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OPTIMIZATION OF THE MACHINING PARAMETERS FOR THE TURNING OF 15-5 PH STAINLESS STEELS USING THE TAGUCHI METHOD

UPORABA TAGUCHI METODE ZA OPTIMIZACIJO PARAMETROV OBDELAVE PRI STRUŽENJU NERJAVNEGA JEKLA 15-5 PH

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The present study investigated the effects of the control factors of cutting speed, feed rate and depth of cut on the response variables of cutting force (F_c) and surface roughness (R_a) in the dry turning of 15-5 PH martensitic stainless steel. Using PVD TiAlN-AlCrO- and CVD TiCN-Al_2O_3-TiN-coated carbide-cutting-tool inserts, a number of turning experiments were conducted via the L_{18} ($2^1 \times 3^3$) Taguchi mixed orthogonal array. The machining parameters were optimized using signal-to-noise ratio (*S/N*) and analysis of variance (ANOVA). Additionally, empirical models were created for predicting the F_c and R_a using multiple-regression analysis. The results indicated that depth of cut was the most significant cutting parameter affecting F_c, while the feed rate contributed the most to R_a. The developed quadratic regression model, showing a high determination coefficient of 0.981 for F_c and 0.988 for R_a, accurately explained the relationship between the response variable and the control factors.

Keywords: Taguchi method, turning, cutting force, surface roughness, 15-5 PH steel

Študija proučuje vplive kontrolnih faktorjev kot so: hitrost rezanja, hitrost podajanja in globina rezanja na spremenljivki odziva: silo rezanja (F_c) in hrapavost površine (R_a) pri suhem struženju martenzitnega nerjavnega jekla 15-5 PH. Z uporabo PVD TiAlN-AlCrO- in CVD TiCN-Al_2O_3-TiN-nanosov na karbidnih vložkih za rezanje, so bili izvedeni številni preizkusi struženja s pomočjo mešane L_{18} ($2^1 \times 3^3$) Taguchi ortogonalne matrike. Parametri obdelave so bili optimirani z uporabo razmerja signala šuma (*S/N*) in analizo variance (ANOVA). Dodatno so bili postavljeni empirični modeli za napovedovanje F_c in R_a z uporabo različnih regresijskih analiz. Rezultati so pokazali, da je globina reza najpomembnejši parameter rezanja, ki vpliva na F_c, medtem ko hitrost podajanja največ prispeva k R_a. Razviti kvadratni regresijski model, ki kaže določen visok koeficient 0,981 za F_c in 0,988 za R_a, natančno pojasni razmerje med spremenljivko odziva in kontrolnimi faktorji.

Ključne besede: Taguchi metoda, struženje, sila rezanja, hrapavost površine, jeklo 15-5 PH

1 INTRODUCTION

15-5 PH is a precipitation-hardened martensitic stainless steel that has the characteristics of high strength, good corrosion resistance, excellent weldability, low distortion and good mechanical properties at temperatures up to 600 °F (316 °C).[1–3] 15-5 PH stainless steel is widely used in the chemical, nuclear, aerospace, paper, food processing, petrochemical and general metalworking industries.[4–5] Stainless steel is one of the materials that exhibits poor machinability. The greatest difficulty in the machining of these materials is poor surface quality and a short tool life.[6] Especially after precipitation hardening, the increase in hardness and mechanical properties makes machinability even more difficult. However, only a few reports exist concerning the machining of precipitation-hardened martensitic stainless steel.

In the aviation and automotive sectors, the turning operation is one of the commonly used metal-cutting methods for industrial component manufacturing. In industries where accuracy and measurement integrity are important, ways to improve the surface quality and lower the costs of lathed components have become perpetual subjects of investigation.[7] Furthermore, surface roughness plays a significant role in the development and specification of the surface qualities of the produced components. When the surface-roughness value falls within the desired limits, it directly affects the material, energy and labor costs. In addition, a good surface quality provides significant improvements in the tribological properties, fatigue strength, corrosion resistance and aesthetic appearance of the finished product.[8–10] One of the most important factors in production is energy consumption. The power consumed during machining is the factor that determines the energy consumption. Apart from the material factor (in terms of kW), the necessary power for the turning operation depends on the cutting depth, feed rate and cutting speed. Depending on the specific cutting resistance of the material with the other factors, the main cutting force (F_c) needed during machining is one of the most important parameters determining the power consumption for machining and consequently the energy cost.[11] There is a strong relation between the cutting force and the surface roughness, accuracy of the workpiece and tool wear.[12] There are a number of parameters, including cutting speed, feed, cutting depth and chip angle, that affect the cutting force and surface roughness.[13–14] Suitable machining parameters must be determined in order to obtain low costs and high-quality products. For this purpose, several optimization methods and techniques are being used, one of which is the Taguchi experimental design method, which has been successfully applied in the solution of optimization problems.[15-16]

D. P. Selvaraj et al.[17] utilized the Taguchi method to define the optimal cutting parameters in the turning of two different grades of duplex stainless steel. The turning operations were carried out with TiC- and TiCN-coated carbide-cutting-tool inserts. The effects of cutting speed and feed rate on the cutting force, surface roughness and tool wear were analyzed and the results showed that the feed rate was the most significant parameter influencing the surface roughness and cutting force. The cutting speed was identified as the most significant parameter influencing the tool wear. C. Camposeco-Negrete[18] conducted an experimental study to optimize machining parameters during the turning of AISI 6061 T6. The machining parameters were optimized using orthogonal array, *S/N* and ANOVA. The results showed that feed rate was the most dominant factor affecting the energy consumption and surface roughness. A. J. Makadia and J. I. Nanavati[10] used response surface methodology (RSM) to determine the optimal cutting parameters for surface roughness in the turning of AISI 410 steel. The developed prediction model showed that the feed rate was the most significant factor on the surface roughness, followed by the tool nose radius. The surface roughness values were found to increase with increasing feed rate and to decrease with increasing tool nose radius. C. Ezilarasan et al.[19] experimentally investigated and analyzed the machining parameters while turning Nimonic C-263 alloy, using Taguchi's experimental design. The cutting parameters considered were cutting speed, feed rate and depth of cut. The response variables of cutting force, tool wear and surface roughness were measured. Optimized cutting parameters were observed at 210 m/min cutting speed, 0.05 mm/r feed rate and 0.50 mm depth of cut. A. Hasçalık and U. Çaydaş[20] studied the turning operation of Ti-6Al-4V alloy and broadly examined the effects of cutting parameters on surface roughness and tool life by using the Taguchi method. An orthogonal array, *S/N* ratio, and ANOVA were employed to investigate the performance characteristics in the turning of commercial Ti-6Al-4V. The feed rate was found to be the most important factor on the surface roughness while cutting speed was the main factor that had a significant effect on tool life.

Upon examining studies in the literature, it can be seen that the Taguchi method has been successfully used in the optimization of machining parameters. On the other hand, the machinability of stainless steels is becoming a subject of perpetual investigation because of their wide usage and hard machinability characteristics. However, in recent years, very few studies have been conducted on the machinability of precipitation-hardened stainless, which, due to their excellent mechanical characteristics, are used especially in the aviation industry. Consequently, in this study, the aim was to optimize the machining parameters affecting the cutting force and surface roughness during the dry turning of 15-5 PH stainless steel using coated cementite-carbide tools. To this purpose, an experimental design employing a Taguchi L_{18} orthogonal array was created and analytical models were developed using regression analysis in order to estimate F_c and R_a. In addition, ANOVA was applied to determine the effect levels of the machining parameters.

2 EXPERIMENTAL PART

2.1 Machine tool and workpiece material

The experimental investigation was carried out using a Johnford TC 35 lathe with a maximum spindle speed of 3500 min^{-1} and a 10-kW drive motor. The workpiece material used for experimentation was 15-5 precipitation-hardened (PH) martensitic stainless steel with a hardness of 42 HRC, in the form of round bars, 40 mm in diameter and 300 mm in length. The chemical composition and mechanical properties of the test samples are given in **Tables 1** and **2**, respectively. The precipitation-hardening treatment consisted of solutionizing at 1040 °C and air quenching, followed by a final tempering at 550 °C for 4 h (H1025 condition). The typical microstructures in the etched condition of the 15-5 PH stainless steel are shown in **Figure 1**. It can be clearly seen that the microstructure of the 15-5 PH precipi-

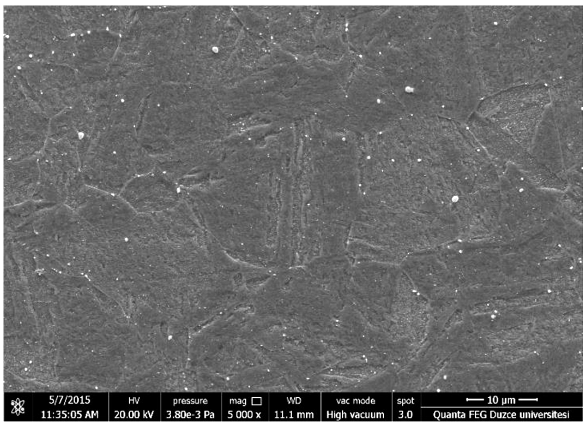


Figure 1: Microstructure of the precipitation-hardened 15-5 stainless steel

Slika 1: Mikrostruktura izločevalno utrjenega nerjavnega jekla 15-5 tation-hardened stainless steel shows lath martensite and fine carbides.

Table 1: Chemical composition of 15-5 PH martensitic stainless steel (*w*/%)

Tabela 1: Kemijska sestava martenzitnega nerjavnega jekla 15-5 PH (*w*/%)

Ni	Cu	Cr	C	Si	Mn	P	S	Nb	Ta
5.08	3.53	15.02	0.07	0.338	0.791	0.022	0.004	0.324	0.15

Table 2: Mechanical properties of 15-5 PH martensitic stainless steel

Tabela 2: Mehanske lastnosti martenzitnega nerjavnega jekla 15-5 PH

Tensile strength (MPa)	Yield strength (MPa)	Percentage elongation (%)	Hardness (HRC)
1202	1172	12	42

2.2 Cutting tools and holder

In the turning tests, commercially available PVD and CVD multilayer-coated carbide inserts (Sandvik Coromant – ISO CNMG 120408) were employed. The properties of the cutting tools and coating materials are given in **Table 3**. A right-hand style mechanical tool holder (ISO PSBNR 2525M12) was used for mounting the inserts. For each experimental parameter, a fresh cutting edge was utilized. The turning experiments were performed using two different cutting tools (PVD and CVD), three cutting speeds (150, 200, and 250) m/min and three feed rates (0.1, 0.2 and 0.3) mm/r.

Table 3: Properties of cutting tools and coating materials

Tabela 3: Lastnosti rezilnih orodij in nanosov

Coated method	Coated materials	Material quality of ISO (Grade)	Coating thickness (μm)	Hardness (HV)
PVD	TiAlN/AlCrO	GC1125	4	1640
CVD	$TiCN/Al_2O_3/TiN$	GC2015	5.5	1500

2.3 Cutting force measurement

During turning, the cutting force (F_c) was measured by using a three-component piezoelectric dynamometer (KISTLER – 9257B). The signals of F_c from the dynamometer were transmitted to a Kistler 5070-A multichannel amplifier. Dynoware software was used for the data-acquisition system of the machine. The experimental setup and cutting force measurements are shown in **Figure 2**.

2.4 Surface-roughness measurement

The average surface roughness (R_a) of the workpiece was measured on a MAHR Perthometer M1 portable surface-roughness device. Cut-off and evaluation lengths for the surface roughness measurements were selected as 0.8 mm and 5.6 mm, respectively. Before the measurements of R_a, the measuring device was calibrated utiliz-

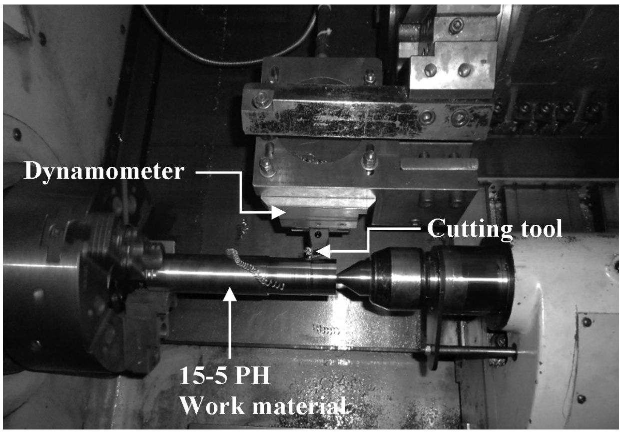


Figure 2: Experimental configuration for the measuring of cutting force

Slika 2: Eksperimentalni sestav za merjene sile rezanja

ing a standard calibration specimen. The measurements were taken at three locations (120° apart) around the circumference of the workpieces in order to minimize the deviation, and the average values were reported. The surface roughness measurements are given in **Figure 3**.

2.5 Taguchi's design of experiments

Taguchi's Design of Experiments provides a simple, efficient and systematic approach for determining the optimum machining parameters in the manufacturing process.[21,22] The Taguchi method significantly decreases the number of tests needed and increases the machining performance by using orthogonal arrays.[23,24] For the realization of the experimental design, first of all, the control factors and their levels must be determined. In this study, the cutting tools (PVD and CVD), cutting speed (*V*), feed rate (*f*) and depth of cut (*ap*) were determined as the control factors. The cutting tool was designated in two levels, whereas the other control factors were in three levels. The control factors and their levels are indicated in **Table 4**.

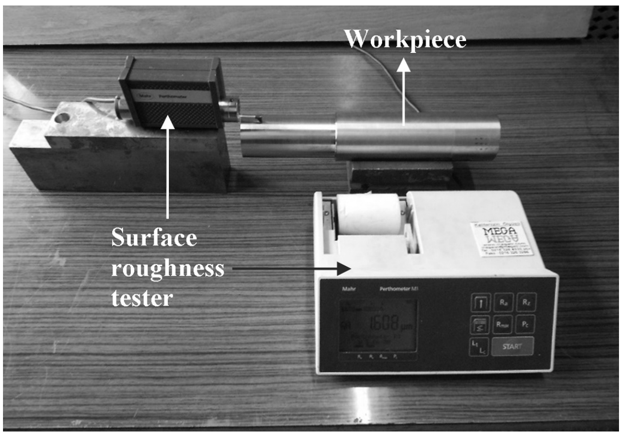


Figure 3: Surface-roughness measurement

Slika 3: Merjenje hrapavosti površine

Table 4: Control factors and their levels
Tabela 4: Kontrolni faktorji in njihovi nivoji

Control factors	Symbol	Level 1	Level 2	Level 3
Cutting tool	A	PVD	CVD	-
Cutting speed (m/min)	B	150	200	250
Feed rate (mm/r)	C	0.1	0.2	0.3
Depth of cut (mm)	D	0.5	1	1.5

The full-factorial experimental design required a large number of 54 ($2^1 \times 3^3$) tests, along with increased costs. Thus, Taguchi's experimental design was able to provide better results with fewer tests. For the specified control factors and their levels, L_{18} was selected as the most suitable orthogonal array (**Table 4**). Consequently, the number of tests was decreased significantly and only 18 tests were made. The Taguchi method uses a loss function to determine the quality characteristics and the values of this loss function are also converted to a *S/N* ratio. In analyzing *S/N* ratios, three different quality characteristics are used: the "lower-the-better", the "higher-the-better" and the "nominal-the-best". Minimization of the F_c and R_a values was the main purpose of this study. For this reason, the "lower-the-better" quality characteristic was used for F_c and R_a.

"Lower is the better" characteristics (minimization):

$$S/N = -10\lg\left[\frac{1}{n}\sum_{i=1}^{n} y_i^2\right] \tag{1}$$

In the Equation (1), y_i is the observed data at the *i*-th experiment and *n* is the number of observations.

3 ANALYSIS AND DISCUSSION

3.1 Analysis of the S/N ratio and ANOVA results

The *S/N* ratio is defined as the ratio of the average for the standard deviation. This ratio is used to measure the deviation of quality characteristics from the desired value. In this study, F_c and R_a were specified as the quality characteristics. Lower F_c and R_a values are important from the point of view of energy consumption and product quality. Therefore, the "lower-the-better" equation was used for the calculation of the S/N ratio. The test results of the F_c and R_a and the corresponding S/N ratios are given in **Table 5**. The averages of the F_c and R_a values obtained from the experimental study were calculated as 447.67 N and 1.97 µm, respectively.

The S/N response table was used for the analysis of the effects of the control factors (Ct, V, f and ap) on the F_c and R_a. The S/N response table for F_c and R_a is given in **Table 6**. The highest S/N ratios in the table show the optimum levels. A graphical representation of variations in the *S/N* ratios depending on the F_c and R_a control factors is given in **Figures 4** and **5**. The optimum levels for F_c and R_a were determined as A2B3C1D1 and A2B2C1D1, respectively. Thus, the optimum cutting-force value was obtained at 250 m/min cutting speed, 0.1 mm/rev feed rate and 0.5 mm cutting depth using the

Table 5: Experimental results and *S/N* ratios values
Tabela 5: Rezultati eksperimentov in vrednosti razmerja *S/N*

Exp. No.	Control factors				Cutting force, F_c (*N*)	S/N ratio for F_c (dB)	Surface roughness, R_a (µm)	*S/N* ratio for R_a (dB)
	A Cutting tool (*Ct*)	B Cutting speed (*V*)	C Feed rate (*f*)	D Depth of cut (*ap*)				
1	PVD	150	0.1	0.5	195	-45.80	0.71	2.97
2	PVD	150	0.2	1.0	452	-53.10	1.99	-5.98
3	PVD	150	0.3	1.5	927	-59.34	3.97	-11.98
4	PVD	200	0.1	0.5	183	-45.25	0.42	7.54
5	PVD	200	0.2	1.0	460	-53.26	1.51	-3.58
6	PVD	200	0.3	1.5	912	-59.20	3.48	-10.83
7	PVD	250	0.1	1.0	308	-49.77	1.89	-5.53
8	PVD	250	0.2	1.5	627	-55.95	1.94	-5.76
9	PVD	250	0.3	0.5	357	-51.05	3.22	-10.16
10	CVD	150	0.1	1.5	411	-52.28	1.06	-0.51
11	CVD	150	0.2	0.5	273	-48.72	1.67	-4.44
12	CVD	150	0.3	1.0	656	-56.34	3.86	-11.73
13	CVD	200	0.1	1.0	277	-48.85	0.61	4.29
14	CVD	200	0.2	1.5	687	-56.74	1.53	-3.69
15	CVD	200	0.3	0.5	356	-51.03	3.08	-9.77
16	CVD	250	0.1	1.5	397	-51.98	0.57	4.88
17	CVD	250	0.2	0.5	268	-48.56	0.88	1.11
18	CVD	250	0.3	1.0	312	-49.88	3.12	-9.88

T_{Fc} (cutting force total mean value) = 447.67 N
$T_{Fc\text{-}S/N}$ (cutting force *S/N* ratio total mean value) = -52.06 dB
T_{Ra} (surface roughness total mean value) = 1.97 µm
$T_{Ra\text{-}S/N}$ (surface roughness *S/N* ratio total mean value) = -4.06 dB

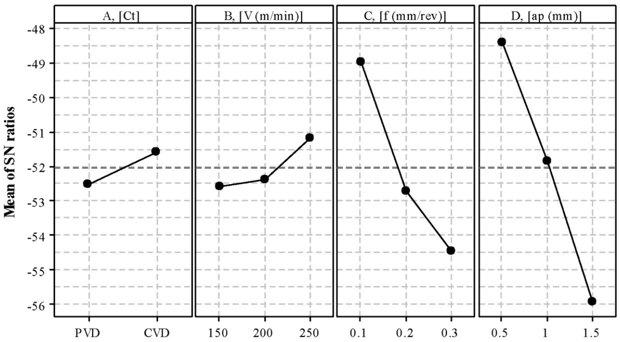


Figure 4: *S/N* graph for cutting force
Slika 4: *S/N* diagram za silo rezanja

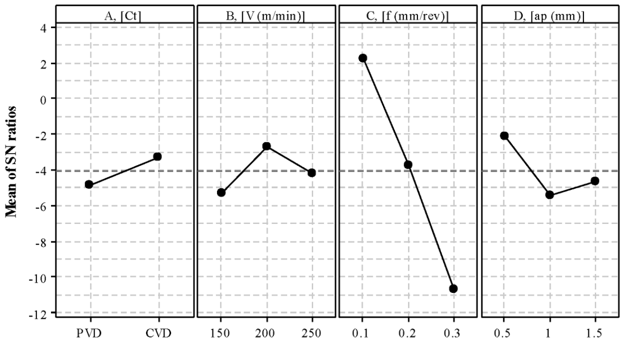


Figure 5: *S/N* graph for surface roughness
Slika 5: *S/N* diagram za hrapavost površine

Table 6: *S/N* response table for F_c and R_a control factors
Tabela 6: Tabela *S/N* odgovora za F_c in R_a kontrolna faktorja

Levels	Cutting force (F_c)				Surface roughness (R_a)			
	A	B	C	D	A	B	C	D
Level 1	-52.52	-52.60	-48.99	-48.40	-4.811	-5.276	2.275	-2.125
Level 2	-51.60	-52.39	-52.72	-51.87	-3.304	-2.675	-3.723	-5.400
Level 3	-	-51.20	-54.47	-55.91	-	-4.222	-10.724	-4.647
Delta	0.93	1.40	5.49	7.51	1.506	2.601	12.999	3.275

CVD-coated tool, whereas the optimum R_a was obtained at 200 m/min cutting speed, 0.1 mm/rev feed rate and 0.5 mm cutting depth, also by using the CVD-coated tool.

Table 7: Results of ANOVA for cutting force and surface roughness
Tabela 7: Rezultati ANOVA za silo rezanja in hrapavost površine

Variance source	Degree of freedom (DoF)	Sum of squares (SS)	Mean square (MS)	F ratio	Contribution rate (%)
F_c					
A	1	34148	34148	5.33	3.96
B	2	43599	21799	3.40	5.05
C	2	256557	128278	20.01	29.74
D	2	464230	232115	36.21	53.82
Error	10	64098	6410	-	7.43
Total	17	862632	-	-	100
R_a					
A	1	0.4214	0.4214	3.78	1.74
B	2	0.5862	0.2931	2.63	2.41
C	2	21.2808	10.6404	95.38	87.64
D	2	0.8777	0.4388	3.93	3.61
Error	10	1.1156	0.1116	-	4.59
Total	17	24.2816	-	-	100

ANOVA was used for the purpose of determining the effects of the control factors (Ct, V, f and ap) of the experimental design on F_c and R_a. The ANOVA analysis was performed with a 5 % significance level and 95 % confidence level. The ANOVA results for the F_c and R_a are shown in **Table 7**. In the determination of the significance levels of the control parameters, F ratio values were used, and from this, the contribution ratios of the machining parameters were calculated. The most effective factor on the F_c was revealed to be the depth of cut (factor D) with a 53.82 % contribution ratio, whereas on the R_a, the most effective factor was the feed rate (factor C) with a contribution ratio of 87.64 %. **Figure 6** shows the percentage contributions of the control factors on F_c and R_a. The error percentages were extremely low at 7.43 % and 4.59 %, respectively, for F_c and R_a.

3.2 Evaluation of the experimental results

The variations in the cutting forces obtained during the experimental study for precipitation-hardened 15-5 PH steel are given in the graphs of **Figure 7**. The cutting force exhibited a slight decrease with the increasing cutting speed. It is thought that the increasing cutting speed caused a decrease in the tool-chip contact area, resulting in a decrease in the cutting forces.[25] From the point of obtaining lower cutting force values, the CVD TiCN-Al2O3-TiN-coated tool showed some advantage over the PVD TiAlN-AlCrO-coated tool (**Figure 7a**). Cutting depth and feed rate had a significant effect on the cutting force (**Figure 7b**). Increase in the feed rate and

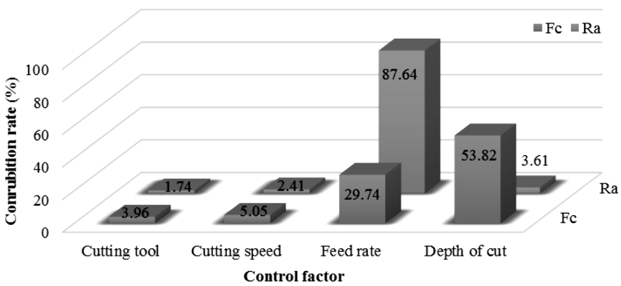


Figure 6: Percentage contribution of the control factors for cutting force and surface roughness
Slika 6: Prispevek kontrolnih faktorjev v odstotkih na silo rezanja in hrapavost površine

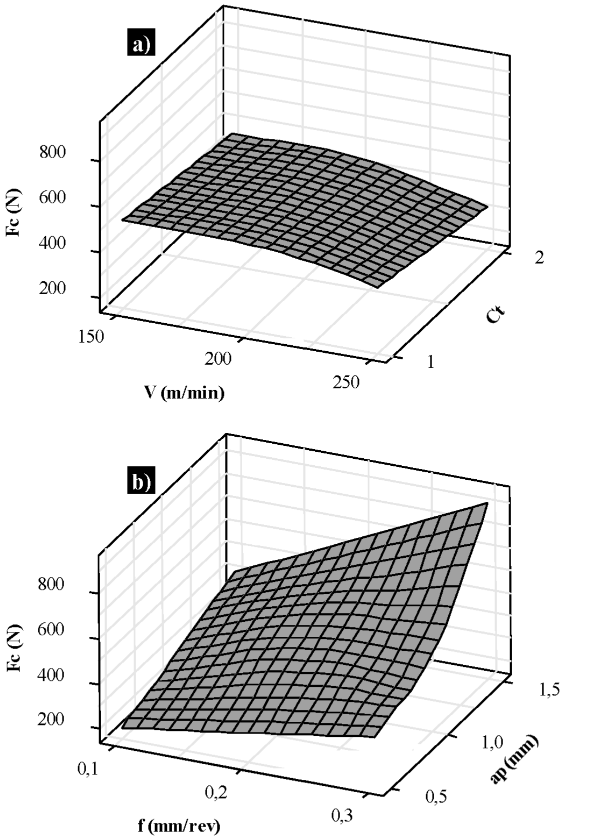


Figure 7: Effect of cutting parameters on cutting force: a) cutting speed and cutting tool, b) feed rate and depth of cut

Slika 7: Vpliv parametrov rezanja na silo rezanja: a) hitrost rezanja in rezilno orodje, b) hitrost podajanja in globina rezanja

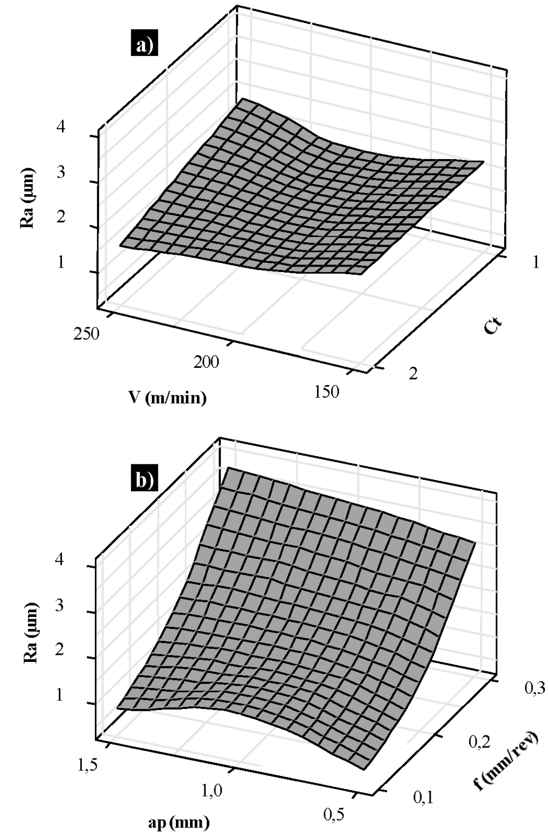


Figure 8: Effect of cutting parameters on surface roughness: a) cutting speed and cutting tool, b) feed rate and depth of cut

Slika 8: Vpliv parametrov rezanja na hrapavost površine: a) hitrost rezanja in rezilno orodje, b) hitrost podajanja in globina rezanja

depth of cut values increased the cutting force considerably. After precipitation hardening, the hardness of the material reached a value of 42 HRC and its resistance was increased against the penetration of the cutting tool. In addition to the increase in hardness, the martensite formation in the material structure following the heat treatment played an important role in the increasing cutting forces. Consequently, with the increase in F_c, the cutting depth was more effective than the feed rate.

The variations in surface roughness obtained in the experimental study for precipitation-hardened 15-5 PH steel are given in the graphs of **Figure 8**. Especially in the tests made with the CVD-coated tool, the R_a values decreased with increasing cutting speed. Although the application of different coatings had no effect on surface roughness, lower and R_a values were obtained with the CVD-coated tool. At a feed rate of 0.2 and 0.3 mm/r, increasing cutting depth caused the R_a values to increase (**Figure 8b**). Therefore, it is possible to say that among the parameters tested, the feed rate was the most effective parameter on the R_a. Since the R_a is a function of the feed rate, the increased values increased the R_a significantly. Moreover, the results of variance analysis also verified that feed rate, with a contribution rate of 87.64 %, was the most effective parameter on R_a. The cutting speed increasing in a way parallel to the cutting forces caused a decrease in the R_a values. Furthermore, the increasing cutting depth, especially at higher feed rates, caused the R_a values to increase slightly. As was the case with the cutting forces, with the surface roughness, the CVD TiCN-Al2O3-TiN-coated tool also displayed some advantage over the PVD TiAlN-AlCrO-coated tool. This can be explained by the lower frictional coefficient of the TiN coating on the uppermost layer of the CVD coating.

3.3 Empirical models and prediction performance

For the purpose of defining the relationship between one dependent variable and one or more independent variables, regression analysis was used.[26] In this study, dependent variables were defined as F_c and R_a, whereas the independent variables were specified as the cutting tool, cutting speed, feed rate and cutting depth. Estimation equations for F_c and R_a were established for linear and quadratic regression models separately. The estimation equations obtained for the linear-regression model of F_c and R_a are given in Equations (2) and (3), whereas the estimation equations obtained for the quadratic regression model are given in Equations (4) and (5).

$$\begin{aligned} Fc_l &= 113.667 - 871111Ct - \\ &- 1.075V + 1457.5f + 388.167ap \end{aligned} \qquad (2)$$

R-Sq = 89,93 % R-Sq(adj) = 86,83 %

$$Ra_l = -0.0297778 - 0.306Ct - -0.00272667V + 12.89f + 0.428667ap \tag{3}$$

R-Sq = 87,04 % R-Sq(adj) = 83,05 %

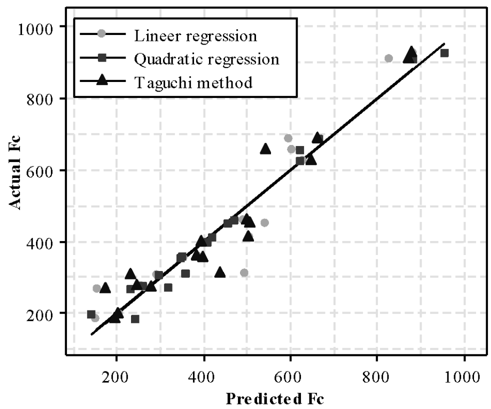
$$FC_q = -1098.02 + 142.084Ct + 9.25331V + 4854.61f - 348.127ap - 0.857436CtV - 330.082Ctf + 47.4709Ctap - 0.0130256VV - 14.1955Vf - 0.699091Vap - 3055.32ff + 1174.87fap + 258.969apap \tag{4}$$

R-Sq = 98.11 % R-Sq(adj) = 91.97 %

$$Ra_q = 2.20536 + 0.939478Ct + 0.0300324V + +8.99345f - 3.17844ap - 0.00727744CtV - 2.5756Ctf + +0.352393Ctap - 0.000113441VV - 0.0278727Vf - -0.00193455Vap - 61.1292ff + 1.41846fap + +0.74574apap \tag{5}$$

R-Sq = 98.79 % R-Sq(adj) = 94.87 %

The correlation coefficient (R^2) of the equations obtained with the linear-regression model for F_c and R_a were calculated as 89.93 % and 87.04 %, respectively. These values were calculated for the quadratic regression model as 98.11 % and 98.79 %. When compared with the linear-regression model, it can be seen that more accurate estimations can be made using the quadratic regression model. **Figure 9** gives the comparison of the Taguchi method with regression models for the estimation of F_c and R_a. From the figure it is clear that for both F_c and R_a, the closest values to the line were obtained with the quadratic regression model, followed by the values obtained by the Taguchi method and the linear regression model. Thus, it is possible to apply the quadratic regression model successfully for the estimation of F_c and R_a.



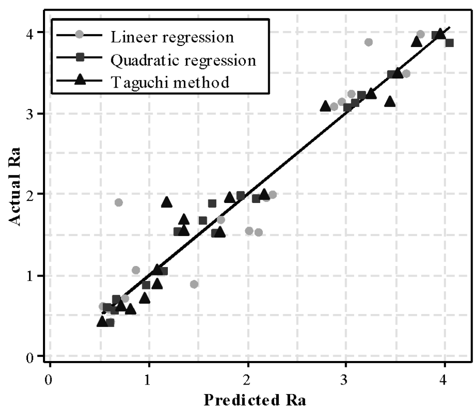


Figure 9: Comparisons of actual predicted values for: a) cutting force and b) surface roughness

Slika 9: Primerjave dobljenih-napovedanih vrednosti za: a) silo rezanja in b) hrapavost površine

4 CONCLUSION

This study was focused on the optimization (via the Taguchi method) of machining parameters, which included cutting tool, cutting speed, feed rate and cutting depth affecting cutting force and surface roughness in the turning of 15-5 PH martensitic stainless steel. Analytical models were developed using regression analysis for the estimation of F_c and R_a. The results are summarized as follows:

The optimum levels of the control factors for minimizing F_c and R_a were defined by using signal-to-noise ratios. The optimum control factors for cutting force (A2B3C1D1) were determined as a CVD-coated cutting tool, a cutting speed of 250 m/min, a feed rate of 0.1 mm/r and a depth of cut of 0.5 mm, while the optimum control factors for surface roughness (A2B2C1D1) were determined as a CVD-coated cutting tool, a cutting speed of 200 m/min, a feed rate of 0.1 mm/r and a depth of cut of 0.5 mm.

The ANOVA analysis revealed that the depth of cut was the most dominant parameter on F_c with the contribution ratio of 53.82 %, and that the feed rate was the most dominant parameter on R_a with the contribution ratio of 87.64 %.

The R^2 values of the equations obtained by the linear-regression model for the cutting force and surface roughness were calculated as 89.93 % and 87.04 %, respectively. These values were found to be 98.11 % and 98.79 % for the quadratic regression model. The higher correlation coefficients showed that the models had a good estimation ability. Consequently, from the point of view of estimation performances, the best result was obtained with the quadratic regression model, followed by the Taguchi method and the linear regression model, accordingly.

From the point of view of obtaining lower cutting force and lower surface roughness, the CVD TiCN-Al_2O_3-TiN-coated tool exhibited some advantage over the PVD TiAlN-AlCrO-coated tool.

In conclusion, in the turning of precipitation-hardened 15-5 PH stainless steel, the Taguchi method can be used successfully to decrease energy consumption and to increase product quality.

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