97.7%, TiO_2 – 2.2%, SiO_2 – 0.1%). These powders were manufactured by Castolin. Composite coating material consisted of a matrix of Ni-5%Al and 15% of the disperse phase volume fraction of alumina (Al_2O_3). Spray torch was used, “Casto-Dyn 8000”, the company Castolin. Flame spraying alloy coatings and composites were carried out assuming the following process parameters: pressure flammable gas – acetylene: 0.07 MPa oxygen pressure: 0.4 MPa, air pressure equal: 0.1 MPa, the speed of the torch equal 25 m/min, feed rate equal: 3 mm/rev, the distance from the torch surface to be sprayed: 150 mm, the number of superimposed layers: 6. Steel substrate was pre-heated in the temperature range 333-373 K. Flame spraying was carried out at temperatures exceeding 523 K. Then the coating has been subjected to very precise straight turning. To determine the parameters of machining the alloy coatings and composites based on nickel flame sprayed onto the substrate steel, the preliminary study was conducted for straight turning of high precision. Such turning has been realized with different cutting speed (v_c = 45-214 m/min), feed rate (f = 0.06-0.2 mm/rev) and depth of cut (a_p = 0.05-0.3 mm). Based on analysis of test results, it was determined that the best surface quality was obtained for samples of coated steel, nickel based alloys, using the cutting speed v_c = 214 m/min in the case of treatment with inserts of borazon, v_c = 107 m/min in the case of inserts treated with tungsten carbide cutting. Then it was determined that the best gain of the sample surface quality of coated steel composite was obtained for cutting speed v_c = 157 m/min, in the case of treatment with CBN inserts, v_c = 83 m/min after treatment tungsten carbide inserts. For machining alloy coatings and composites used feed f = 0.06 mm/rev and depth of cut a_p = 0.3 mm.

Straight turning were subjected to a precise external cylindrical surfaces of steel samples with alloy and composite coatings, which samples were of diameter ϕ41 mm and of thickness equal 2 mm. The determination of the optimal geometry of the cutting tool is synonymous with the selection of the optimum shape and dimensions of the insert.

The appropriate holder and edged tiles were chosen, which could be square, round, triangular, trigon, made of tungsten carbide (with grades: GC2015, GC3205, GC3210, GC3215, GC4015, H10F) and cubic boron nitride (CBN, grade CB7015). The research program is presented in Tab. 1. Surface texture of the alloy and composite coatings was measured with a Hommel Tester T1000 profilometer. During the turning of alloy and composite coatings is usually short durability of the insert. It is therefore important to determine the length of spiral cutting. This is the length cutting, which are chosen for recommended cutting, thus allowing for a reliable process. Length of spiral cutting is applied to the insert, geometry, and grade, depth of cut and material that shall be subject machined. Length of spiral cutting (L_{SC}) can be calculated from the formula [2, 8]:

$$L_{SC} = \frac{\Pi \, D_m \, l_m}{f} , \tag{1}$$

where:
D_m – the diameter of the workpiece in the machined surface, mm ($D_m = 41$ mm),
l_m – length of the machined surface, mm,
f – feed rate, mm/rev.

Tab. 1. The shape and grade inserts

Sample Number		Insert Type	Insert Grade	Insert Shape
Alloy Coatings	Composite Coatings			
A.1	**C.1**	**SNGA 120408 S01030A**	**CB7015**	**Square**
A.2	**C.2**	**N123J1-0600-RE**	**CB7015**	**Round**
A.3	C.3	TNMX 160408-WM	GC4015	Triangular
A.4	C.4	TNMG 160408-23	H10F	Triangular
A.5	C.5	WNMG 080408-WF	GC2015	Trigon
A.6	**C.6**	**WNMG 080408 S01030A**	**CB7015**	**Trigon**
A.7	C.7	WNMA 080408-KR	GC3205	Trigon
A.8	C.8	WNMG 080408-KM	GC3205	Trigon
A.9	C.9	WNMG 080408-KM	GC3210	Trigon
A.10	**C.10**	**WNMG 080408-KF**	**GC3215**	**Trigon**

3. Results of research

Samples with applied alloy and composite coatings was turned by turning tools the different types of inserts by Sandvik-Coromant. The study allowed for determination, that there are relationships between the surface texture of alloy and composite coatings and the type of grade used and the shape of the inserts. Trigon insert WNMG 080 408 S01030A and round insert N123J1-0600-RE 7015 of CBN was characterized by a smaller flank wear as compared to a square insert with SNGA 120 408 S01030A 7015 of CBN.

Surface roughness (refer with Tab. 2) of the surface texture alloy coatings of Ni-5%Al turned insert trigon (Ra = 0.47 μm) and round (Ra = 0.39 μm) is nearly three times smaller than the roughness of the coatings faced a square insert (Ra = 1.07 μm). Using the trigon insert made of tungsten carbide determined that the minimum surface roughness of alloy coatings are obtained for grade GC3215 (Ra = 0.54 μm). After turning composite Ni-5%Al-15%Al_2O_3 using square insert SNGA120408S01030A 7015, specifies that the arithmetical mean deviation of the assessed profile reached a lower value of Ra = 1.08 μm (refer with: Tab. 2) in comparison to the roughness of the surface texture with the trigon insert made of the same grades (CB7015) and also with the trigon of tungsten carbide (about the grades: GC2015, GC3205, GC3210, GC3215) and tungsten carbide (for grades: GC4015, H10F) for triangular inserts. The lowest surface roughness Ra = 0.65μm (refer with Tab. 2) is achieved, composite coating turned insert round N123J1-0600-RE 7015. Round insert after turning composite coatings are characterized by the lowest flank wear compared to the square, trigon and triangular.

Tab. 2. Surface texture parameters turned alloy coatings Ni-5%Al and composite coatings Ni-5%Al-15%Al_2O_3

Sample Number	Ra, µm	Rz, µm	Rk, µm	Rpk, µm	Rvk, µm	Rmr, µm	Mr1, %	Mr2, %	Rsk, µm	Wt, µm
					Alloy Coatings					
A.1	**1.07**	**5.79**	**3.29**	**1.60**	**0.91**	**4.78**	**13.1**	**91.1**	**0.481**	**3.99**
A.2	**0.39**	**3.29**	**1.26**	**0.62**	**0.99**	**2.16**	**13**	**86.2**	**-0.336**	**2.05**
A.3	0.49	2.87	1.29	0.57	0.61	1.95	6.7	88.8	-0.156	2.35
A.4	0.82	4.21	2.96	1.41	0.38	3.97	15.3	97.4	0.882	12.24
A.5	0.51	3.52	1.71	0.96	0.69	2.57	10.6	92.1	0.555	2.39
A.6	**0.47**	**2.79**	**1.51**	**0.81**	**0.55**	**2.58**	**9.6**	**88.3**	**0.546**	**1.63**
A.7	0.79	5.22	2.41	0.71	1.25	3.27	7.1	84.2	-0.456	2.65
A.8	0.85	5.86	2.54	0.54	1.58	2.61	7.1	85.1	-0.685	1.38
A.9	0.65	4.20	2.09	0.61	0.95	1.89	8.6	87.9	-0.317	2.53
A.10	**0.54**	**3.79**	**1.52**	**0.45**	**1.26**	**1.54**	**6.7**	**83.2**	**-0.904**	**3.07**
					Composite Coatings					
C.1	**1.08**	**6.72**	**3.34**	**1.49**	**1.28**	**4.89**	**11.9**	**88.1**	**0.224**	**4.69**
C.2	**0.65**	**6.33**	**2.68**	**0.81**	**2.23**	**2.82**	**7.1**	**89.9**	**-1.775**	**5.89**
C.3	2.98	17.45	6.96	2.59	8.73	9.56	9.1	79.9	-1.148	19.87
C.4	3.04	18.98	7.24	1.93	7.65	7.85	6.7	79.1	-0.926	10.26
C.5	2.74	15.70	3.57	1.82	9.94	5.73	8.6	72.2	-1.721	6.58
C.6	**1.51**	**13.6**	**3.89**	**2.93**	**6.42**	**6.58**	**8.3**	**84.9**	**-1.864**	**11.99**
C.7	3.00	20.63	6.40	2.33	9.12	7.87	6.5	76.2	-1.619	13.03
C.8	3.55	23.82	8.24	1.97	9.27	9.05	6	75.9	-1.181	17.32
C.9	3.71	21.19	9.24	4.09	9.42	13.58	4.8	79.7	-1.062	14.85
C.10	**3.75**	**22.73**	**9.08**	**2.21**	**10.13**	**8.84**	**7.0**	**79.3**	**-0.948**	**11.63**

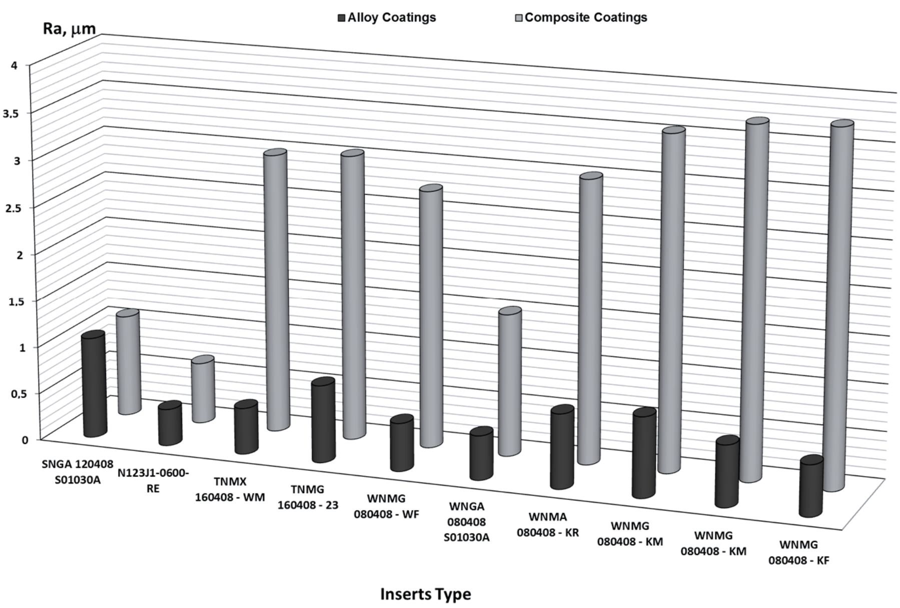

Fig. 1. The arithmetical mean deviation for coatings: alloy Ni-5%Al and composite Ni-5%Al-15%Al_2O_3 for turned samples inserts according to the research program

Figure 1 shown the arithmetical mean deviation of the assessed profile for alloy Ni-5%Al and composite Ni-5%Al-Al_2O_3 coatings after turned for various type inserts.

Parameter (Rpk) of the reduced peak height (which should be the lowest) is characteristic for the upper surface layer that quickly undergoes abrasion after start of i.e. engine running. Reduced depth of roughness profile valley is described by (Rvk) parameter (which should be the highest). It is a measure of the working surfaces ability to keep the lubricant in the valleys created mechanically. Parameter (Rk) defines the core roughness depth (which should be the lowest) (Fig. 2).

After turning the external cylindrical stainless steel samples with coating of alloys and composites, it was determined, that there were relationships between surface texture and the type of material used and the shape of the tool inserts. Based on analysis of test results, it was determined, that due to obtaining the smallest surface roughness of alloy coatings, it was expedient to use trigon inserts made of tungsten carbide with grade GC3215 and trigon inserts made of cubic boron nitride grade CB7015 and round inserts (CB7015).

Turning surfaces of have been subjected to the external cylindrical stainless steel samples of coated alloys and composites. After experimental studies determined that there are relationships between surface texture and the type of material used and the shape of the tool inserts. Based on analysis of test results determined that due to obtaining the smallest surface roughness alloy coatings, it was expedient to use trigon inserts made of tungsten carbide with grade GC3215 and cubic boron nitride grade CB7015 and round inserts (CB7015). For samples No. A.2 coated Ni-5%Al subjected to turning determined that the arithmetical mean deviation of the assessed profile and the Abbott-Firestone curve surface roughness parameters take the smallest value (refer with: Fig. 3).

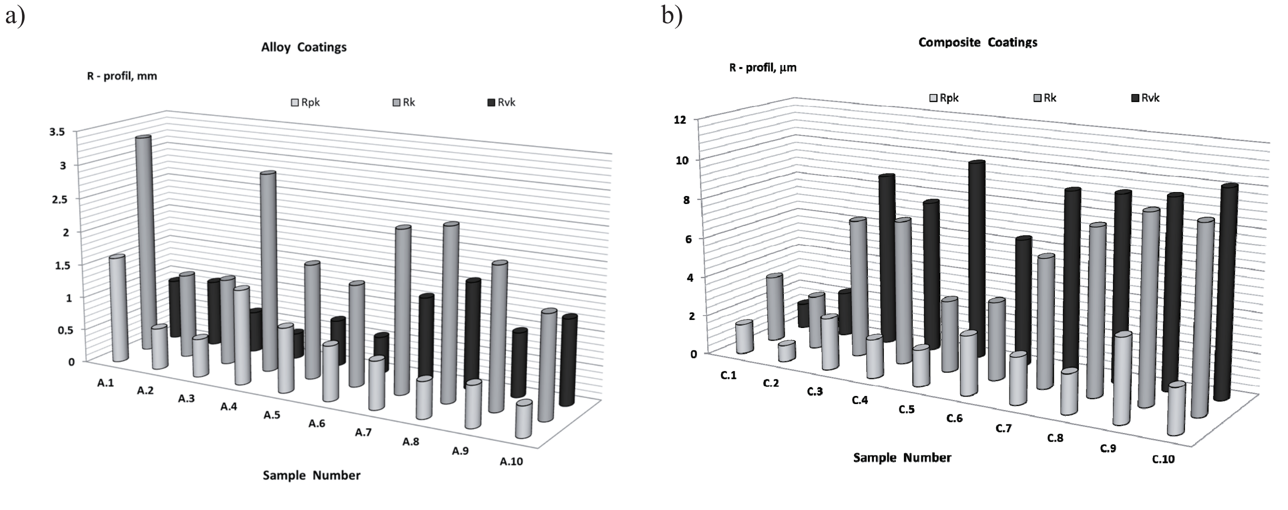

Fig. 2. The characterized parameters of the material ratio curve for a) alloy Ni-5%Al coatings and b) composite coatings Ni-5%Al-15%Al₂O₃ after turned for different type inserts
WNMG 080408 S01030A (No. A.6)

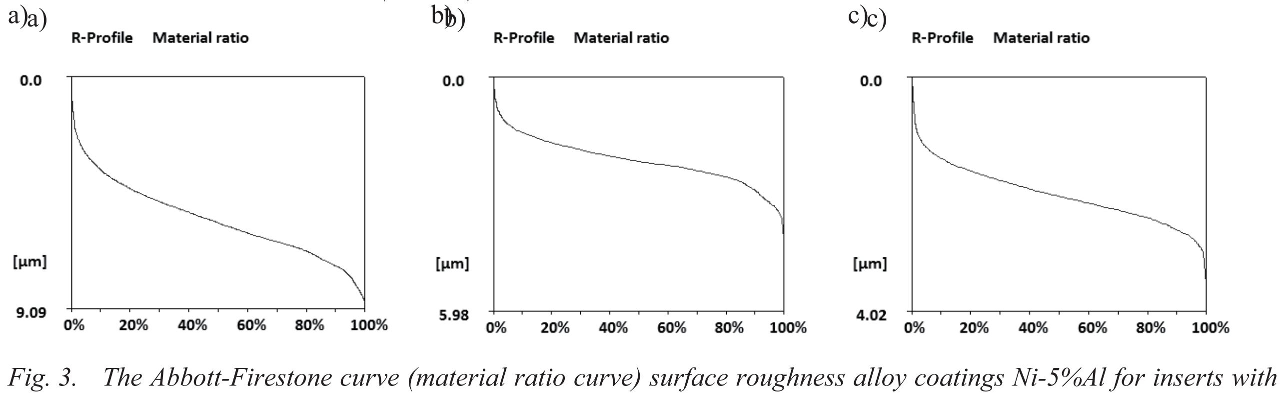

Fig. 3. The Abbott-Firestone curve (material ratio curve) surface roughness alloy coatings Ni-5%Al for inserts with CB7015: a) square SNGA120408S01030A (No. A.1) and b) round N123J1-0600-RE (No. A.2) and c) trigon WNMG 080408 S01030A (No. A.6)

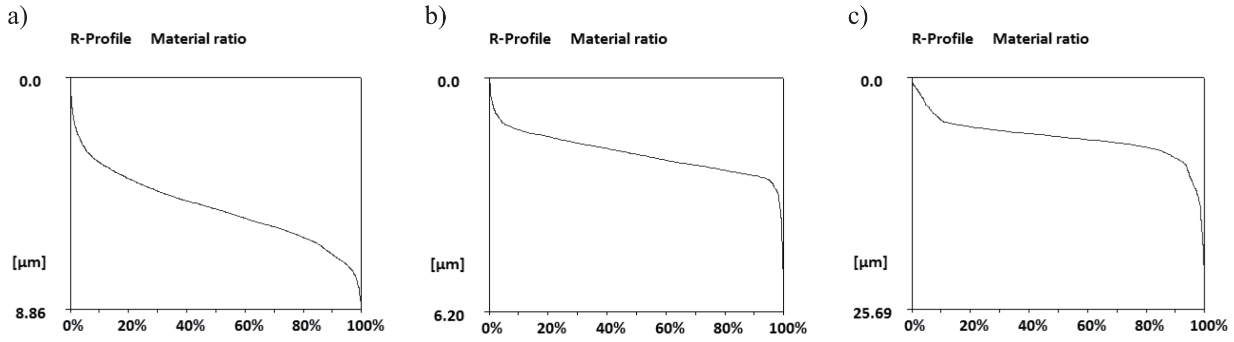

Fig. 4. The Abbott-Firestone curve (material ratio curve) surface roughness composite coatings Ni-5%Al-15%Al2O3 for inserts with CB7015: a) square SNGA120408S01030A (No. C.1) and b) round N123J1-0600-RE (No. C.2) and c) trigon WNMG 080408 S01030A (No. C.6)

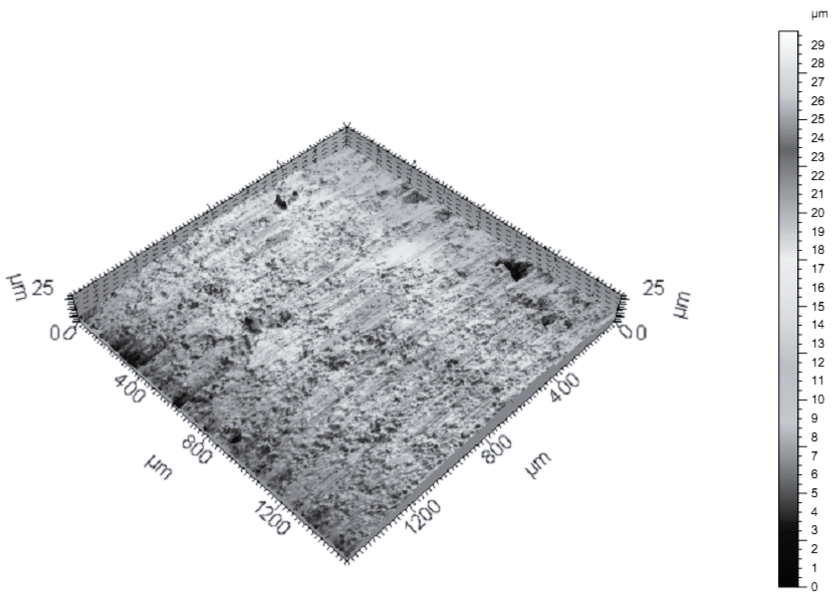

Fig. 5. An example of the surface topography of the composite coatings Ni-5%Al-15%Al2O3 turned for inserts with WNMG 080408 S01030A CB7015 [13]

Based on analysis of test results determined that due to obtaining the smallest surface roughness turned alloy coatings of Ni-5% Al, with the least wear on the insert flank face and tool face, for a constant length of spiral cutting (L_{SC} = 1.1 * 10^6 mm), targeted to was the use of trigon inserts made of cubic boron nitride on the grade CB7015 and an insert grade GC3215 and the round profile of the CB7015. Roughness of the surface texture of Ni-5%Al subjected to turning by trigon insert with CBN is three times smaller than the roughness of the alloy coatings a square insert. Thus, it is advisable not use square inserts for machining alloy coatings. Based on analysis of experimental results after turning composite coatings can be determined that the roughness profile parameters and parameter values of the bearing area curve reached the lowest values for samples No. C.2 (refer with Fig. 4). Fig. 5 shown example of the surface topography of the composite coatings turned for inserts with WNMG 080408 S01030A CB7015.

4. Conclusions

Coatings obtained by flame spraying have a large surface roughness. Therefore, these coatings must be subjected to finishing. The most commonly used machining (e.g., finish turning, grinding). Flame spray coatings are applied taking into account the allowance for finishing. Finishing should ensure not only adequate coating thickness associated with the nominal size of an object but also to obtain the required surface roughness and waviness. Surface texture is very important where it has a direct influence on the quality of the elements machine parts. Therefore, it has to be defined as precisely as possible with the help of standardized surface texture parameters. The best tool contour and angles, selected the required shape and grade the inserts, you need to obtain a minimum surface roughness. After you finish turning of studies of alloy and composite coatings determined that due to obtaining the smallest surface roughness, with the least wear on the insert flank face and tool face, for a constant length of spiral cutting, targeted to be the use of inserts round with borazon. Alloy and composite coatings used in the production and regeneration, it appears possible to achieve the technological quality of the elements machine parts (e.g. shafts of centrifugal pumps). It can be argued that due to the surface quality coatings and durability of the turning inserts: for turning shafts of centrifugal pumps with a coating alloy would need to be round and trigon inserts with borazon and trigon with tungsten carbide, for turning shafts of centrifugal pumps with composite coatings should be applied round inserts with borazon.

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