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Grinding Tungsten Carbide Used for Manufacturing Gun Drills

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This paper presents a study of grinding cemented carbide DK460UF (91 % WC and 9 % Co), a material used to produce cutting tools with solid cutting edges. The aim is to establish the manufacturing conditions that lead to high surface quality. A model of the main factors that influence the grinding process is presented first. Following that, grinding wheel wear and surface roughness are analysed. Grinding wheel wear is studied in experimental conditions under which small diameter gun drills were sharpened with two diamond grinding wheels of different grain sizes. Finally, the wear curve can be made. The "G ratio" is used to characterise the performance of the grinding process. Next, the experimental research examines how independent parameters, depth of cut, feed, grit, and speed influence roughness. The influence of the grinding wheel wear on roughness is also studied. The aspect of ground surfaces is examined by using a scanning electron microscope (SEM). The experimental study allowed the determination of the required grinding wheel grit (46 µm) and the optimum processing parameters (depth of cut ap = 0.01 mm, feed = 0.005 mm/rev, cutting speed v = 55 m/s) to obtain the imposed surface roughness for cutting tool surfaces (Rz = 0.3 µm). The maximum allowed radial wear (Δr) of the grinding wheel is 30 µm.

Keywords: tungsten carbide, grinding, grinding wheel, roughness, grit, wear

Highlights

- *The research is focused on analysing the grinding process of the cemented carbide DK460UF (91 % WC and 9 % Co), a material used to produce cutting tools with solid cutting edges.*
- *A theoretical study is conducted to detect the main factors that influence the quality of surfaces.*
- *An experimental analysis of tool wear is done.*
- *An experimental study of the roughness obtained by grinding under different cutting conditions is done.*
- *Optimal grinding parameters and maximum admissible wear of the grinding wheel necessary for obtaining the desired roughness are revealed.*

0 INTRODUCTION

Grinding is a highly complex manufacturing process due to the stochastic nature of the active zone (composed of grains, binder, and pores) and, because of the large numbers of parameters, it influences the surface quality and material removal rate, which are the two main goals of this process.

An important grinding application is the sharpening of cemented carbide cutting tools. Additional features of these processes compared to other types of grinding are the following: the small surfaces to be processed, which have many edges; high surface quality; small production series; different depths of cut; and specific mechanical properties of the cemented carbides used for cutting tools. The application is important because the quality of the clearance and relief surfaces (of the cutting tool) is important for the precision of the manufactured surface and the tool life of the cutting tool.

The research focused on DK460UF tungsten carbide that consists of 91 % WC and 9 % Co. It is the main material used in twist drills, gun drills, end mills, etc.

The aim of this study was to determine the optimum manufacturing parameters that lead to the desired surface quality.

1 STATE OF THE ART

Given its importance, the grinding process has been the subject of many investigations. In his book [1], Shaw presents the first grinding models developed in the 1990s.

Currently, a large range of models are being developed. Some of them are physically focused. In this category, we include the fundamental analytical models, the kinematic, finite element method, regression and molecular dynamics. Empirical process models include regression and artificial neural models. The last category comprises the rule base models, which are heuristic [2].

Kinematic models explain the grinding mechanisms, the parameters involved in this process, and their interdependence.

Fig. 1 shows an original cumulative model of the main elements influencing the grinding process and the logical interaction between them.

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Starting from them, force models (which allow the prediction of wheel wear and the estimation of grinding energy) can be developed.

Using the previous models (wheel topography, chip thickness, and forces), the surface roughness can be predicted.

The grinding force model is the starting point for an energy model of the process. The grinding energy model allows the development of the temperature model, which is the starting point for the wear model as well as for the surface integrity model. In Fig. 1, it can be observed that a model of the processed surface quality can be generated starting from the tool wear model (grinding wheel).

The first kinematic models were developed by Law and Wu [3], using two-dimensional grain models. Three-dimensional models were developed by Chen and Rowe [4], Gong et al. [5], Inasaki [6], Koshy et al. [7], and Zhou and Xi [8].

High carbide hardness requires processing with diamond grinding wheels [9]. Increasing material volume and cutting depth causes an increase in grinding wheel wear. To obtain a low rate of grinding wheel wear we can use larger diameter discs. Depreciation is lower if the number of active grains on the wheel circumference is higher [10].

The problem of grinding wheel wear has been the subject of numerous analyses of the factors that accelerate the occurrence of this phenomenon. Knowing the process elements that enhance wear, it is important to monitor the behaviour of the grinding wheel during processing [11]. Some researchers have shown that wear depends on the length of contact between the wheel and the surface to be manufactured, the pressure in the contact area, and cutting forces [12]. More specific aspects related to wheel wear grinding cemented carbides were presented by Liu et al. [13].

Binder hardness connecting diamond abrasive grains and binder material porosity is relevant in determining the wheel's capacity to grind. Porous grinding wheels demonstrated a greater capacity than conventional abrades and are easier to balance and recondition. Grinding capacity increases if fine abrasive grains are used [14].

The structure of a complex model that allows predicting the output parameters of the grinding process (roughness, presence of defects and processing accuracy) was shown by Shipulin [15].

Chen et al. [16] studies roughness when specific areas (gears) are ground. Application and development of a highly efficient abrasive process were presented by Wang and Li [17].

The state of the art related to regression grinding models shows that general studies were conducted. More information is needed on the grinding of very hard material, specific application (such as the grinding of carbides for cutting tool manufacturing) and grinding without lubricant [16].

Based on previous research, this paper aims to determine surface roughness for the tungsten carbide gun drills (less frequently studied) in terms of different cutting conditions, using different grinding wheel grit and taking into account the grinding wheel wear.

There is a special case of sharpening small diameter deep hole drilling tools. In this case, grinding wheel wear increases considerably due to the existence of many surfaces and edges on the drilling

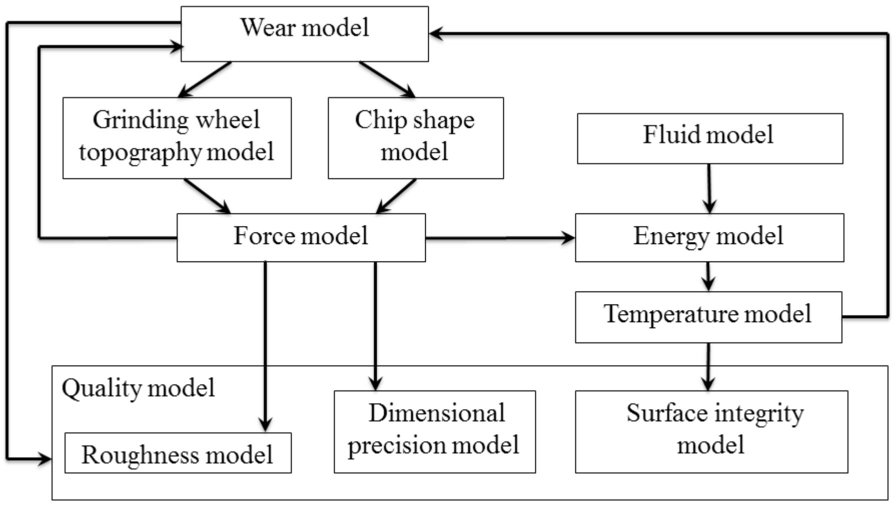


Fig. 1. *Grinding kinematic models*

tools. These surfaces and edges cause shocks when the cutting edges enter into the chips.

2 THE GRINDING MODEL

Grinding is a complex process influenced by many factors, a model of which is presented in Fig. 2.

First, the model establishes the framework in which the manufacturing process will take place. This refers to the work piece, machine tool, cutting tool, and coolant-lubrication.

The work piece material is characterised by size, shape, general mechanical proprieties, and the degree of elastic recovery after the tool crosses. The technological system refers to the machine tool and grinding wheel. The technical characteristics and manufacturing system stiffness are important to be known. The presence and nature of the coolant-lubrication fluid are also of great importance.

The input parameters are the cutting parameters. For grinding, these are feed, depth of cut, and speed. These values depend on the manufacturing material, imposed quality surface, etc.

The optimization of these parameters is the aim of most grinding studies. The grinding optimisation can be done only through the understanding of the physical processes that accompany the grinding. These are chip removal, cutting forces, vibrations, noise, consumed power in the cutting process, energy, the temperature of the wheel and of the manufactured material, and grinding wheel wear. Most of these phenomena can be modelled kinematically, by the Finite Element method, and/or experimentally.

Grinding is a finishing operation. The most important output parameters are those that describe the surface quality.

The removal rate and the costs associated with the process are also important and must be taken into account. The study refers to the grinding process of the active surfaces of the gun drills made from tungsten carbide DK460U.

The tool life of cutting tools made of cemented carbide is greater when the active surface roughness is low. The machined surfaces are small and have varied geometries (active surfaces of the cutting tools). The production batch number is small. These issues make kinematic modelling more difficult. Therefore, we have chosen to conduct an experimental analysis concerning both grinding wheel wear and the roughness of the cemented carbide surfaces.

3 EXPERIMENTAL RESEARCHES

The present study is aimed at optimising the manufacturing parameters of DK460UF tungsten carbide, processed with diamond abrasive grinding wheels to obtain a high quality of the processed surface.

This material is a hard metal (or cemented carbide) with 91 % WC and 9 % Co, which is the

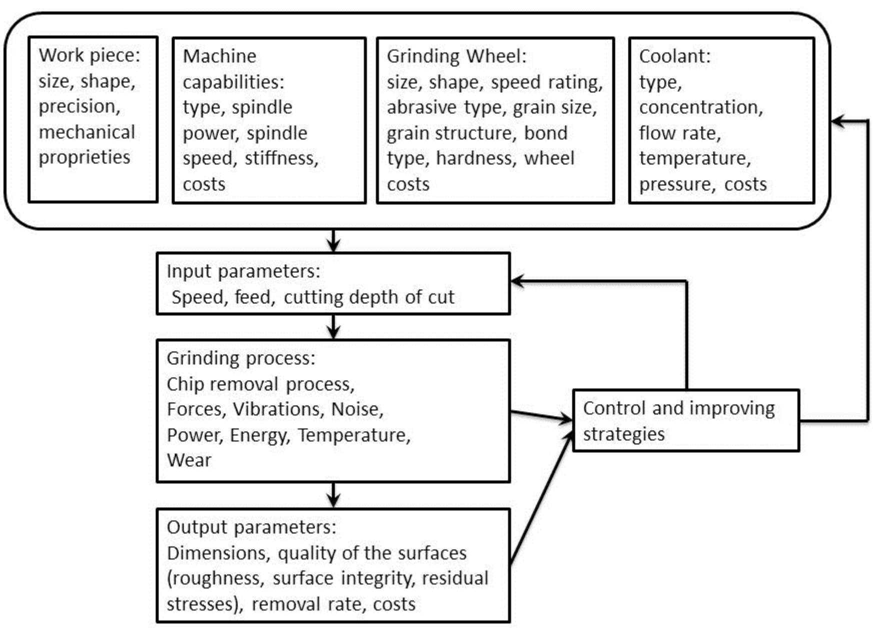


Fig. 2. *Grinding model*

main material currently used in cutting tool with solid cutting edges (drills, end mills, etc.). Some characteristics of this material are the grain size of 0.5 µm and the hardness of 1620 HV [18].

To do this, we carried out:

- an experimental analysis of tool wear (diamond grinding wheel);
- an experimental study of the roughness obtained by grinding under different cutting conditions using diamond abrasive grinding wheels that have various grit and wear degrees.

Previous research showed that the processing of these cemented carbides can be done with diamond abrasive wheels. In this study, diamond grinding wheels with 46 µm and 54 µm grit have been used (these are the most common grits used for processing hard metal cutting tools). The diameters of the grinding wheels are D = 180 mm and D = 150 mm, and the width 10 mm.

3.1 Experimental Research on Grinding Wheel Wear

The first study refers to grinding wheel wear. There are three distinct mechanisms relating to this wear: grain breaking, binder breakage and attrition of the grain. Wheel profile wear develops as a result of the friction between abrasive grains and the processed surface. As the worn area increases, the sliding forces increase and, therefore, will develop more heat, affecting the quality of the processed surface.

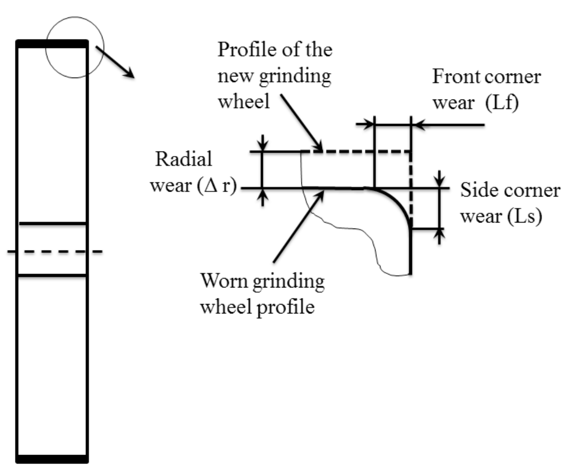


Fig. 3. *Grinding wheel wear*

The global wear of the grinding wheels is very important for this study and, therefore, we have used an experimental analysis in this case. The main parameters that estimate the grinding wheel wear are shown in Fig. 3:

- radial wear (Δr);
- side corner wear.

The grinding wheel wear was monitored in the process of sharpening the gun drills for small diameters (within the range 2.025 mm to 2.5 mm).

Gun drills were sharpened on a Walter Helitronic Minipower Machine grinding tool, shown in Fig. 4. The cutting environment was an emulsion of water and 5 % oil Petrofer superfin at 1 MPa pressure (suitable for grinding high-quality surfaces with diamond grinding wheels).

Fig. 4. *Helectronic mini power grinding machine*

Fig. 5. *Walter Helicheck Basic, optical CNC measuring machine*

Every gun drill was processed on five different surfaces to obtain the active tool surfaces.

The grinding parameters were the following: depth of cut: 0.01 mm; feed rate: 0.005 mm/rev; and speed: 55 m/s.

The average depth of the removed layer on the active cutting tool surfaces is 0.3 mm. The average volume removed for a gun drill is 1.02 mm³.

The grinding wheel wear was measured after processing each group of 100 work pieces. With a grinding wheel of 46 µm grit (D46 type), a total of 1058 gun drills were manufactured; 876 gun drills were processed with a grinding wheel type D54. After the sharpening of these gun drills, the corresponding

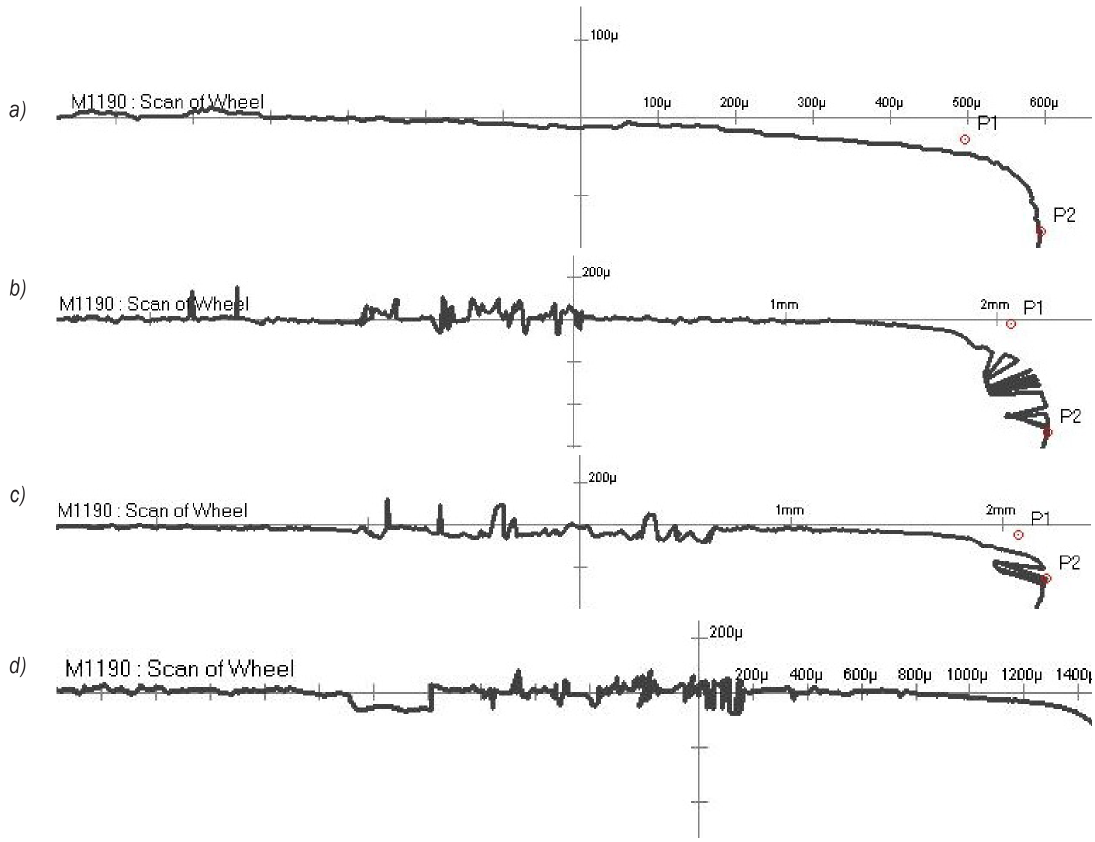


Fig. 6. *Grinding wheel profiles with 54 μm grit a) unused wheel; b); c) and d) grinding wheel after sharpening of 300, 600, 800 gun drills*

Table 1. *Grinding wheel wear in the sharpening process of gun drills*

Number of sharpened gun drills	Material removed volume [mm^3]	Grinding wheel with grit of 46 μm		Grinding wheel with grit of 54 μm	
		radial wear [μm]	edge wear [μm]	radial wear [μm]	edge wear [μm]
0		0.00	0	0.00	0
100	102	5.24	27.04	7.75	32.56
200	204	8.30	43.16	11.50	43.52
300	306	16.34	115.23	21.75	92.53
400	408	28.56	167.81	32.20	138.56
500	510	43.12	224.57	48.80	227.82
600	612	54.76	281.32	64.20	337.86
700	714	68.05	351.71	90.30	469.63
800	816	79.37	408.73	115.00	587.79
900	918	93.17	482.52		
1100	1122	112.4	568.34		

grinding wheels reached the catastrophic wear. Catastrophic wear was considered for a radial wear of 0.1 mm.

The grinding wheel wear measurement was performed on a Walter Helicheck Basic Optical CNC measuring machine, shown in Fig. 5.

Fig. 6 presents the wear of the grinding wheel profile for a wheel of D 54 grit, after processing 0, (the disc is new) 300, 600 and 800 work pieces. Radial wear was measured on the same Walter Helicheck Basic, Optical CNC measuring machine. Table 1 and Fig. 7 show the results of these measurements. By analysing wear curves, we observed that grinding wheels with greater grit wear out faster. Larger granules fracture and pull out more easily than smaller ones because granule density is lower, so the cutting force is distributed on a smaller number of granules and the force to which granules are subjected is higher. In contrast, due to the size of the largest granules, a higher bending moment develops on each granule, leading to a more probable fracture and pulling out of the granule.

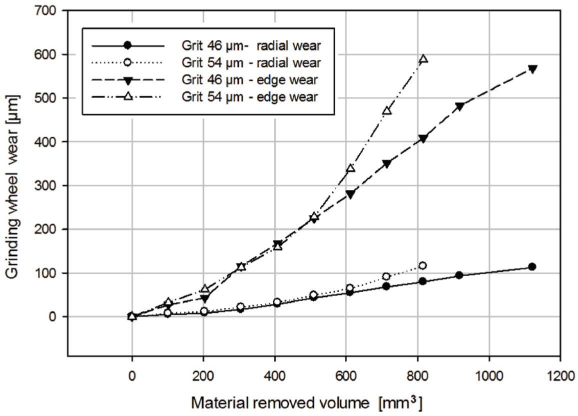


Fig. 7. *Grinding wheel wear*

An important parameter in the grinding process is the grinding ratio (*G-ratio*), which is simply a ratio comprising the volume of the work piece material removed and the volume of the grinding wheel expanded (volumetric wheel wear).

$$G-ratio = \frac{Material\ removed\ volume}{Volumetric\ wheel\ wear}. \quad (1)$$

In the technical literature, there is some information about the *G-ratio* values. For the processing of ferrous materials, the *G-ratio* can vary from 20:1 to 80:1 [19]. In the experiments done by Izumi [20] on heavy grinding of large surfaces, the grinding ratio varied between 6.5 and 10. In difficult-to-grind materials operating under adverse conditions, the *G-ratio* may drop to 1 [21]. High grinding wheel performance is characterized by greater values of the *G-ratio*. Because of the small machined surfaces and numerous edges, one hypothesis for our experimental study is that the G-ratio values will be small.

Table 1 indicates the values of the volume of material removed. These have been computed starting from the average removed volume for one gun drill multiplied by the number of processed tools.

The removed volume for one gun drill has been computed with the relation:

$$V_{ri} = S_i \cdot A, \quad (2)$$

where V_{ri} is the removed volume for one gun drill, S_i the active surface processed for one gun drill, and A the average depth of the removed layer.

In our study, the average of the removed volume for one gun drill was 0.034 mm³.

Volumetric wheel wear is defined with the relation:

$$V_W = \pi \cdot D \cdot \Delta r \cdot B, \quad (3)$$

where V_W is the volumetric wheel wear, D grinding wheel diameter, Δr radial wear, and B grinding wheel width.

In our study, the size of the grinding wheel was D =150 mm and B = 10 mm.

Table 2 and Fig. 8 show the grinding ratio in the grinding process using wheels with two grits.

The study shows that the *G-ratio* decreases as the grinding wheel wear increases. With worn grinding wheels, the number of cutting peaks decreases because part of the granule edges become blunt, some break and others are pulled apart. Because of clogged pores and damaged edges, the friction between the blank and the grinding wheel increases. Both these phenomena decrease the efficiency and the *G-ratio*.

In this study, *G-ratio* values are generally low, which shows that the processing of these cemented carbide tools (with many small surfaces) is more difficult than the grinding of large areas. The grinding wheel that processes small surfaces is subject to more input shocks than large surfaces. This causes a more pronounced wear.

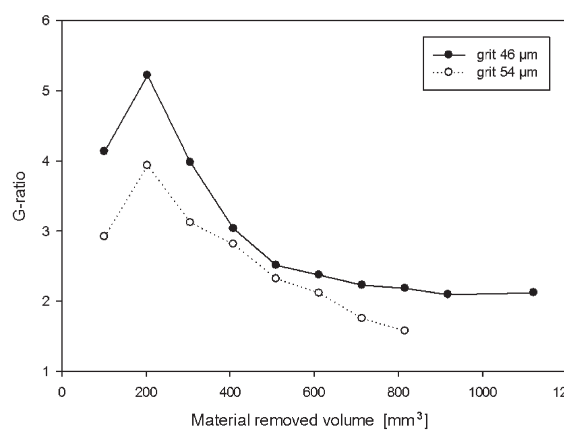


Fig. 8. *G-ratio*

Furthermore, it can be observed that the G-ratio is greater for lower grit values because grinding wheels with lower grit wear less than those with higher grit, as described before. That means that the process is more efficient. Therefore, from the point of view of

Table 2. *Grinding ratio*

Material removed volume [mm³]	Grinding wheel with grit of 46 μm - radial wear [μm]	Grinding wheel with grit of 54 μm - radial wear [μm]	Volumetric wheel wear for grit of 46 μm [mm³]	Volumetric wheel wear for grit of 54 μm [mm³]	*G-ratio* for grit of 46 μm	*G-ratio* for grit of 54 μm
0	0.00	0.00	0	0		
102	5.24	7.75	24.68	34.96	4.13	2.91
204	8.30	11.50	39.09	51.86	5.21	3.93
306	16.34	21.75	76.96	84.56	3.97	3.12
408	28.56	32.20	134.52	122.67	3.03	2.81
510	43.12	48.80	203.09	188.51	2.51	2.70
612	54.76	64.20	257.91	289.54	2.37	2.11
714	68.05	90.30	320.51	407.25	2.22	1.75
816	79.37	115.00	373.83	518.65	2.18	1.57
918	93.17		438.83		2.09	
1122	112.4		529.40		2.11	

sustainability, grinding wheels with smaller grits are more desirable.

3.2 Experimental Study of Surface Roughness

Surface roughness, an indicator of surface quality, is one of the most specified requirements in machining parts. Surface roughness influences not only the dimensional accuracy of machined parts but also their properties.

Based on the theoretical research presented at the beginning of this paper, it was found that the main parameters that indirectly influence the roughness are the grinding wheel grit, feed rate, depth of cut, and grinding speed.

In order to analyse the influence of these parameters on roughness, the following experimental studies have been carried out:

- A 2^4 factorial experiment that has grinding wheel grit, speed, feed, and depth of cut as independent parameters when machining with a new disc;
- Using an optimal regime from the point of view of roughness, several samples have been manufactured with grinding wheels with the wear presented in Table 1. As a result, the influence of the grinding wheel wear on the roughness has been outlined.

3.2.1 Experimental Study About the Influence of Grinding Wheel Grit, Speed, Feed, and Depth of Cut on the Surface Roughness

The main factors influencing the roughness are the grinding wheel grit, the depth of cut, the feed, and the speed. In this application, the influence on these four factors on the roughness of the ground surface was investigated. The "design of experiments" methodology was used. The units and settings on the low and high levels of these factors are presented in Table 3. The experimenter measured the surface roughness (Table 4).

Table 3. *The four varied factors*

Name	Abbr.	Unit	Settings
depth of cut	a_p	[mm]	0.01 to 0.03
feed	f	[mm/rev]	0.005 to 0.008
speed	v	[m/s]	40 to 55
grit	$grit$	[μm]	46 to 54

Table 4. *The measured response parameters*

Name	Abbr.	Unit
Roughness Ra	R_a	[μm]
Roughness Rz	R_z	[μm]

Table 5. *The low and high level of the investigation parameters*

Parameter	low	high
Grinding wheel grit	46 μm	56 μm
Depth of cut	0.01 mm	0.03 mm
Feed	0.05 mm/rev	0.08 mm/rev
Speed	40 m/s	55 m/s

The goal is to establish the values of the input factors that determine the minimum value for the response parameters (roughness).

The manufacturing process has been performed on DK460UF tungsten carbide rectangular blocks samples of 20 mm × 50 mm × 100 mm. The independent variables include grinding wheel grit, feed, depth of cut, and speed. The diamond grinding wheels were new (without wear). The grinding

Table 6. *Roughness obtained by processing tungsten carbide DK460UF with diamond abrasive grinding wheels D46VB4P/A and D54VB4P/A*

	Grinding wheel grit [μm]	Depth of cut a_p [mm]	Feed f [mm/rev]	Speed v [m/s]	Roughness R_a [μm]	Roughness R_z [μm]
1	46	0.03	0.005	40	0.126	0.504
2	46	0.03	0.005	55	0.113	0.452
3	46	0.03	0.008	40	0.142	0.568
4	46	0.03	0.008	55	0.132	0.532
5	46	0.01	0.005	40	0.063	0.290
6	46	0.01	0.005	55	0.057	0.228
7	46	0.01	0.008	40	0.084	0.328
8	46	0.01	0.008	55	0.077	0.316
9	54	0.03	0.005	40	0.139	0.572
10	54	0.03	0.005	55	0.128	0.512
11	54	0.03	0.008	40	0.156	0.645
12	54	0.03	0.008	55	0.150	0.597
13	54	0.01	0.005	40	0.072	0.342
14	54	0.01	0.005	55	0.065	0.276
15	54	0.01	0.008	40	0.095	0.381
16	54	0.01	0.008	55	0.087	0.362

process was done on a CNC machine tool Hawemat 3000, with high stiffness.

The roughness study has been performed on rectangular block samples of 20 mm × 50 mm × 100 mm made from the same material. The cutting environment was the same emulsion (Petrofer Superfin) used in the previous research. Surface roughness was measured with a Mitutoyo Roughness Meter.

The low and the high investigation level of the input parameters are presented in Table 5. The plan of the experiments is presented in Table 6. The first varied factor was the grinding wheel grit; the second was the depth of the cut, the third the feed and the fourth the speed.

The mathematical model (that can draw conclusions on the quality of the processed surface, depending on the grinding wheel grit and cutting regime) was obtained by using the Design Expert software. The linear polynomial regression has been chosen as the mathematical model.

The obtained relations for roughness are the following:

$$R_a = -0.0484 + 3.0375 \cdot a_p + 6.6667 \cdot f + \\ +1.5313 \cdot 10^{-3}\, grit - 5.6667 \cdot 10^{-4} \cdot v, \qquad (4)$$

$$R_z = -0.2179 + 11.98 \cdot a_p + 20.625 \cdot f + \\ +8.047 \cdot 10^{-3}\, grit - 2.54 \cdot 10^{-3} \cdot v. \qquad (5)$$

The adequacy of the roughness models has been based in the ANOVA analysis.

The “F value” is a test for comparing treatment variance with error variance. “Prob > F” is the probability of the observed “F_{value}” if the null hypothesis is true. Generally, if “Prob > F”< 0.05, then the model is statistically significant. If “Prob > F” > 0.1, then the model is not significant.

In the R_a roughness model, the computed “F_{value}” is 716.1. “Prob > F” of 0.00012 shows that the model is significant. There is only 0.01 % chance for the R_a value to be modified due to random noise.

Table 7. *Testing the significance of roughness factors in the R_a model and R_z model*

	R_a model		R_z model	
	F_{value}	Prob > F*	F_{value}	Prob > F*
Factor(depth of cut ap)	2451.10	0.00003 ⟶ significant	639.18	0.0002 ⟶ significant
Factor(feed f)	265.66	0.00005 ⟶ significant	42.62	0.00087 ⟶ significant
Factor (grit)	99.66	0.00007 ⟶ significant	46.13	0.000160 ⟶ significant
Factor (speed v)	47.98	0.000008 ⟶ significant	16.18	0.002 ⟶ significant

Similarly, the R_z roughness model is analysed. “Prob > F” is 0.00014 and shows that the R_z roughness model is also significant.

For the two roughness models, the significance of the factors was tested. The results are shown in Table 7.

The values of “Prob > F” that are less than 0.05 indicate that model factors are significant. Model factors are not significant if “Prob > F” values are greater than 0.1000.

After computing the model coefficients and after carrying out the factor analysis, it has been found that the depth-of-cut factor, feed factor, grit factor, and speed factor (in this order of importance) influence both surface roughness parameters.

Surface roughness values rise as the depth of cut increases. When the depth of cut is large the contact angle between the grinding wheel and blank increases. The granule number increases; the cutting forces and temperature are higher. The growth of the cutting forces determines higher variations of the force, of the depth of cut and vibration, which all increase roughness. Surface roughness can decrease if the depth of cut is reduced when using grinding wheels with small grains.

The feed is a very important parameter that influences surface roughness. When the feed increases, the distances between traces generated by the granules on the blank grow and cause an increase in roughness.

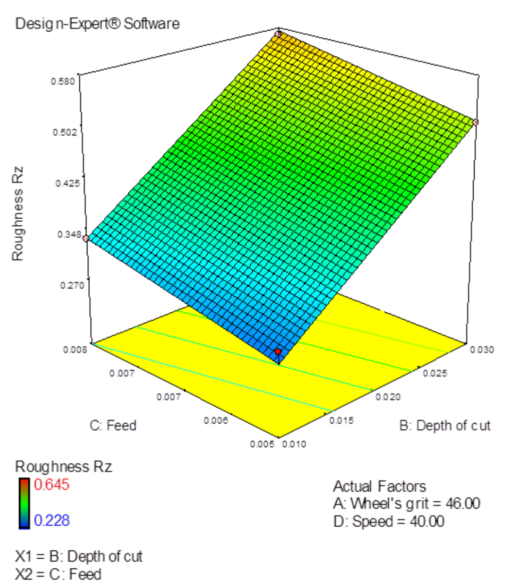
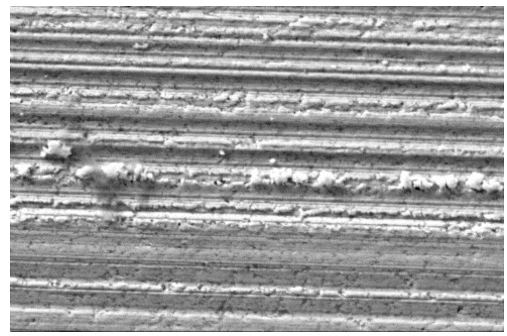


Fig. 9. *Roughness R_z depending on feed and depth of cut*

The grinding wheel grit has a significant influence on surface roughness. When the granules of the grinding wheel are bigger, their traces are fewer and larger so that roughness increases.

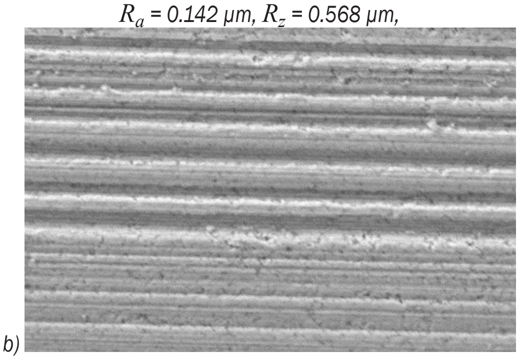
Grinding speed has little effect. An increase in speed causes a small decrease in roughness because plastic deformation is easier.

For a better visualization of the influence of feed and depth of cut on the surface roughness R_a and R_z, their variation curves have been plotted (Fig. 9).

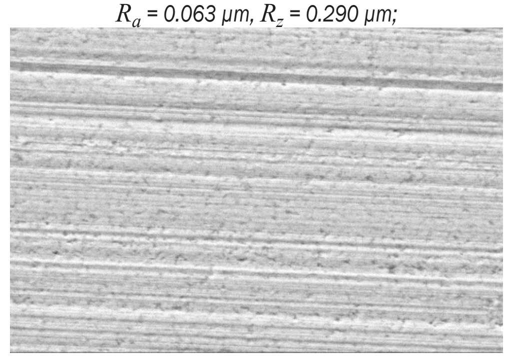


a) a_p = 0.03 mm, f = 0.008 mm/rev, v = 40 m/s, R_a = 0.142 μm, R_z = 0.568 μm,

b)



b) a_p = 0.01 mm, f = 0.005 mm/rev, v = 40 m/s, R_a = 0.063 μm, R_z = 0.290 μm;



c) a_p = 0.01 mm, f = 0.005 mm/rev, v = 55 m/s, R_a = 0.057 μm, R_z = 0.228 μm

Fig. 10. *Grinding surfaces obtained by processing with a grinding wheel in good condition, with 46 μm grit and with different cutting parameters*

The ground samples were examined with the scanning electron microscope (SEM). The surface images complete the information obtained by measuring the roughness. Some of them are shown in Fig. 10.

Roughness analysis and SEM observations of the machined surface have indicated that a surface with good roughness was achieved for cutting parameters, v = 55 m/s, f = 0.005 mm/rev, a_p = 0.01 mm. Grit of 46 µm is indicated to be used in order to obtain a maxim roughness of 0.3 µm.

3.2.2 The influences of Wheel Wear on Manufactured Surface Roughness

Surface quality is also influenced by grinding wheel wear. To analyse the influence of grinding wheel wear on roughness, an optimum cutting set of parameters obtained in the case of unused grinding wheels has been considered. This consists of a_p = 0.015 mm, f = 0.005 mm / rev, and v = 55 m/s.

Processing was performed within this cutting regime with grinding wheels D46 and D54, with successive wears presented in Table 1 and in Fig. 7. It can be seen that the grinding wheel with greater grit wears out more quickly than the one with smaller grit and causes greater roughness of the manufacturing surfaces (Table 8 and Fig. 11). Wear changes the grinding wheels cutting geometry. Granule edges become blunt, some granules break, and pores become clogged. These phenomena cause increased friction, which decreases roughness. Furthermore, because grinding wheels are sharpening various surfaces of complex shapes, the disc loses its cylindricity, which also causes the roughness to increase.

The samples processed by worn grinding wheels were also examined by scanning electron microscope. Fig. 12 shows the some images of the samples processed with grinding wheels with various wear forms. SEM observations indicate that the surfaces' roughness is improper. Each wear form causes major defects on the processed surfaces.

For the previously established optimum cutting parameters, a grinding wheel with maxim grit of 46 µm can be used to obtain a maximum roughness of R_z = 0.3 µm. For this grit, the maximum allowed radial wear Δr is 30 µm.

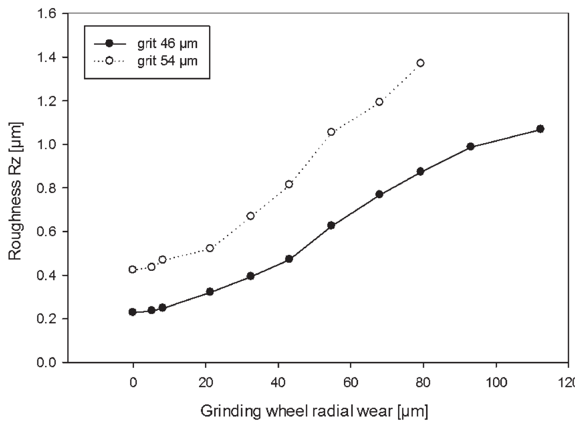


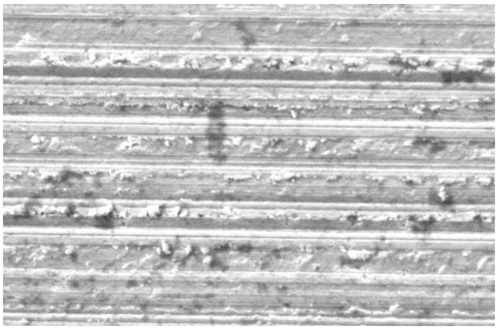
Fig. 11. *Roughness obtained by processing with grinding wheel having different levels of wear*

4 CONCLUSIONS

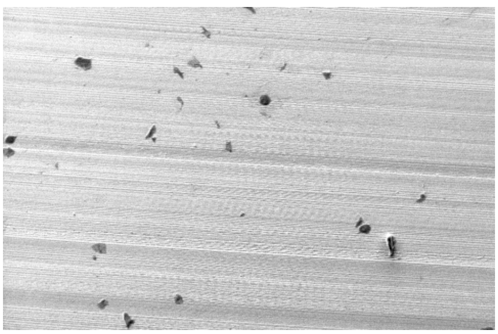
The optimization of the grinding process of tungsten carbides used for cutting tools is important because their active surfaces require certain quality characteristics. The higher surface quality of cemented carbide tools lead to easier chip removal and hence the tool life is greater. The maximum allowable active surface roughness is R_z = 0.3 µm.

Table 8. *Roughness depending on grinding wheel wear (manufacturing parameters: a_p = 0.015 mm, f = 0.005 mm/rev, v = 55 m/s)*

Number of sharpened gun drills	Grinding wheel with grit of 46 µm		Grinding wheel with grit of 54 µm	
	Radial wear [µm]	Roughness R_z [µm]	Radial wear [µm]	Roughness R_z [µm]
0	0.00	0.228	0.00	0.423
100	5.24	0.236	7.75	0.435
200	8.30	0.248	11.50	0.468
300	16.34	0.321	21.75	0.520
400	28.56	0.393	32.20	0.668
500	43.12	0.471	48.80	0.814
600	54.76	0.625	64.20	1.054
700	68.05	0.768	90.30	1.192
800	79.37	0.873	115.00	1.370
900	93.17	0.987		
1100	112.4	1.068		

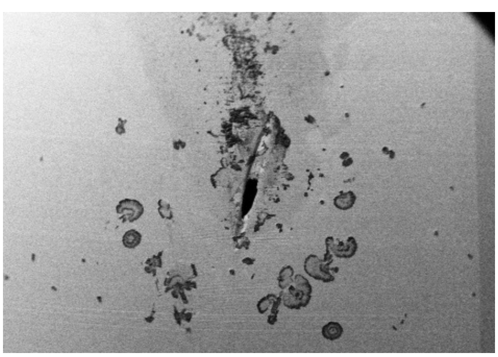


a) Grinding wheel D46VB4P/A with the grit of 46 μm, worn profile of grinding wheel, Δr = 34.75 μm, a_p=0.03 mm, f = 0.008 mm/rev, v=55 m/s, roughness R_z = 1.192 μm. Radial wear of the grinding wheel causes high roughness of the processed surface



b) Grinding wheel D46VB4P/A with the grit of 46 μm, clogged grinding wheel, a_p=0.01 mm, f=0.005 mm/rev, v=40 m/s, roughness R_z = 0.972 μm; the clogging of the grinding wheel causes adhesion of the removed material particles to the machined surface

c)



c) Grinding wheel D54VB4P/A with the grit of 54 μm, blunt grains, a_p=0.03 mm, f=0.008 mm/rev, v=55 m/s, roughness R_z = 0.768 μm; due to the grinding wheel wear, the friction between the work piece surface and the active surface of the grinding wheel is intense, which causes an increasing temperature in the contact area; the layer beneath the machined surface shows changes (oxidation burns)

Fig. 12. *Grinding surfaces obtained by processing with worn grinding wheels*

When sharpening carbide tools, the grinding surfaces are very small and show various geometries with multiple edges (edges of the active surfaces and of the fluid-cutting channel). For this reason, the grinding wheel is subjected to shocks penetrating that cause accelerated wear the material. The high hardness of carbides also causes accelerated wear of the disc.

The performance of the grinding process is assessed by means of the values of the G-ratio, for which it is better to have high values. There are common values of the G-ratio of 20:1 for the processing ferrous materials. By processing DK460UF tungsten carbide tools with small diameters, we obtained low values of the G-ratio between 2:1 and 5:1. It was noted that the value of the G-ratio depends on the grit of the grinding wheel and on its wearing. For the lower wheel grit (D46), a higher G-ratio is obtained. The grinding wheel wear causes a decrease in the G-ratio.

In the second part of the research, the aim was to identify the optimal values of cutting parameters that lead to the achievement of the active surface roughness required for carbide tools.

The results of the experiments allow us to obtain the optimal parameters for the grinding process from the point of view of surface quality. The optimal parameters resulting from the experimental research of the grinding process were the following: depth of cut a_p = 0.01 mm, feed f = 0.005 mm/rev, cutting speed v = 55 m/s, grit of grinding wheel = 46 μm. Under these conditions, the value of the R_z surface roughness was 0.228 μm.

The study of the roughness variation in relation to the radial wear of the grinding wheel shows that the imposed roughness R_z = 0.3 μm can be achieved only by processing with grinding wheels that have the grit smaller than 46 μm. In this case, for a D46 grinding wheel, the maximum allowed radial wear Δr is 30 μm.

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