

Formation of Surface Topography During Turning of AISI 1045 Steel Considering the Type of Cutting Edge Coating

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ABSTRACT

The paper presents evaluation of the surface topography obtained after turning of AISI 1045 steel with the use of cemented carbide tools diversified in terms of applied titanium-based coatings. During the research, three types of coatings deposited with the PVD method on a P25 sintered carbide insert were compared: nitride-titanium TiN, nitride-aluminum-titanium TiAlN and carbon-titanium TiC in a wide range of variable cutting speeds 125–325 m/min and variable feeds 0.05–0.25 mm/rev. The quality of the machined surface was assessed on the Sensofar S neox System optical profile meter using the confocal method. The paper presents the results of 3D parameters, contour maps, isometric views and material ratio curves. The surface topography analysis showed that for the TiAlN coated insert, lower surface roughness parameters were observed in the range of lower cutting speeds and higher feeds, while for higher cutting speeds, lower values of the selected 3D parameters were found for the insert with TiC coating. For the insert with TiC coating, the most even distribution of the valleys and ridges of the machined surface roughness was also observed. The research results determined the range of cutting parameters that allow the selection of the appropriate type of titanium-based coating when machining AISI 1045 steel.

Keywords: titanium coatings, surface topography, dry machining, turning, AISI 1045 steel.

INTRODUCTION

The essence of machining is to produce parts that are characterized by the required geometry and surface quality. This process should also be characterized by the lowest possible production cost. Currently, materials that are also difficult-to-cut are processed with ever higher cutting speeds and feeds [1, 2]. Increasing these parameters increases the temperature in the cutting zone, and thus leads to faster wear of the cutting tools [3]. The dependence of the surface topography on the type of fatigue load that affects the machined surface should also be taken into account. The research of Mack et al. [4] indicate that the samples

with higher values of the S_a parameter, which is the arithmetic mean surface roughness height, showed greater durability. Moreover, its highest values were obtained at loads characterized by a high ratio of maximum stresses, and with its decrease - the S_a value decreased. Although it was unequivocally established that the surface topography depends on the type of load, a special correlation was observed in the case of the torsional load τ , which largely influenced the morphology of the fracture surface S_a , therefore this is one of the challenges that scientists dealing with research on tool life [2, 5]. Another important issue that must also be taken into account nowadays is the protection of the environment. That is why the

German Research Foundation in 2010 announced a priority program aimed at offering solutions to the problems of the application of dry machining [6]. Dry machining has many advantages, but also related disadvantages. The advantages of dry machining include: dry and clean surfaces of manufactured parts, reduction of costs related to the production and recycling of chips due to the absence of oil contamination.

Savings resulting from the use of dry machining, however, require a lot of research and scientific work in order to reduce the excessive wear of tools [7, 8]. In the United States, a national nanotechnology initiative was launched in 2001 that focuses on providing nano-structured coatings and materials that can be successfully applied to cutting tools in dry machining. In 2006, US President George W. Bush donated \$ 497 million to support nano-scale research [9].

One of the effective methods of protecting cutting tools against wear, while ensuring their greater efficiency and productivity, is the application of coatings [10, 11]. The use of coated tools often has a positive effect on the condition of the machined surface integrity, and in combination with high-speed dry machining, it is an efficient and environmentally friendly solution [12, 13]. However, care should be taken to ensure that the coating has good adhesive

properties. Otherwise, during machining, hard particles contained in a workpiece, can lead to increased wear of the cutting edge [14]. Initially, the coatings were applied in the form of a single layer, but the development in this area resulted in the use of multilayer coatings, combining, for example, the abrasion resistance provided by coatings containing titanium with chemical stability guaranteed by oxides [15]. Basically, two methods are distinguished in the coating application process: physical vapor deposition (PVD) and chemical vapor deposition (CVD) [2, 16]. Currently, 50% of all cutting inserts available on the market are sintered carbide inserts, and as much as 80–90% of them are PVD or CVD coated, which proves the positive effect of the coating on machinability indicators [17, 18]. During the study, scientists found that PVD coatings are more suitable for finishing, while CVD coatings show better properties during roughing [19, 20]. However, the selection of a specific type of coating is based on the conditions in which the cutting process is carried out. Not only the machined material and the cutting speed are taken into account, but also the types of wear that usually occur under the adapted machining conditions [21].

The use of a coating on the cutting insert results in: increased thermal resistance, hardness, better thermal properties, greater chemical stability, temperature resistance, tool life and a lower friction coefficient [5, 22]. Coatings aimed at increasing the wear resistance of the tool include: nitrides, carbides or carbonitrides, which results from their metal-like and ceramic properties [23, 24]. The most commonly used coatings are: Al_2O_3 , TiCN, TiC, TiAlN and TiN [20, 25]. The use of coatings based on metal nitrides based on titanium (e.g. TiN) began in the 1970s, but it was not until 20 years later that they were enriched with other elements, obtaining, among others, TiAlSiN [19, 26]. Numerous studies show that Ti (C, N) coatings, in addition to wear resistance, have properties such as high resistance to plastic deformation or good ductility. Moreover, their effectiveness in increasing the durability of the cutting edge can also be improved by adding boron [27, 28]. Due to their increased hardness compared to TiN and TiAlN coatings [29], they effectively prevent abrasive wear and are used mainly during milling or thread cutting [30, 31].

DLC (diamond-like carbon) coatings are also becoming more and more popular, which are

Nomenclature	
a_p	depth of cut (mm)
A_s	unit elongation (%)
CVD	chemical vapor deposition
DLC	diamond-like carbon
f	feed (mm/rev)
HB	Brinell hardness
PVD	physical vapor deposition
r_ϵ	corner radius (mm)
Ra	arithmetic mean roughness (μm)
R_e	yield strength (MPa)
R_m	ultimate strength (MPa)
Sa	arithmetic mean of the surface (μm)
Sp	maximum peak height (μm)
Sv	maximum pit height (μm)
Sz	maximum height of surface (μm)
v_c	cutting speed (m/min)
γ_o	rake angle ($^\circ$)
κ_r	main tool angle ($^\circ$)
κ_r'	auxiliary tool angle ($^\circ$)
λ_s	tool inclination angle ($^\circ$)

especially used in the machining of aluminum. They prevent the adhesion of the machined material to the tool, and moreover, they are characterized by high hardness, chemical stability and thermal conductivity, lower friction coefficient, and lower machined surface roughness [32, 33].

Research is still ongoing, focusing on the effects of coated cutting tools in machining. Çelik et al. [34] performed dry turning of Ti-6Al-4V alloy with the use of tools with coatings: TiCN + Al₂O₃ + TiN applied by CVD method and TiAlN applied by PVD method. It was observed that for lower cutting parameters the wear of the cutting edge with the PVD coating was lower compared to the effects reached during cutting with the tool with CVD coating. On the other hand, after increasing these values, the obtained results were opposite. In this case, the greater wear of the PVD coated tool was due to the chemical interaction between the workpiece and the tool. The surface roughness for lower cutting parameters was lower than for their higher values, however, in the case of machining this alloy, the authors recommend additionally grinding in order to obtain the desired quality of the machined surface. However, they emphasize that the values of the *Ra* parameter after increasing the depth of cut and feed were higher for the PVD coating compared to the CVD coating.

Özkan et al. [35] conducted tests with the use of H13 tool steel samples, on which AlTiSiN + TiSiN coatings, as well as CrN, TiN and AlCrN as intermediate layers, were applied using the PVD method. The tribological tests were carried out dry and under lubrication conditions with the use of mineral oil containing 5% zinc dithiophosphate. As a counter-sample, balls made of aluminum with a diameter of 6 mm were used. The tests showed that the best lubrication conditions were provided by the coating consisting of AlTiSiN + TiSiN, for which the friction coefficient was respectively 0.11 and 0.18 with and without the use of lubricating oil. In turn, the sample with the coating containing an additional TiN intermediate layer was characterized by the highest wear resistance. This resulted, inter alia, from high adhesion and grain size of 14 nm, and moreover, the deposition of a thin layer of TiSiN on a thicker layer of AlTiSiN ensured the best mechanical properties of the TiN layer. On the other hand, when using the AlCrN layer, less friction was observed, but also lower efficiency in terms of sample wear. The research showed that the type of the intermediate layer affects the degree of wear, and the best results in

conditions with and without lubricating oil can be obtained thanks to the AlTiSiN + TiSiN coating with a TiN intermediate layer.

In another study, Velmurugan and Venkatesan [36] used waspaloy alloy as the workpiece. This time, dry turning was also carried out with the use of TiAlN (PVD) and TiN-Al₂O₃-TiCN (CVD) coatings. It was shown that thanks to the PVD coating, the cutting force was reduced by about 60% compared to the cutting tool with the CVD coating. However, the machined surface had a higher surface roughness in this case. For the CVD coated tool, the surface roughness parameters values decreased by approximately 67% compared to the values reached during cutting with PVD coating. The analysis of the chips also showed that the chips obtained during cutting with the CVD coated tool had a segmented shape, showed lateral flow and had a golden color, which indicated intensive tool wear and high temperatures accompanying the cutting process. The chips obtained with the PVD-coated tool, in turn, were silver in color, as the heat increase at the contact point of the tool with the chip was eliminated in this case.

Martinho et al. [37] milled duplex steel with the use of inserts with two types of coatings: AlTiN (PVD) and TiN/TiCN/Al₂O₃ (CVD). The study showed that in this case the AlTiN coated tool was more susceptible to damage compared to tool equipped with TiN/TiCN/Al₂O₃. Wear on the CVD-coated tools was lower, however, no better surface quality was obtained then. For this reason, the authors indicate that this type of coating on cutting tool works better during roughing, because obtaining the appropriate surface roughness is then not necessary. On the other hand, PVD-coated tools are more suitable for finishing. Such differences are due to the fact that compared to the multi-layer CVD coating, the PVD coating consisting of one layer is thinner. Finishing is not as demanding for cutting inserts as it is for roughing, therefore tools with thin coatings are able to provide good results. Conversely, during roughing operations, the thin coatings that are expected to withstand the stresses generated during cutting wear out quickly. Therefore, in this case, coatings with increased thickness work better.

Fernández-Abia et al. [38] focused on turning of AISI 304L austenitic steel using four types of PVD coatings: AlTiSiN, TiAlCrN, AlTiN, AlCrSiN. As a result of the performed turning, it was proved that tools with AlTiSiN and AlTiN coatings provide the best results under the adapted machining

conditions. This conclusion was drawn on the basis of: low Ra surface roughness parameter values ensuring good surface quality, low flank wear values and reduced cutting forces compared to the other tested coatings. Comparing AlTiN and AlTiSiN with each other, it was also found that the second of the mentioned coatings allows for the best machining results, which is caused by its nanocrystalline structure. As a result, aluminum diffuses towards the surface of the cutting edge, which quickly forms a protective layer. In turn, thanks to it, the adhesion of the workpiece material is reduced, and what is more - thermal conductivity is reduced.

Liu et al. [39] carried out dry turning using tools with PVD TiAlN and CrAlN coatings. In addition, they were combined with cutting tools without any coatings. Gray cast iron HT250 was used as the workpiece material. As a result of machining with speeds in the range of 200–300 m/min, it was observed that the coatings contributed to the extension of the tool life, with better results in this range obtained for CrAlN. This was due to the microstructure of the coating, characterized by higher surface hardness, higher density and smaller grains compared to TiAlN. The main type of wear that occurred on the cutting inserts was abrasive wear. Adhesive wear played a slightly smaller but also significant role, and it occurred more intensively in the case of coated cutting inserts. In terms of the quality of the machined surface, it was found that the best results were obtained during cutting with uncoated inserts and those with CrAlN coating. The TiAlN coating in this case contributed to the higher Ra parameter values.

Due to ecological trends and the continuous development of dry machining, the main goal of this study is to assess the impact of a cutting edge with three types of titanium-based coatings on the surface topography formed during turning of AISI 1045 steel with variable feed values and cutting speeds. In addition to the analysis of 3D height parameters, the focus was also on the material ratio curve, which provides information on the operational properties of the surface.

EXPERIMENT

Cutting tools and workpiece

The tests were carried out on the CU-502 universal lathe with the use of the SNUN120408-PF insert and the CSRNR2525 toolholder with the following cutting insert geometry: corner radius $r_e = 0.8$ mm, entering angle of the main cutting edge $\kappa_r = 75^\circ$, entering angle of the secondary cutting edge $\kappa_r' = 15^\circ$, cutting edge helix angle $\lambda_s = -6^\circ$; rake angle $\gamma_o = -6^\circ$. The cutting insert is made of P25 cemented carbide, which has been coated with three types of coatings:

- nitride-titanium TiN, thickness 2.2 μm - PVD method;
- 2 μm thick nitride-aluminum-titanium TiAlN – PVD method;
- 2.2 μm thick carbon-titanium TiC - PVD method.

Cutting parameters were selected in accordance with the manufacturer recommendations for the coated tools. During the experiment, the cutting speed range was $v_c = 125\text{--}325$ m/min,

Table 1. Cutting parameters applied in the research

Machining parameters	Test point number									
	1	2	3	4	5	6	7	8	9	10
v_c [m/min]	250					125	175	225	275	325
f [mm/rev]	0.05	0.1	0.15	0.2	0.25	0.15				
a_p [mm]	0.5									

Table 2. Chemical composition, mechanical properties and microstructure of AISI 1045 steel

Chemical composition (%)							
C	Si_{max}	S_{max}	P_{max}	Mn	Cr_{max}	Cu_{max}	Ni_{max}
0.42÷0.5	0.4	0.045	0.04	0.5÷0.8	0.3	0.3	0.4
Mechanical properties							
R_e (MPa)	R_m (MPa)		A_5 (%)			HB	
305	580		16			250	

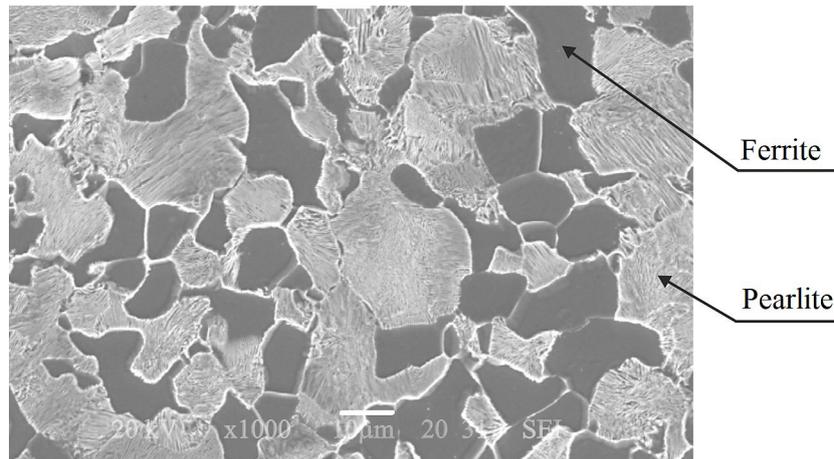


Fig. 1. Microstructure of AISI 1045 steel

feed $f = 0.05\text{--}0.25$ mm/rev and constant cutting depth $a_p = 0.5$ mm. The cutting parameters were applied for a finishing process. The values of individual cutting parameters applied during machining tests are depicted in Table 1.

During the tests, the AISI 1045 steel was used, which is widely applied for the production of equipment and machinery elements, e.g. shafts, levers, axes, spindles, etc. The mechanical properties, chemical composition of AISI 1045 steel were taken from the certificate attached by the manufacturer and the values are presented in Table 2, while the microstructure is shown in Figure 1.

Measurement apparatus

The surface topography analysis was performed on the Sensofar S neox optical profile meter system (Figure 2) that allows samples to be scanned using three different technologies: Focus Variation, Confocal and Interferometric. The confocal method was used during the research, as it is a method that is used for demanding surface topography and inspection of complex geometries (e.g. almost vertical slopes). The filtration during the measurements was performed in accordance with the ISO 3274 standard. In accordance with the standard, the authors used λs filtering to remove microcracks, which are usually caused by instrument or ambient noise. Then a λc filter was applied to separate the waviness from the roughness. The surface topography was analyzed with the use of height parameters: the arithmetic mean of the surface height Sa , maximum pit height Sv , the maximum peak height Sp , and the maximum height of surface roughness Sz . The paper also presents contour maps and isometric views,

which revealed the specific features of the surface affecting the functional properties of the surface. The results of the material ratio curve provided information about the shape of surface irregularities, therefore it is mainly used to analyze surfaces generated by multi-operational surface shaping. The material ratio curve in combination with amplitude density distribution histogram is a very useful tool in describing the surface texture of the tested object. The histogram shows the density of the distribution of points (amplitudes) in the analyzed profile [40].

RESULTS AND DISCUSSIONS

The dependencies between the applied coatings and the obtained Sa parameter during cutting with variable cutting parameters are shown in Figure 3.

When analyzing the values of the Sa parameter at variable feed (Fig. 3a), it was observed that for feeds $f < 0.1$ mm/rev, the smallest values of the arithmetic mean surface height were obtained during cutting with the TiAlN coating on the cutting edge. For the feed value in the range 0.11–0.2 mm/rev, the lowest Sa values were found during cutting with tool with TiC coating. From the feed value of 0.2 mm/rev during turning process with tools equipped with TiAlN and TiC coatings, similar values of the Sa parameter were found. In the entire range of variable feed, the highest values of the arithmetic mean surface height were found for a surfaces machined with a tool equipped with the TiN coating. The reduction of the selected Sa parameter by the TiC coating is due to its greater hardness compared to other

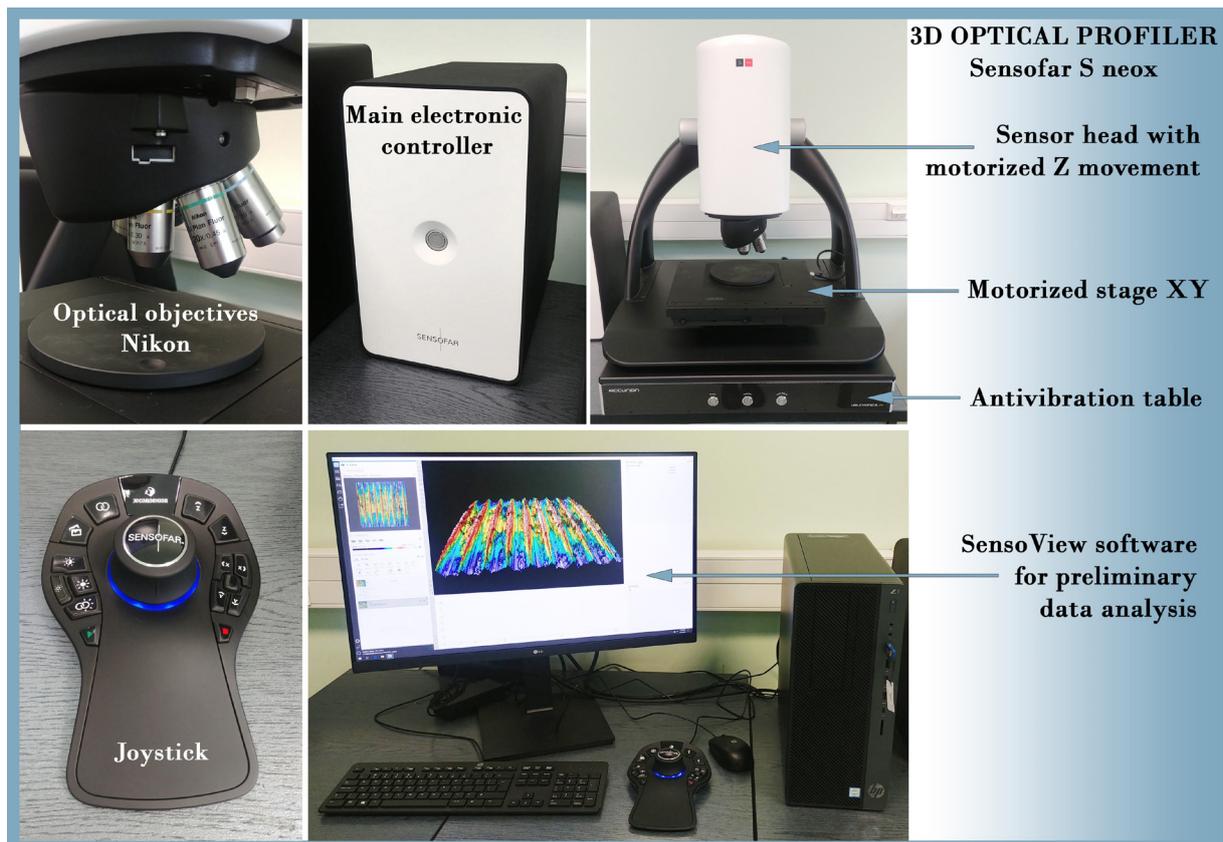


Fig. 2. Sensofar S neox System applied in experiment

coatings, in particular to the TiN coating [41]. The use of the TiC coating has a positive effect on the resistance of the cutting insert to abrasive wear, and as a result enables obtaining a surface with reduced surface roughness [30]. On the other hand, for variable cutting speed at $v_c = 125$ m/min (Fig. 3b), the use of the TiC coating contributed to the increase of the value of the S_a parameter, compared to the cutting inserts with TiAlN and TiN coatings. Up to the cutting speed of 225 m/min, the smallest values of the arithmetic mean surface roughness height were noticed when using a tool with a TiAlN coating. This is due to the addition of aluminum, which increases the hardness of the coating and improves the thermal properties of the coating. The TiAlN coating is therefore resistant to the effects of temperature in the cutting zone, resistant to oxidation, which ensures a higher quality of the machined surface [42]. The increase in the cutting speed caused the reduction of the selected 3D parameters for all the applied coatings, which is a typical phenomenon accompanying the cutting of metallic materials [43]. Above the speed of 225 m/min, the lowest values of the S_a parameter were observed when using the TiC coating, where a decrease of the

considered 3D surface roughness parameter was noted, respectively, by 34.02% compared to the TiAlN coating and by 27.27% for the TiN coating.

The effect of the type of coating deposited on the cutting edge on the S_z parameter depending on the variable feed and cutting speed is shown in Figure 4. Up to the feed value of 0.15 mm/rev, the maximum surface height values for all types of coatings ranged from 10 μm to 17.5 μm with no clear trend (Fig. 4a). After exceeding the feed $f > 0.15$ mm/rev, the S_z parameter increased with the feed increase. For the lowest feed of 0.05 mm/rev and the average value of 0.15 mm/rev, the lowest values of the S_z parameter were found for the surface after machining with a TiC coated insert, while for a TiAlN coated insert, the lowest S_z values were reached above the feed of 0.15 mm/rev. Reducing the surface roughness in this case can be correlated with an increase in the resistance of this coating to oxidation compared to the TiN coating, which results in the protection of the tool in the range of higher temperatures, from 850–900 $^\circ\text{C}$ [44]. In almost the entire range of the variable feed, the highest values of the S_z parameter were observed for the insert with the TiN coating. Although the application of a tool with TiN coating

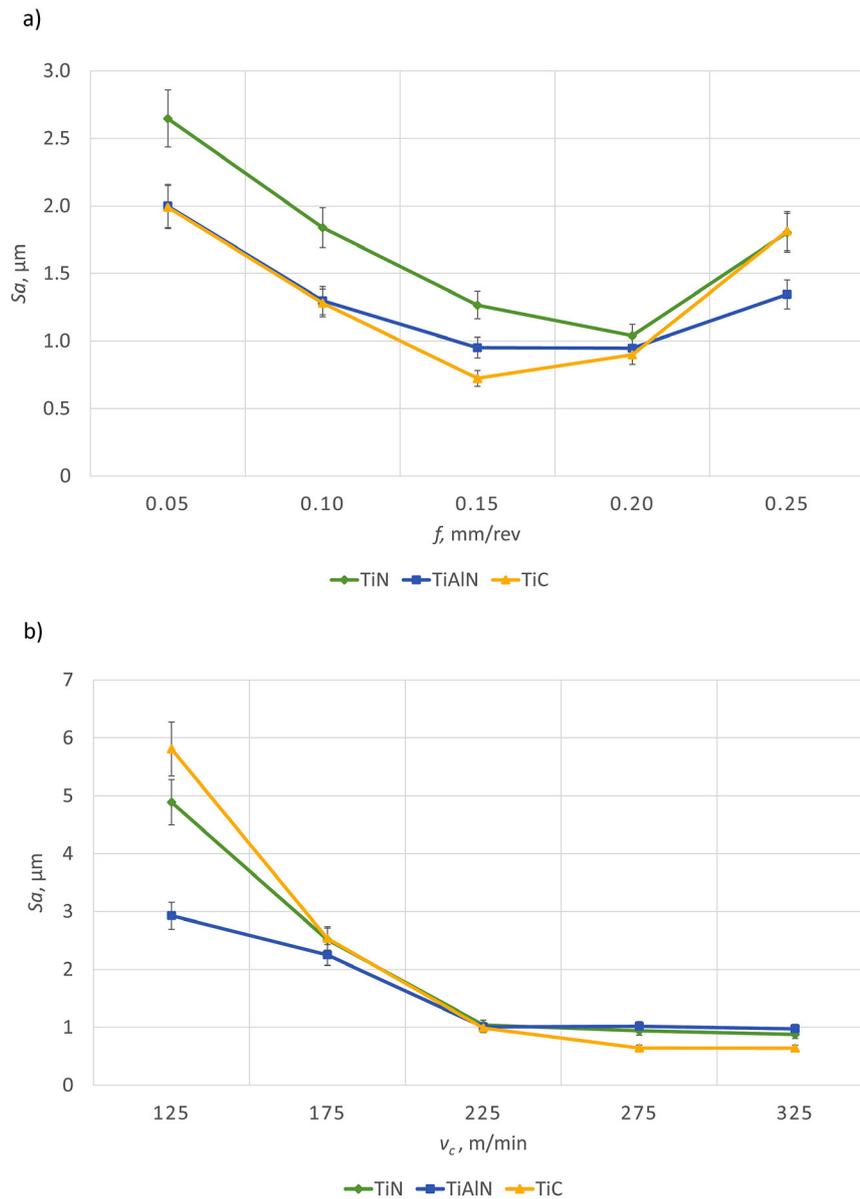


Fig. 3. The influence of the type of cutting edge coating on the values of the S_a parameter for: a) variable feed f ; b) variable cutting speed v_c

can cause a reduction in tool wear, it also has a low fracture toughness and, moreover, an increased residual stress. As a result, it is often not able to fully meet all the requirements for coatings applied to cutting tools used during machining [45].

In the case of an increase in the cutting speed (Fig. 4b), a decrease in the 3D surface roughness parameters values were observed for machining with tools with each of the tested coatings. For lower cutting speeds, up to 225 m/min, the lowest value of the maximum surface height was found for cutting with tool equipped with the TiAlN coating, and the highest for the machining with TiN coated tool. This observation is confirmed by the fact that with the increase of aluminum

content in the coating, the hardness of the cutting insert increases [20, 46], thanks to which it is able to reduce the machined surface roughness. From the value of 225 m/min, the values of the considered 3D roughness parameter for tools equipped with different coatings are more similar. For the highest cutting speed, the lowest value of the S_z parameter was observed for the surface machined with the TiC coated tool, but the percentage of reduction of a given parameter did not exceed 10% compared to other coatings.

Figure 5 and Figure 6 show the values of the S_p , S_v parameters and their sum being the parameter S_z obtained on the surfaces machined with tested inserts. The S_p parameter is of particular

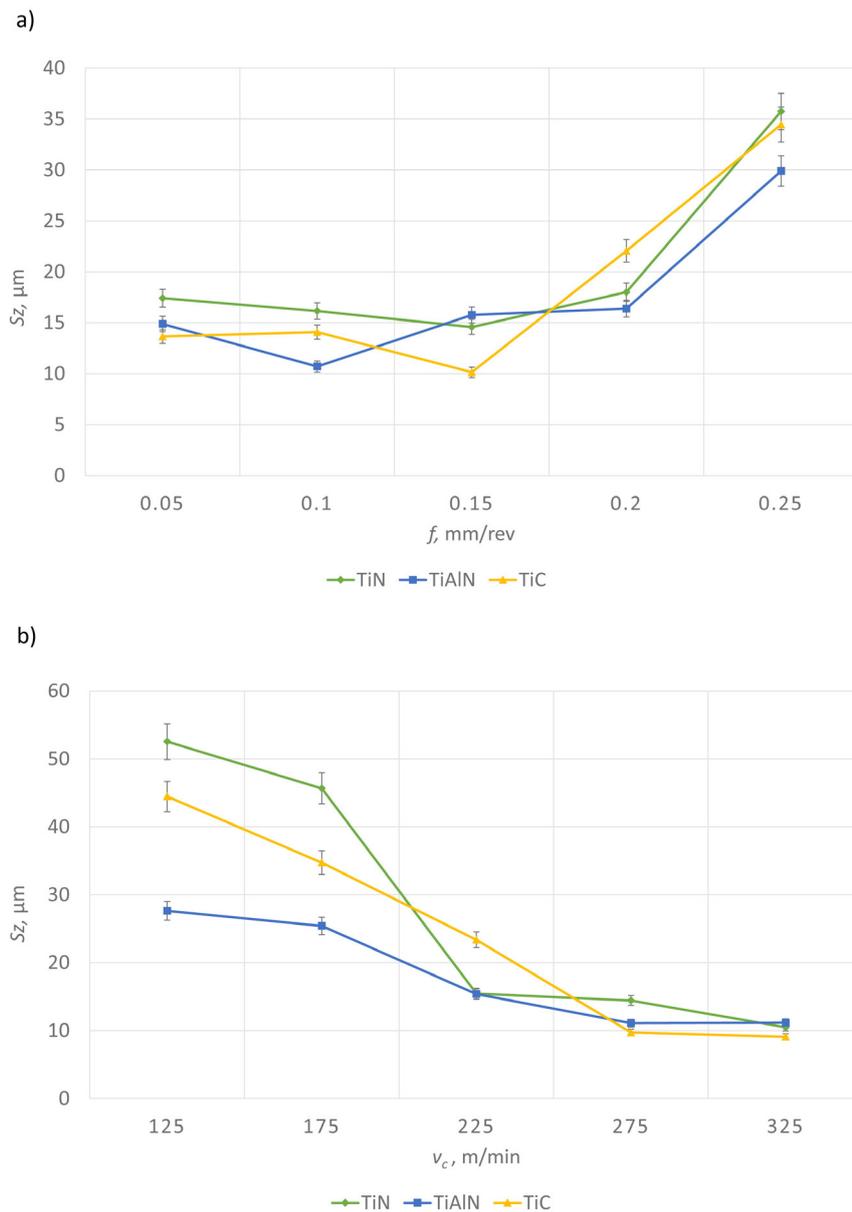


Fig. 4. Influence of the type of cutting edge coating on the values of the S_z parameter for: a) variable feed f ; b) variable cutting speed v_c

importance in the case of surfaces whose application includes sliding applications, while S_v is used especially when the aspect of fluid retention on a given surface is important. In such a situation, great importance is attached to the depth of the valleys formed during machining [47].

During cutting with variable feed (Fig. 5), the change in the values of S_p and S_v parameters was observed analogous to the S_z parameter. With the increase of the feed to the value of 0.15 mm/rev, there were no significant increases in the selected 3D surface roughness parameters. However for a higher feeds a sharp increase in the surface roughness values was observed during cutting with the

tested tools. Among the three cutting parameters (feed, depth of cut and cutting speed), the feed is the factor influencing the surface roughness to the greatest extent [34, 48]. In the entire range of variable feed, the lowest values of the surface roughness parameters were observed for the surface machined with a tool with a TiAlN coating. The exception was the value of S_p for $f = 0.15$ mm/rev, where the lowest value was recorded during turning with the TiN coated tool. The lowest values of the S_v parameter were found for the surface machined with a cutting insert with a TiC coating (three considered feed values) and with a TiAlN coating (for two feed values).

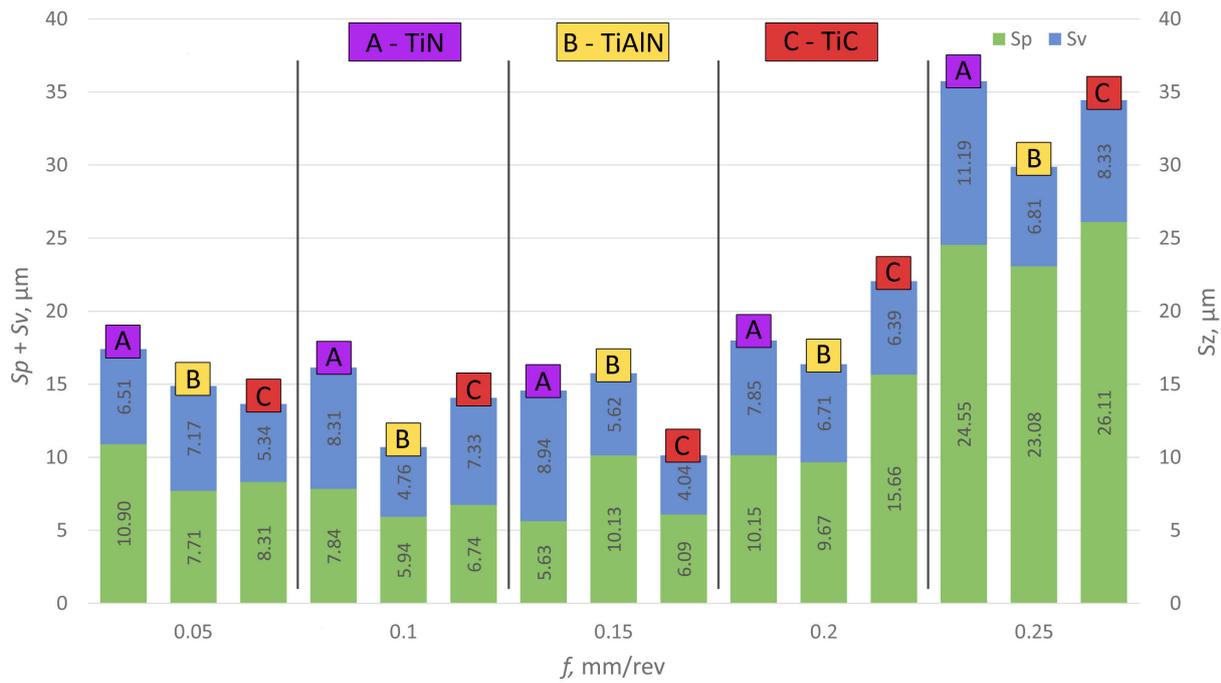


Fig. 5. Influence of the type of cutting edge coating on the values of S_p and S_v parameters depending on the variable value of the feed after turning of AISI 1045 steel

The change in cutting speed (Fig. 6) was characterized, by a decrease in the values of S_p and S_v parameters with an increase in the cutting parameters for all three types of coatings. This is due to the fact that an increase in v_c leads to a reduction in the contact zone of the chip with the cutting edge. Consequently it causes a reduction

of friction and the risk of: flank wear and thermal cracks. As it is known, tool wear adversely affects the quality of the machined surface, hence increasing the cutting speed may contribute to its improvement. However, for this to be possible, the coatings must withstand increasing thermal loads, resulting from an increase in the value of

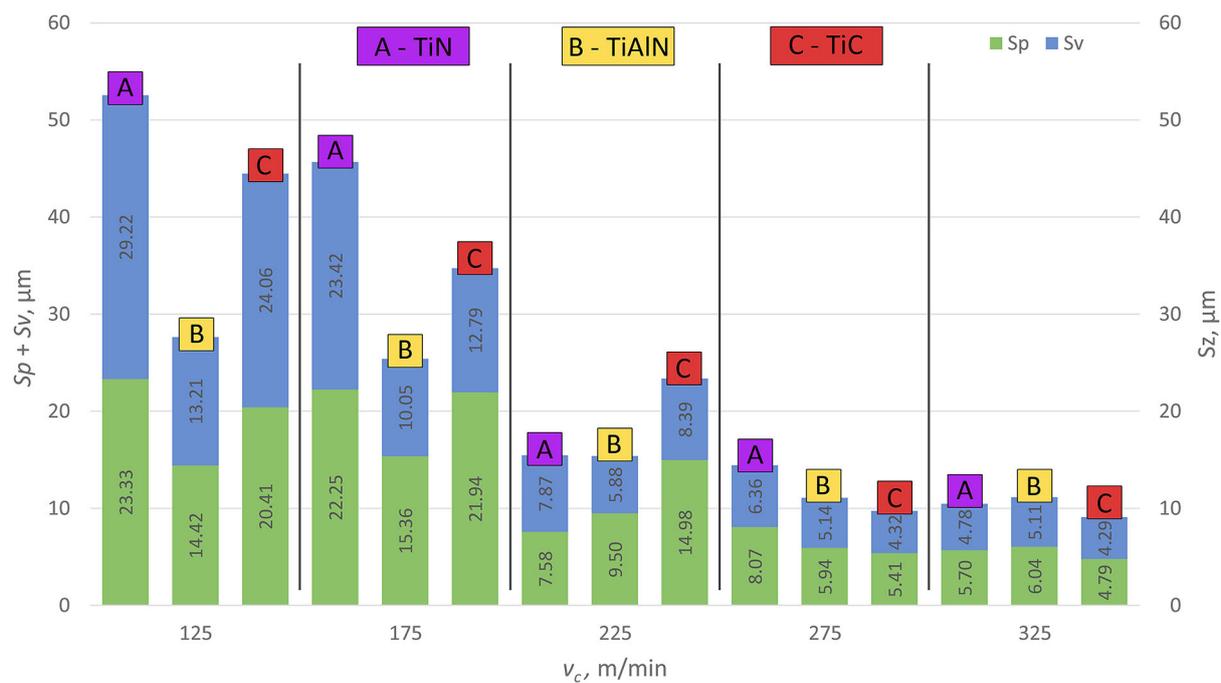


Fig. 6. Influence of the type of titanium coating on the values of S_p and S_v parameters depending on the variable value of the cutting speed during cutting of AISI 1045 steel

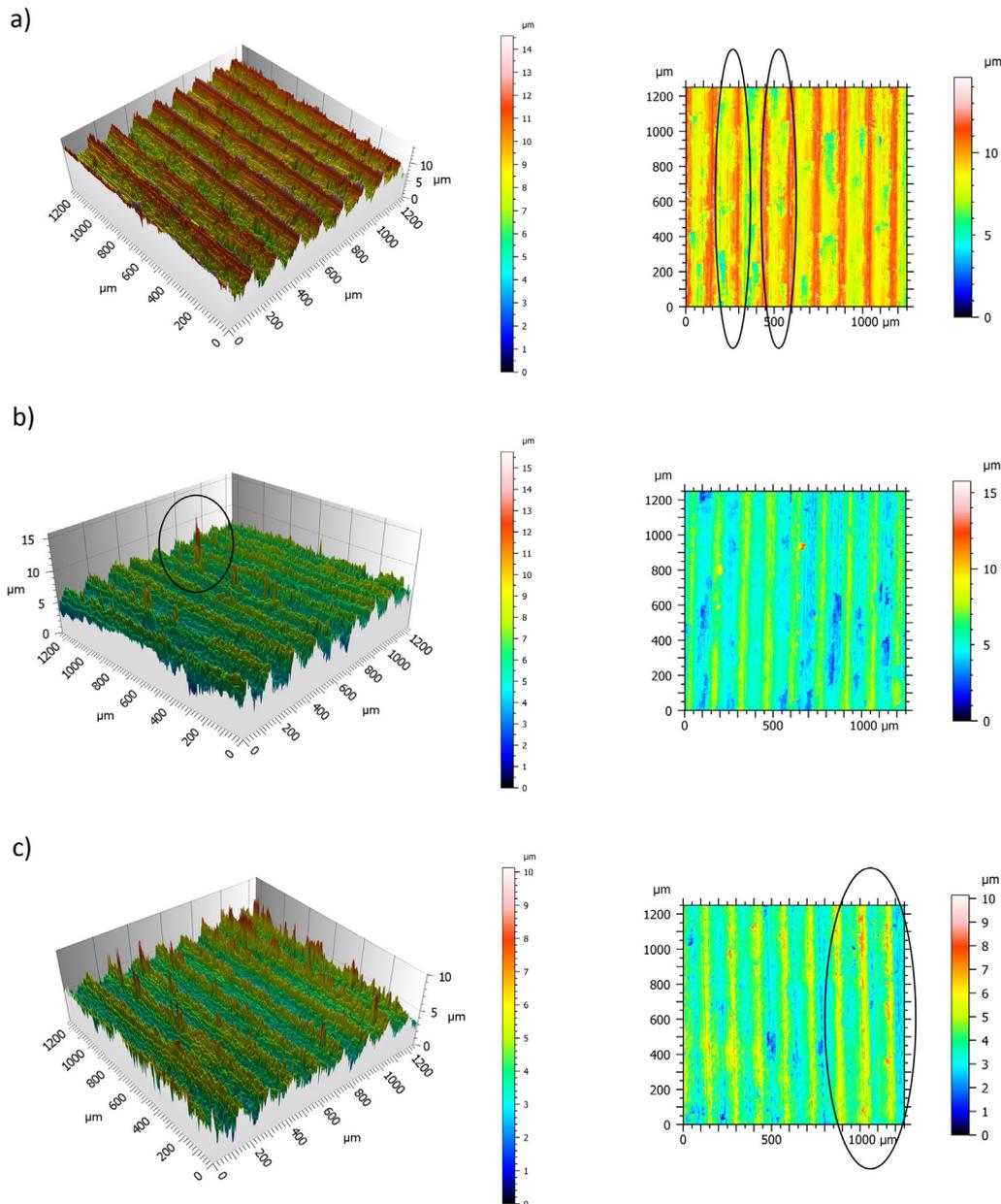


Fig. 7. Isometric view and contour map of the machined surface after turning AISI 1045 steel with cutting parameters $f = 0.15$ mm/rev, $v_c = 250$ m/min, $a_p = 0.5$ mm for insert with a coating: a) TiN, b) TiAlN, c) TiC

v_c leading to an increase in temperature in the cutting zone. Otherwise, the cutting tool may be deformed [10, 49]. For lower cutting speed v_c values, the lowest machined surface roughness, both in terms of the S_p and S_v parameters, was found for the TiAlN coated tool. The application of this coating resulted in obtaining the lowest values of the S_p parameter for lower cutting speeds, up to 225 m/min, and above this value for the TiC coated tool (the only exception was $v_c = 225$ m/min, for which the lowest surface roughness values were observed for the TiN coated tool). A similar relationship was found when considering the S_v parameter. For the cutting speed $v_c \leq 225$

m/min, the lowest value of the S_v parameter was noticed when using the tool with TiAlN coating, and above this value for the TiC coated tool. Due to the fact that the S_p and S_v parameters are influenced by single valleys or peaks formed on the machined surface [47], the obtained values indicate that (thanks to the TiC coating) the problem related to formation of peaks and pits was most effectively reduced for higher cutting speeds corresponding to finishing turning.

The isometric view and the contour map for each tested insert after turning of AISI 1045 steel in the conditions of using the average values of cutting parameters are shown in Figure 7.

When analyzing the topography of the machined surface (Fig. 7a) using an insert with a TiN coating, an even distribution of valleys and ridges resulting from the applied feed value was noticed. This surface is characterized by very high ridges and a higher average surface roughness compared to the surfaces machined with other tools. When analyzing the contour map of this surface, it was noticed that some of the ridges merge with each other, causing the irregular shape of the valleys. The surface machined with the TiAlN coated insert was characterized by wide valleys, which may be due to the increased hardness of this coating. The isometric view (Fig. 7b) also revealed a few single peaks due to deformations or vibrations resulting from the instantaneous built-up-edge [49]. The sample after turning with the TiC coated tools was characterized by the lowest surface roughness despite numerous irregular peaks. The application of this coating resulted in an even distribution of valleys and ridges on the machined surface.

In the last stage of the surface topography analysis, the material ratio curves for selected

variable values of cutting parameters were analyzed, taking into account all applied coatings, which allowed for obtaining information on the surface unevenness and its operational properties. The shape of the material ratio curve depends mainly on the shape of the surface topography and is an important tool for describing the surface texture in combination with the amplitude density distribution histogram. The histogram shows the point distribution density in the analyzed surface roughness profile. Figure 8 shows the material ratio curves of the machined surfaces formed during turning with tested tools. All analyzed curves are characterized by a degressive-progressive shape. The analyzed surfaces are characterized by an even distribution of the material over the surface with a slightly more concentrated distribution of amplitude density for the TiN coated tool. The shape of this surface is closer to the surface after grinding, without excessive peaks on the surface. Surfaces made with tools coated with a TiAlN and TiC coatings are characterized by the densities of point distributions in the analyzed profile, less concentrated on average values.

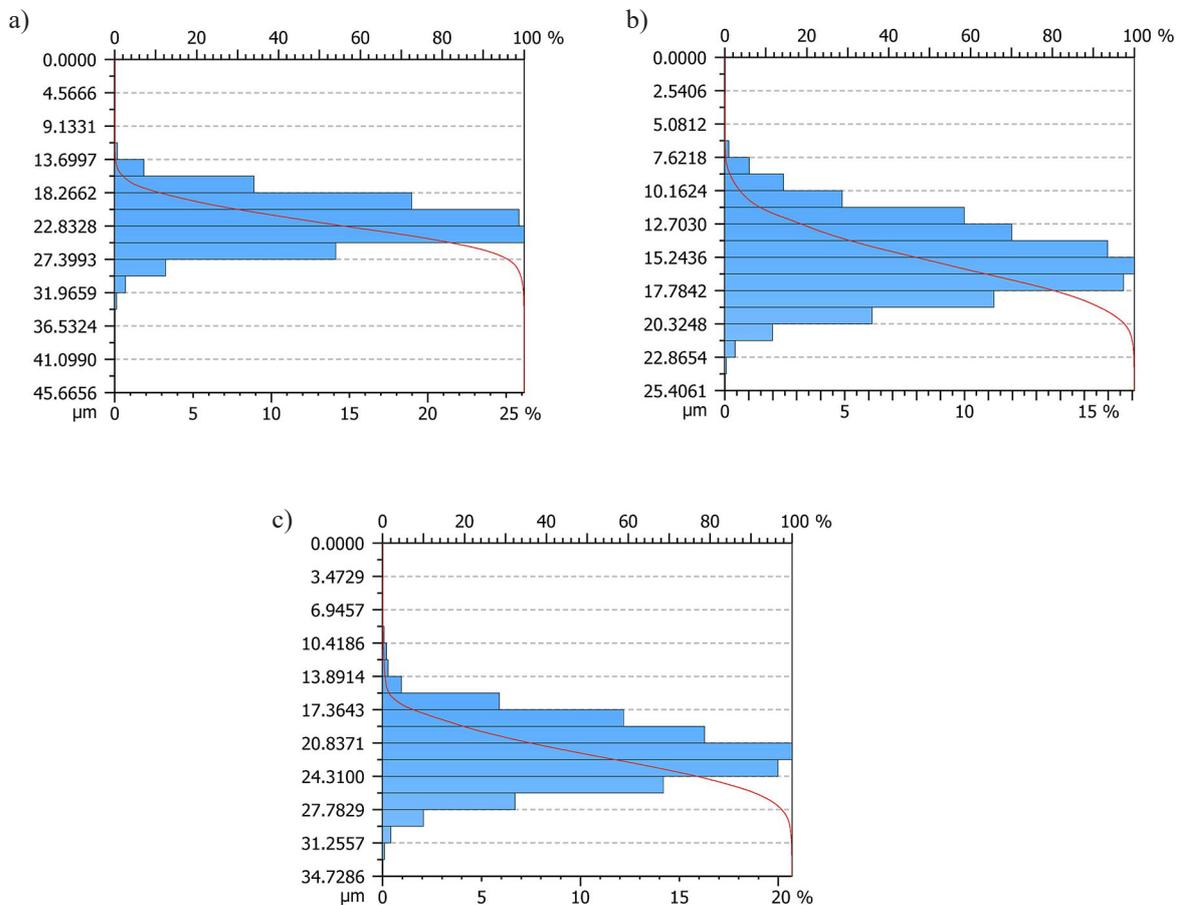


Fig. 8. Material ratio curves of the surfaces after turning with cutting parameters $f = 0.15$ mm/rev, $v_c = 250$ m/min, $a_p = 0.5$ mm and tools with coatings: a) TiN, b) TiAlN, c) TiC

CONCLUSIONS

The conducted research allowed for a detailed analysis of the surface topography of the AISI 1045 steel machined with the use of three cutting inserts diversified in terms of coatings and taking into account variable cutting parameters. The test results allow the selection of the appropriate type of coating and cutting parameters in order to obtain a machined surface with a highest quality. The results obtained for the following coatings were summarized and on this basis the following conclusions were formulated:

- The use of TiC coating on sintered carbide inserts affects the reduction of machined surface roughness in the range of higher cutting speeds ($v_c > 225$ m/min) and higher feeds ($f < 0.15$ mm/rev). The TiAlN coating is used for machining of AISI 1045 carbon steel in the range of the lowest feed values ($f > 0.15$ mm/rev) and lower cutting speeds ($v_c \leq 225$ m/min).
- The use of titanium-based coatings for cutting inserts can be employed for a formation of surface topography with evenly distributed valleys and peaks. The TiN coating as the lowest hardness coating enabled the obtainment of machined surface with a contour map characterized by the wide ridges, while the use of a harder TiAlN coated tool showed the formation of wide valleys on the machined surface. The surface machined with the hardest TiC coated tool, despite a few irregular peaks, was characterized by the most even distribution and the lowest surface roughness.
- The values of the Sa parameter affect the material ratio curve, contributing to the concentration of ordinates, which was observed during cutting with the TiC coated insert at a slightly higher cutting speed. This indicates an improvement in the operational suitability of the obtained machined surface.
- In order to obtain a higher quality of the machined surface during turning of AISI 1045 steel in conditions consistent with the test, it is recommended to use a TiC coated tool for the feed value not exceeding 0.15 mm/rev and cutting speed above 225 m/min.

Subsequent research will be devoted to the study of the impact of the type of selected cutting edge coatings on the tool wear and parameters of the machined surface integrity. The authors will determine the influence of coatings on the

microhardness of AISI 1045 steel and the stresses in the surface layer. The cycle of these tests will allow for a detailed analysis of the use of the type of coating when turning the selected carbon steel, both in terms of tool wear and obtaining the appropriate properties of the surface layer and the corresponding range of cutting parameters.

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