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ANALYSIS OF SURFACE ROUGHNESS IN THE TURNING PROCESS FOR HARD METAL

Drilon Beqiri[1], Edon Bunjaku[2]
[1]University of Mitrovica, Faculty of Mechanical and Computer Engineering, Mitrovica, Kosova

ABSTRACT: In this paper, we aim to predict an optimized combination of processing parameters creating minimum force and surface roughness during turning of C45 steel with the cutting tool TOOL NAVI Cutting Conditions under dry conditions – without cooling emulsion.To achieve the expected quality of the surface must be applied different technological factors. The processing parameters, the characteristics of the material that was taken for research, the characteristics of the cutting instrument, and the machine that was worked on are important factors in the turning process.Our goal is to find the appropriate processing parameters for C45 steel with cutting process, in order to obtain the required (specified) shape, size, and surface roughness.
Keywords: *hard metal, turning process, machining parameters, surface roughness*

INTRODUCTION

Cutting processing technology, or as it is also called chip removal processing technology, is the main basis for the development of the mechanical industry, as it enables the production of mechanical details and other high-quality parts. The metal cutting process is defined as the process of removing chip from the workpiece in order to obtain a final product with the desired dimensions, shape, and roughness [1].

Obtaining the expected quality of the processed surfaces depends on a number of different technological factors, such as processing regimes, machine stability, characteristics of the working material, and characteristics of the cutting instrument. Steel machining is a challenging task [2]. In this presented research were investigated the surface roughness Rz is analyzed and presented in this paper.

The steel for research is C45 which has very good cutting ability, wear resistance, temperature stability and good physical and chemical properties. Such steels are important for the manufacturing sector.Lathe machine where the research was conducted is Type: SM-16A, 71 – 3150 r/pm.

Manufacturer: TOS TRENCIN – Galanta, Czechoslovakia. The measurement of these parameters was conducted in the laboratory of the Faculty of Mechanical Engineering with the Surface Roughness Tester SJ301 device for measuring the roughness of the processed surface. Knowing the characteristics of the material, we also made the right choice of the cutting tool [3]. The material of the cutting blade, must be with high mechanical properties, high wear and temperatures resistance, as well as other properties based on the metal processing, machining and investigation of surface roughness [4, 5, 6 and 7].

METHOD AND MATERIAL

C45 steel is a steel which has a medium carbon content and is part of the alloy steels for improvement. C45 is a medium strength steel with good machinability and excellent tensile properties, with a typical tensile strength range of 570 – 700 Mpa and Brinell hardness range of 170 – 210.

Table 2 Chemical content of C45 steel according to(DIN) Standard

DIN	C%	Si%	Mn%	Cr%	Mo%	Pmax%	Smax%
C45	0.46	0.25-0.35	0.50-0.80	<0.10	<0.40	0.045	0.045

1.2 The impact of cutting temperatures on the structure of C45 material

Cutting temperature is a key factor that directly affects cutting tools and wear, work piece surface and precision machining, according to the relative movement between the cutting tool and the work pieces. The generated amount of heat varies with the type of material used and the cutting factors, particularly the cutting speed.[8, 9 and 10].During the experimental research we also measured the temperatures during the cutting process with the Keller Cella Cast temperature measuring device.

Fig2.1Keller Cella Cast measuring temperatures during the turning process.

2.3 The cutting instrument (insert) used in the research:

For C45 steel are mainly used hard metals cutting tools. In our research, we used the cutting tool TOOL NAVI Cutting Conditions in dry conditions - without emulsion.

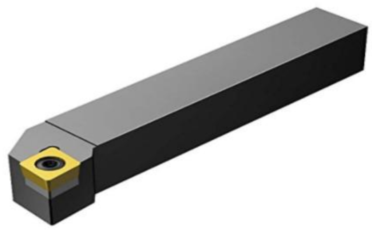

Fig2.2 tooland insert

Table2.2 Table for reading the coefficients to set the recommended speed

Work material	Soft ← (Hardness of workpiece) → Hard											
	120HB	140HB	160HB	180HB	200HB	220HB	240HB	260HB	280HB	300HB	320HB	340HB
P	1.34	1.19	1.08	1.00	0.92	0.85	0.80	0.75	0.71	0.68	0.64	0.61
M	1.41	1.23	1.10	1.00	0.91	0.85	0.78	0.72	0.68	0.64	0.61	0.58
K	1.27	1.19	1.09	1.00	0.97	0.91	0.88	0.85	0.81	0.78	0.75	0.72

By multiplying the coefficient value by the recommended cutting speed, you use to calculate a new cutting speed: 310x0.88= 272.8 r/min.

2.4 Lathe machine used for workpiece processing

Lathe specifications:**Type:** SM-16A/ 71 – 3150 rp/min.**Manufacturer:** TOS TRENCIN – Galant, Chechoslovakia

Fig2.3 Lathe SM-16A (FIM-Prishtinë)

2.5Processing parameters

The processing was conducted by changing the sizes of the cutting mode parameters for v, s and a.The dimensions of the workpiece for the experiment: ϴ 55 x 450 mm for C45 steel. The cutting speed and the number of rotation were taken for three levels (nmax,nmea,nmin) and the cutting speed was calculated for three levels (Vmin, Vmea, Vmax):

Table 2.3 Cuttingregime parameters used

Sizes	Cutting speed	Feed	Depth
Nr. of exp.	v [m/min]	s [mm/rr]	a [mm]
1	800	0.056	0.6
2	800	0.056	0.2
3	800	0.020	0.6
4	400	0.020	0.6
5	400	0.056	0.2
6	400	0.056	0.2
7	800	0.020	0.2
8	400	0.020	0.2
9	560	0.040	0.4
10	560	0.040	0.4
11	560	0.040	0.4
12	560	0.040	0.4

SCIENTIFIC METHOD USED FOR RESEARCH

3.1 Mathematical models:

Mathematical models use certain mathematical formulas to denote the original variables or parameters. With using of the dispersive analysis, we determine the significance of the regression coefficients.

3.2 Dispersive Analysis

With dispersive analysis, we determine the significance of the regression coefficients and the adequacy of the mathematical model.

Table 3: Dispersive analysis calculation:

Variation Source	*Degrees of freedom (fi)*	*Square sum (s)*	*Evaluation of variant (s^2)*	*Test –Fr (calculated)*
$b_0 = 1.5435$	$f_0 = 1$	28.58860	28.58860	F_{R0}= 2236.46(sig.)
$b_1 =$ -0.2031	$f_1 = 1$	0.33007	0.33007	F_{R1}= 25.8211 (sig)
$b_2 =$ -0.0465	$f_2 = 1$	0.01735	0.01735	F_{R2}=1.3571 (sig)
$b_3 =$ -0.3066	$f_3 = 1$	0.75219	0.75219	F_{R3}= 58.8432 (sig)
Residual sum	$f_R = N - K - 1$ $f_R = 12 - 3 - 1 = 8$	$S_R = 1.1812$	$S_R^2 = 0.1477$	*F_{Ri}>F_t Sepse F_t(0.05,3.1)>10.1 F_{R0}, F_{R1}, F_{R2}, F_{R3}, jane signifikant*
Errors of the experiment at the zero point	$f_E = n_0 - 1$ $f_E = 4 - 1 = 3$	$S_E = 0.0383$	$S_E^2 = 0.0127$	
The error of the whole experiment	$f_a = f_R - f_E$ $f_a = 8 - 3 = 5$	$S_a = 1.1428$	$S_a^2 = 0.2285$	
Mathematical model				*Frz = 17.881*

3.3 Roughness measuring device

Roughness measurements conducted in the Laboratory of the Faculty of Mechanical Engineering with the Surface Roughness Tester device type SJ301, manufacturer Mitutoyo (Japan).
The measured results are read digitally

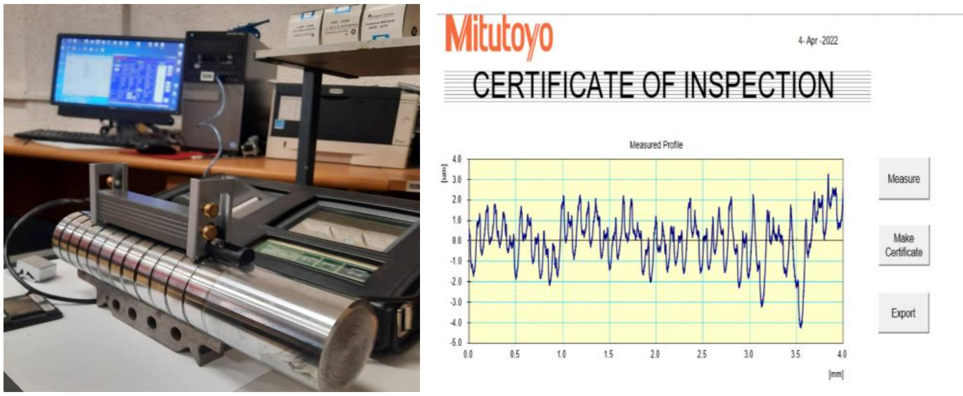

Fig3: Measurement of Surface roughness and theoretical results

3.4Experimental plan, experiment performance and measurement results for Rz

For the realization of the experiment, the plan of the three orthogonal factors experiment is set with a measurement at the points of the plan and the repetition at the zero point four times.

Table.3.1. Characteristics of the cutting regimes and the level of the code used

CHARACTERISTICS OF INDEPENDENT VARIABLES					
Nr.	*Sizes*	*Level Code*	*Maximal*	*Mean*	*Minimal*
			1	*0*	*-1*
1.	*v (m/min)*	X_1	*138.160*	*96.712*	*69.080*
2.	*s (mm/rrot)*	X_2	*0.056*	*0.04*	*0.02*
3.	*t (mm)*	X_3	*0.6*	*0.4*	*0.2*

Tab.3.2 Three-factor first-order coded matrix plan

Nr.	*Coding levels*				$R_z[\mu m]$	$lnR_z[\mu m]$	*Theoretical values* R_z *[μm]*
	X_0	X_1	X_2	X_3			
1	*1*	*-1*	*-1*	*-1*	11.8200	2.4698	8.1639
2	*1*	*1*	*-1*	*-1*	5.8600	1.7681	5.4383
3	*1*	*-1*	*1*	*-1*	9.8100	2.2834	7.4379
4	*1*	*1*	*1*	*-1*	5.5100	1.7066	4.9547
5	*1*	*-1*	*-1*	*1*	4.6700	1.5412	4.4214
6	*1*	*1*	*-1*	*1*	4.0900	1.4085	2.9453
7	*1*	*-1*	*1*	*1*	4.5700	1.5195	4.0282
8	*1*	*1*	*1*	*1*	3.6900	1.3056	2.6834
9	*1*	*0*	*0*	*0*	3.1500	1.1474	4.2755
10	*1*	*0*	*0*	*0*	3.5700	1.2726	4.2755
11	*1*	*0*	*0*	*0*	3.0000	1.0986	4.2755
12	*1*	*0*	*0*	*0*	2.7200	1.006	4.2755

3.4.1 Dispersive Analysis

With dispersive analysis, we determine the significance of the regression coefficients and the adequacy of the mathematical model.

Tab. 3.3 The calculated values of the elements are given in the following table:

Variation Source	Ease rates (fi)	Square sum (s)	Evaluation of variant (s^2)	Test –Fr (calculated)
$b_0 = 0.4761$	$f_0 = 1$	2.7204	2.7204	F_{R0}=766.07 (sig.)
$b_1 = -0.1858$	$f_1 = 1$	0.2762	0.2762	F_{R1}=77.869 (sig.)
$b_2 = 0.3182$	$f_2 = 1$	0.8100	0.8100	F_{R2}=228.30 (sig.)
$b_3 = 0.1131$	$f_3 = 1$	0.1023	0.1023	F_{R3}=28.84(sig.)
Residual sum	$f_R = N - K - 1$ $f_R = 12 - 3 - 1 = 8$	$S_R = 0.1430$	$S_R^2 = 0.0179$	F_{Ri}>F_t Sepse F_t(0.05,3.1)>10.1 F_{R0}, F_{R1}, F_{R2},, F_{R3} janë signifikant
The mistakes of the experiment at the zero point	$f_E = n_0 - 1$ $f_E = 4 - 1 = 3$	$S_E = 0.0106$	$S_E^2 = 0.0035$	
Total mistake of the experiment	$f_a = f_R - f_E$ $f_a = 8 - 3 = 5$	$S_a = 0.1324$	$S_a^2 = 0.0264$	
Mathematical mod				7.464
Adequacy of the model	The mathematical model is adequate because F_t>F_{Ra}, 9.01>7.464			

3.4.2 Tabular values of dispersive sizes

According to Fisher's criterion (distribution-table). Coefficients are significant if:

$$F_{ri} > F_t$$

for $\alpha = 0.05$ tabular values:

$$F_t(\alpha, f_i; f_E)$$

$$Ft(5\% \quad 1;3) = 10{,}1 < F_{ri}$$

The mathematical model is adequate if:

$$F_r > F_t$$

for $\alpha = 0.05$, $F_t(f_a; f_E)$

$$F_{r(b_0)} = \frac{S_{b_0}}{S_E^2} = \frac{2.7204}{0.0035} = 766.706$$

$$F_{r(b_1)} = \frac{S_{b_1}}{S_E^2} = \frac{0.2762}{0.0035} = 77.8692$$

$$F_{r(b_2)} = \frac{S_{b_2}}{S_E^2} = \frac{0.8100}{0.0035} = 228.305$$

$$F_{r(b_3)} = \frac{S_{b_3}}{S_E^2} = \frac{0.1023}{0.0035} = 28.8496$$

By comparing the results, we can draw the conclusions that all the regression coefficients are significant, and that the mathematical model adequately describes the phenomenon.

3.5 Decoding the mathematical model

3.5.1 Level of input sizes

$V_{1\max} = X_{1\max} = 138.160 \qquad S_{2\max} = X_{2\max} = 0.056 \qquad t_{3\max} = X_{3\max} = 0.6$

$V_{1\min} = X_{1\min} = 69.080 \qquad S_{2\min} = X_{2\min} = 0.02 \qquad t_{3\min} = X_{3\min} = 0.2$

$$\beta_0 = b_0 + b_1 \cdot a_1 + b_2 \cdot a_2 + b_3 \cdot a_3 = 0.4761 + (-0.1858) \cdot (-13.220392) + 0.318211 \cdot 6.598969 +$$
$$+ 0.11312 \cdot 1.929947 = 5.2511856$$

$$a_1 = 1 - A_1 \ln X_{1\max} = 1 - 2.8853901 \cdot \ln 138.160 = -13.220392$$

$$a_2 = 1 - A_2 \ln X_{2\max} = 1 - 1.9424653 \cdot \ln 0.056 = 6.598969$$

$$a_3 = 1 - A_3 \ln X_{3\max} = 1 - 1.8204785 \cdot \ln 0.6 = 1.929947$$

$$\beta_1 = A_1 \cdot b_1 = 2.8853901 \cdot (-0.1858) = -0.536$$

$$\beta_2 = A_2 \cdot b_2 = 1.9424653 \cdot 0.318211 = 0.618$$

$$\beta_3 = A_3 \cdot b_3 = 1.8204785 \cdot 0.11312 = 0.206$$

$$B = e^{\beta_0} = e^{5.2511856} = 190.7622$$

3.5.2 The decoded form of the equation

(1) $-1 -1 -1$

$$R_z = 27.92928 \cdot v^{-0.586} \cdot s^{-0.090} \cdot t^{-0.558} = 27.92928 \cdot 69.080^{-0.586} \cdot 0.02^{-0.090} \cdot 0.2^{-0.558} = 8.1639 \text{ [m}\mu]$$

(2) $1 -1 -1$

$$R_z = 27.92928 \cdot v^{-0.586} \cdot s^{-0.090} \cdot t^{-0.558} = 27.92928 \cdot 138.160^{-0.586} \cdot 0.02^{-0.090} \cdot 0.2^{-0.558} = 5.4383 \text{[m}\mu]$$

(3) $-1 \; 1 -1$

$$R_z = 27.92928 \cdot v^{-0.586} \cdot s^{-0.090} \cdot t^{-0.558} = 27.92928 \cdot 69.080^{-0.586} \cdot 0.056^{-0.090} \cdot 0.2^{-0.558} = 7.4379 \text{ [m}\mu]$$

(4) $1 \; 1 -1$

$$R_z = 27.92928 \cdot v^{-0.586} \cdot s^{-0.090} \cdot t^{-0.558} = 27.92928 \cdot 138.160^{-0.586} \cdot 0.056^{-0.090} \cdot 0.2^{-0.558} = 4.9547 \text{ [m}\mu]$$

(5) $-1 -1 \; 1$

$$R_z = 27.92928 \cdot v^{-0.586} \cdot s^{-0.090} \cdot t^{-0.558} = 27.92928 \cdot 69.080^{-0.586} \cdot 0.02^{-0.090} \cdot 0.6^{-0.558} = 4.4214 \text{ [m}\mu]$$

(6) $1 -1 \; 1$

$$R_z = 27.92928 \cdot v^{-0.586} \cdot s^{-0.090} \cdot t^{-0.558} = 27.92928 \cdot 138.160^{-0.586} \cdot 0.02^{-0.090} \cdot 0.6^{-0.558} = 2.9453 \text{ [m}\mu]$$

(7) $-1 \; 1 \; 1$

$$R_z = 27.92928 \cdot v^{-0.586} \cdot s^{-0.090} \cdot t^{-0.558} = 27.92928 \cdot 69.080^{-0.586} \cdot 0.056^{-0.090} \cdot 0.6^{-0.558} = 4.0282 \text{[m}\mu]$$

(8) $1 \; 1 \; 1$

$$R_z = 27.92928 \cdot v^{-0.586} \cdot s^{-0.090} \cdot t^{-0.558} = 27.92928 \cdot 138.160^{-0.586} \cdot 0.056^{-0.090} \cdot 0.6^{-0.558} = 2.6834 \text{[m}\mu]$$

(9) $0 \; 0 \; 0$

$$R_z = 27.92928 \cdot v^{-0.586} \cdot s^{-0.090} \cdot t^{-0.558} = 27.92928 \cdot 96.712^{-0.586} \cdot 0.04^{-0.090} \cdot 0.4^{-0.558} = 4.2755 \text{ [m}\mu]$$

(10) $0 \; 0 \; 0$

$$R_z = 27.92928 \cdot v^{-0.586} \cdot s^{-0.090} \cdot t^{-0.558} = 27.92928 \cdot 96.712^{-0.586} \cdot 0.04^{-0.090} \cdot 0.4^{-0.558} = 4.2755 \text{ [m}\mu]$$

(11) $0 \; 0 \; 0$

$$R_z = 27.92928 \cdot v^{-0.586} \cdot s^{-0.090} \cdot t^{-0.558} = 27.92928 \cdot 96.712^{-0.586} \cdot 0.04^{-0.090} \cdot 0.4^{-0.558} = 4.2755 \text{ [m}\mu]$$

+

(12) $0 \; 0 \; 0$

$$R_z = 27.92928 \cdot v^{-0.586} \cdot s^{-0.090} \cdot t^{-0.558} = 27.92928 \cdot 96.712^{-0.586} \cdot 0.04^{-0.090} \cdot 0.4^{-0.558} = 4.2755 \text{ [m}\mu]$$

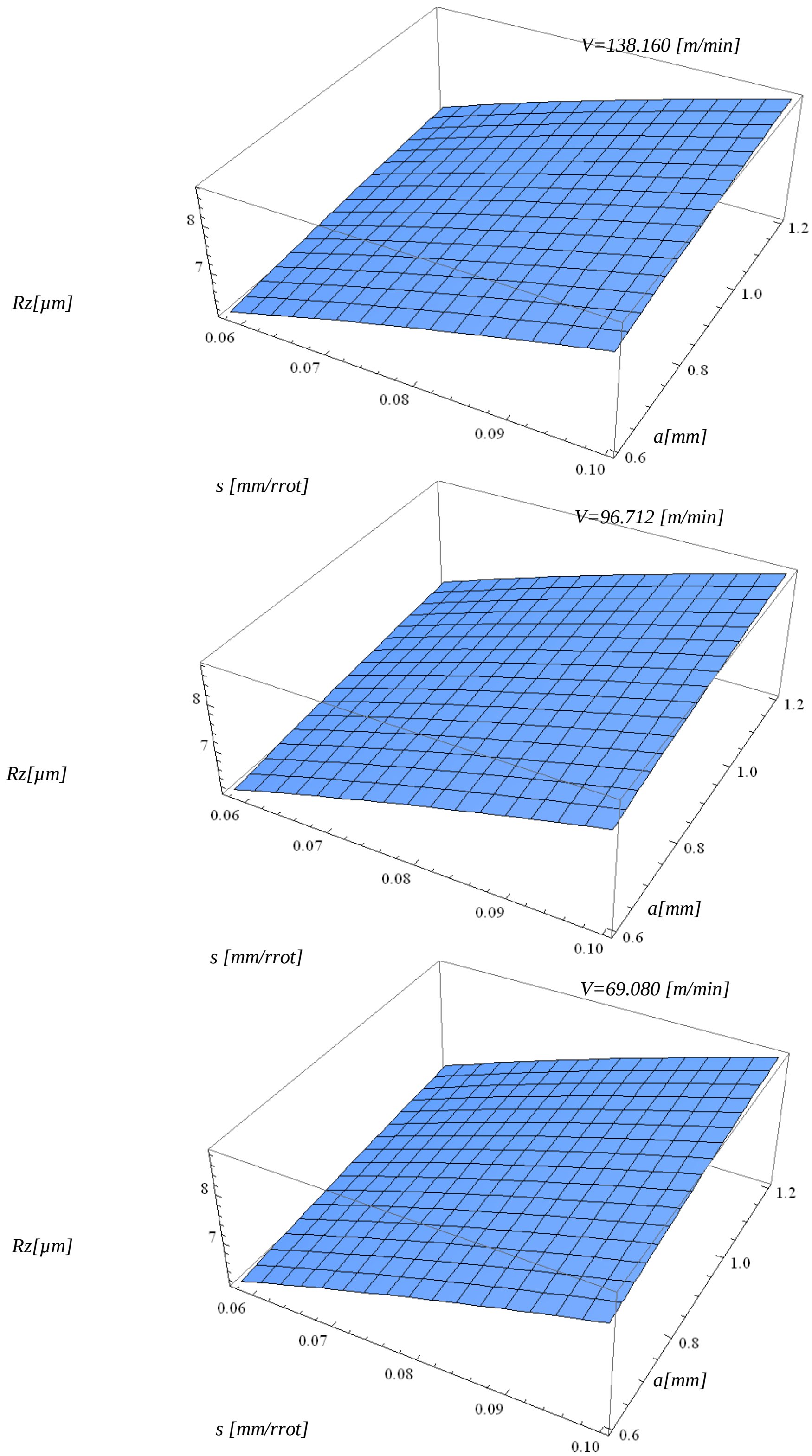

Fig.3.1.Graphical interpretation of the mathematical model Rz

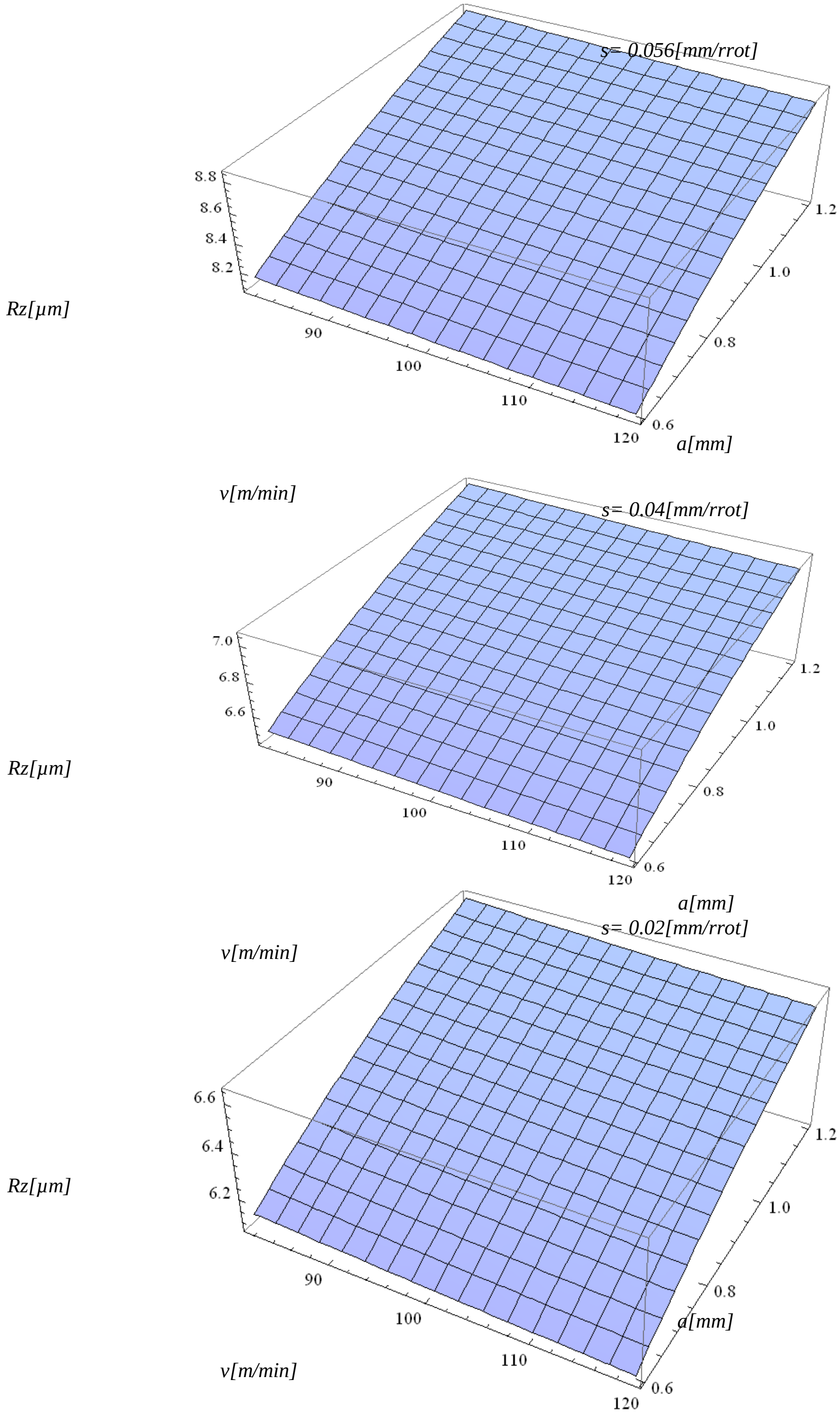

Fig.3.2. Graphical interpretation of the mathematical model Rz

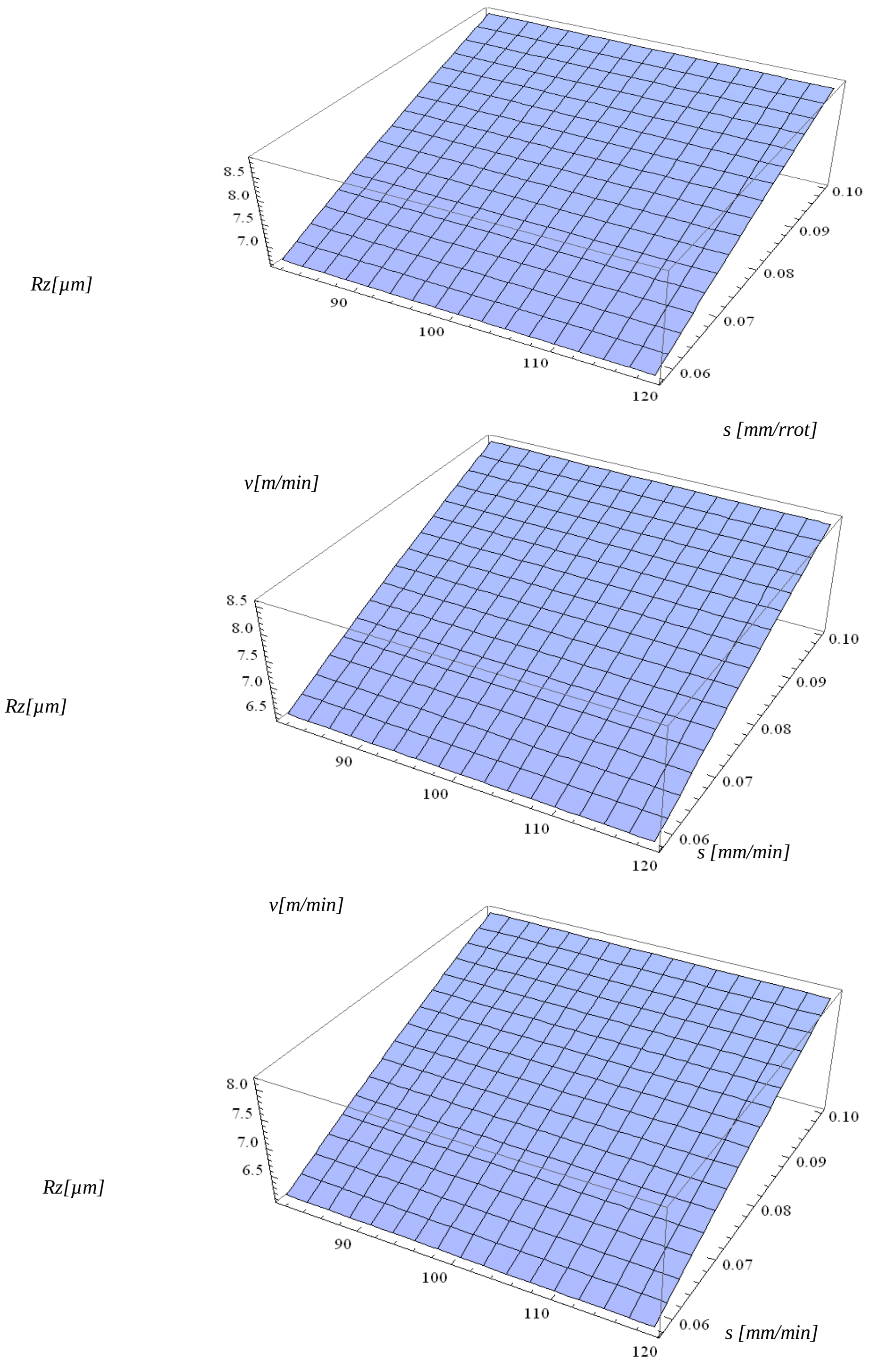

Fig 3.3 Graphical interpretation of the mathematical model Rz

ANALYSIS OF RESULTS

Based on the results obtained during the roughness research for C45 steel (according to the DIN Standard), the mathematical model and the graphic interpretation have proven the impact of the factors that were used for the realization of the experiment (cutting speed, feed rate and cutting depth).

The cutting speed (v) has a great impact on the processed surface roughness. The higher the speed, the smaller the height of the raised micros, which means that by increasing the cutting speed, the surfaces roughness decreases.

Feed rate (s) - The most influential factor in the size of the surfaces roughness scale is the cutting feed. During the research, it was proven that by increasing the feed (s) affected the increase ofroughness. During processing with a high feed rate, i.e., maximum feed (s=0.056), there is an increase of the surfaces roughness. This happens because by increasing the feed rate, the cutting resistance increases, the cutting temperature increases, which also leads to an increase in the size of the plastic deformations in the cutting area. During processing with a lowfeedrate (s=0.02), the results have proven that by decreasing the feed, the surface roughness also decreases.

Cutting depth (a). Based on the analysis of the results, the cutting depth, in relation to the feed rate and the cutting speed, is less influential on the processed surface roughness. With the increase of the depth (amax=0.6) we have obtained higher values of the roughness parameters of the processed surfaces because, by increasing the cutting depth, there is an increase of the cutting resistances, the temperatures in the cutting area, the deformations, etc., while on the other hand, by decreasing the cutting depth (amin=0.2), there is decrease of roughness parameters of the worked surface. This happens because by decreasing the cutting depth, the cutting resistances and the temperatures in the cutting area also decrease.

Based on the results achieved during the research of the surface roughness for this steel, the influence of the factors that were used for the realization of the experiment such as the cutting speed, feed rate and cutting depth is reflected.

Number of experiments	Cutting speed	Feed	Depth
Experiment 1	800	0.056	0.6
Experiment 7	800	0.020	0.2
Experiment 9	560	0.040	0.4

Based on the results obtained during the measurement, we can conclude that the factor with a positive influence is the cutting speed, where the higher the cutting speed, the values of the roughness parameters of the worked surfaces also decrease. Experiment 7 where the cutting speed was maximum:

Measuring Tool	SurfTest SJ-301	Comment	Ver4.00
Standard	ISO 1997	N	5
Profile	R	Cut-Off	0.8 mm
Range	AUTO	Filter	GAUSS
Ra	0.80um		
Rz	4.57um		
Rq	0.99um		

Experiment 1, where the maximum values of s, v and a were used, we see how it affected the increase of roughness parameters:

Work Name	Sample	Operator	Mitutoyo
Measuring Tool	SurfTest SJ-301	Comment	Ver4.00
Standard	ISO 1997	N	5
Profile	R	Cut-Off	0.8 mm
Range	AUTO	Filter	GAUSS
Ra	2.69um		
Rz	11.82um		
Rq	3.14um		

The coordination of the parameters of the cutting regime between the speed, feed and the cutting depth plays a very important role in the surface roughness, where by using the meancutting parameters, also affected indecrease of the roughness parameters:

Work Name	Sample	Operator	Mitutoyo
Measuring Tool	SurfTest SJ-301	Comment	Ver4.00
Standard	ISO 1997	N	5
Profile	R	Cut-Off	0.8 mm
Range	AUTO	Filter	GAUSS
Ra	0.53um		
Rz	3.15um		
Rq	0.65um		

The mathematical model for the arithmetic mean deviation of the surface roughness profile after the necessary calculations is:

$$R_a = 190.7622 \cdot v^{-0.536} \cdot s^{0.618} \cdot t^{0.206}$$

The mathematical model for the maximum height of non-planes of surface roughness after the necessary calculations is:

$$R_t = 7.2694 \cdot v^{-0.648} \cdot s^{-0.084} \cdot t^{-0.687}$$

The mathematical model for the mean height of non-planes of the surface roughness after the necessary calculations is obtained:

$$R_z = 27.92928 \cdot v^{-0.586} \cdot s^{-0.090} \cdot t^{-0.558}$$

Analyzing the results of the mathematical models, we come to the conclusion that the Ra mathematical model is adequate, because: $F_t > F_{Ra}$, *9.01>7.464.*

The mathematical model for Rt, the results show that the model is not adequate, because
$F_t > F_{Ra}$, *9.01>24.629*.

The mathematical model for Rz, the results show that the model is not adequate, because
$F_t > F_{Ra}$, *9.01>17.881*.

CONCLUSION

Based on the results achieved during the research of the surface roughness for C45 steel, the analysis of mathematical models, the graphic interpretation, the influence of the factors used in the experiment is reflected. The roughness of the machined surface depends on many factors, but, for research, factors such as: cutting speed (v), feed rate (s) and cutting depth (a) have been adopted.

During the experimental research, the rate of the surface roughness was measured for 12 experiments.

Experimental investigations for our specific conditions of the cutting process provide enough accurate results for practical needs.

The analysis of the experimentally obtained mathematical models allows reaching the following conclusion related to the surface roughness research for C45 steel:

- By increasing cutting speed, the roughness parameters of the worked surface decrease,
- By decreasing the feed rate, the roughness parameters of the worked surface decrease,
- By increasing the cutting depth, the roughness of the worked surfaces also increases.

In addition to the cutting tool wear, the hardness, durability, chemical composition and structure of the workpiece have a great impact on the roughness of the processed surface.

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