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OPTIMIZATION OF TURNING PARAMETERS WITH CARBIDE TOOL FOR SURFACE ROUGHNESS ANALYSIS USING RESPONSE SURFACE METHODOLOGY

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Abstract

This experimental study concentrates on the understanding of machining process in turning of 11sMn30 using carbide tip insert under dry condition.11SMn30 is an alloy of magnesium and zinc which is mainly used in the free cutting steel for bulk applications for joining elements in mechanical engineering and automotive components. The experimentation was carried out using three variables namely cutting speed, feed rate and depth of cut. The main objective of this work is to find out the optimal cutting parameters that affect the surface roughness values Ra and Rz. Tool used for the study was ANOVA. The optimized values for surface roughness Ra and Rz were obtained and found out that the effect of feed rate is the most significant factor on the surface roughness of the work piece.

***Keywords**:* Turning, Optimization, RSM

1. Introduction

Machining operations are used to produce a desired shape and size by removing excess stock from a blank in the form of chips. New surfaces are generated through a process of plastic deformation and crack propagation. The work piece is subjected to intense mechanical stresses and localized heating by tools having one or more shaped cutting edges. Surface roughness indicates the state of a machined surface. When a surface's level of shininess or asperity is clearly quantified, it is called surface roughness, which plays an important role in defining the character of a surface. The surface irregularities of a component or material may be intentionally created by machining, but they can also be created by a wide range of factors such as tool wobbling caused by motor vibration during machining. Process optimization is the discipline of adjusting a process so as to optimize some specified set of parameters without violating some constraints. The most common goals are minimizing cost, maximizing output, and/or efficiency. When optimizing a process, the goal is to maximize one or more of the process specifications, while keeping all others within their constraints.

Some of the related literature studies shown here Kagde and Deshmukh investigated on the optimization and the effect of cutting parameters on multiple performance characteristics (work piece surface roughness, spindle load) obtained by turning operations. CNMG 090308 PF carbide insert as tool and HCHC steel as work piece material were used in experiments [1]. Results showed that Spindle Speed and Feed rate were the more critical attributes on multiple cutting performance characteristics. The main tool used for the study was Experimental analysis. At high speeds, surface finish is least affected. At low speed surface roughness increases with increasing .optimum values of HCHC work piece material were speed 1700 rmp,feed rate 0.1rev/min and depth of cut 0.05 to 0.1 mm.

T. Rajmohan, K. Palanikumar and M. Kathirvel used Taguchi method and grey analysis to optimize the machining parameters in drilling hybrid metal matrix Al356/SiC-mica composites [2]. The drilling parameters were spindle speed, feed, drill type and mass fraction of mica were optimized based on the multiple performance characteristics including trust force, surface roughness, tool wear and burr height .the results obtained depicts that the feed rate and the type of drill are the most significant factors which affect the drilling process.

Azlan Mohd Zain, Habibollah Haron and Safian Sharif made an attempt using Genetic Algorithm and Simulated Annealing to search for a set of optimal process parameters value that leads to the minimum value of machining performance [3]. The main objectives included estimatimation of machining performance, estimation of the optimal process parameters values that has to be within the range of the minimum and maximum coded values for process parameters of experimental design and to evaluate the number of iteration generated by the computational approaches that lead to the minimum value of machining performance. The results of this study showed that both of the computational approaches managed to estimate the optimal process parameters, leading to the minimum value of machining performance when compared to the result of real experimental data.

Bharat Chandra Routara,Saumya Darsan Mohanty, Saurav Datta,Asish Bandyopadhyay And Siba Sankar Mahapatra conducted a study on a multi-objective optimization problem by applying utility concept coupled with Taguchi method through a case study in CNC end milling of UNS C34000 medium leaded brass. This study also made use of S/N ratio [4]. The case study indicates application feasibility of the aforesaid methodology proposed for multiresponse optimization and off-line control of multiple surface quality characteristics in CNC end milling.

Tao FU, Jibin ZHAO and Weijun LIU made an investigation on the optimization problems of cutting parameters in high speed milling of NAK 80 mold steel [5]. Tools used were Grey relational analysis and taguchi analysis and the input parameters were cutting speed, feed and depth of cut. The results of experiments show that grey relational analysis coupled with principal component analysis can effectively acquire the optimal combination of cutting parameters and the proposed approach can be a useful tool to reduce the cutting force.

S. Saikumar & M. S. Shunmugam conducted a study on Investigations into high-speed rough and finish end-milling of hardened EN24 steel for implementation of control strategies [6]. EN24 steel using single Insert cutter under different sets of cutting parameters for roughing and finishing operations. A response surface is developed to predict material removal volume and a set of cutting parameters is selected for a given range of material removal volume using differential evolution (DE) algorithm till the tool wear reaches certain value. The experimental data is also used to develop Bayesian-based artificial neural network (ANN) model. The predicted responses of ANN models will be useful to develop real-time control strategy for high-speed end-milling to achieve high productivity and quality.

V.N. Gaitondea, S.R. Karnikb and J. Paulo Davimc presented a methodology of Taguchi optimization method for simultaneous minimization of delimitation factor at entry and exit of the holes in drilling of SUPERPAN D´ECOR (melamine coating layer) MDF panel [7] . The experiments were carried out as per L9 orthogonal array with each experiment performed under different conditions of feed rate and cutting speed. The analysis of means (ANOM) was performed to determine the optimal levels of the parameters and the analysis of variance (ANOVA) was employed to identify the level of importance of the machining parameters on delimitation factor. The investigations revealed that the delaminating can be effectively reduced in drilling of MDF materials by employing the higher cutting speed and lower feed rate values.

Gül Tosun utilized taguchi analysis and signal to noise ratio to perform the statistical analysis of process parameters for surface roughness in drilling of Al/SiCp metal matrix composite [8]. The input parameters were spindle speed, feed rate, drill type, point angle of drill, and heat treatment. The level of importance of the drilling parameters is determined by using analysis of variance. The optimal drilling performance for the surface roughness was obtained at 0.16 mm/rev feed rate, 260 rev/min spindle speed, 130° drill point angle, carbide drill type, and as-received heat treatment settings.

S. Ramesh ,L. Karunamoorthy and K. Palanikumar conducted a study on the effect of cutting parameters on the surface roughness in turning of titanium alloy has been investigated using response surface methodology .the input parameters were cutting speed, feed and depth of cut [9]. The chip formation and SEM analysis are discussed to enhance the supportive surface quality achieved in turning. The work material used for the present investigation is commercial aerospace titanium alloy (gr5) and the tool used is RCMT 10T300 – MT TT3500 round insert. The equation developed using response surface methodology is used for predicting the surface roughness in machining of titanium alloy. The results revealed that the feed was the most influential factor which affects the surface roughness.

K. Palanikumar and J. Paulo Davim developed a mathematical model has been developed to predict the tool wear on the machining of GFRP composites using regression analysis and analysis of variance (ANOVA) in order to study the main and interaction effects of machining parameters, viz., cutting speed, feed rate, depth of cut and work piece fiber orientation angle [10].From the study conducted it was found out that the cutting speed has the most significant effect on tool wear followed by feed rate .

K. Palanikumar, L. Karunamoorthy and R. Karthikeyan made an attempt to assess the influence of machining parameters on the machining of GFRP composites [11]. Design of experiments was used as a tool for doing the experiments. The machining experiments were conducted on all geared lathe using coated cement tool inserts with two levels of factors. The factors considered were cutting speed, work piece fiber orientation angle, depth of cut and feed rate. From the study conducted it was noted that feed rate is the factor, which has greater influence on surface roughness, followed by cutting speed.

Hement Kumar Agarwal [12] conducted a study on study of surface roughness in turning of aisi1050 mildsteel.In this study the Taguchi method is used to find the optimal cutting parameters for surface roughness in turning. The orthogonal array, S/N ratio, and ANOVA are used to study the performance characteristics in turning operations of AISI 1050 steel bars using uncoated tools. Three cutting parameters namely spindle speed, feed rate and depth of cut are optimized with considerations of surface roughness. Experimental results are provided to illustrate the effectiveness of this approach.

In this study the turning was carried out on 11sMn30 and WIDIA CNMG 120408-49-TN 2000 was used as tool tip using various important machining parameters namely cutting speed, feed rate and depth of cut. Surface roughness was measured using Mitutoyo SJ-210 portable surface roughness tester after machining was completed .The data obtained from the experiment was analyzed using RSM to determine the combination of machining parameters that offer the best optimal performance in terms of cutting speed, feed and depth of cut .

2. Experimental Procedure

The experiment work was carried out on CNC Turning Center STALLION 200, the main drive power is 7.5KW and the speed range was in the range 100-4000rpm.Rapid traverse-cross/longitudinal were 15/20 m/min. The work material was an alloy of mild steel and magnesium rod (22Ǿ x 150mm), 11SMn30 was used for the experiment. Its composition is 0.08%C, 0.04%Si, 1.10%Mn, 0.07%P, 0.30%S. Tensile Strength of the material is 395N/mm^2 and hardness of 159HB.Mainly Applied in the free cutting steel for bulk applications for joining elements in mechanical engineering and automotive components. WIDIA CNMG 120408-49-TN 2000 was used as tool tip. After every experiment, the surface roughness values Ra and Rz were measured by MItutoyo SJ- 201 surface roughness tester and measurements were repeated thrice. Using Taguchi Standard Orthogonal array, the experiment results are shown in table 2.This plan was developed for establishing the quadratic model of the surface roughness using response surface analysis.

The literature survey and in agreement with ISO 3685 identified the turning parameters and their levels for the experiment. As a result three parameters such as spindle speed, Feed rate and depth of cut are selected and experimental conditions are given in the table below

Table 1: *Cutting parameters and their levels for turning*

Symbol	Control Factor	Unit	Level 1	Level 2	Level 3
V	speed	m/min	135	180	225
f	Feed	mm/rev	0.1	0.2	0.3
d	Depth of Cut	mm	0.5	1	1.5

The surface roughness Ra and Rz, were measured using Mitutoyo SJ-210 portable surface roughness tester. These values were the average of four values measured from the three different points on the circumference of the machined part.

Figure 1:*Mitutoyo SJ-210 portable surface roughness tester*

Figure2 :*CNC Turning Center STALLION 200*

3. Results and discussions

The surface roughness parameters were measured using the input factors namely cutting speed, feed rate and depth of cut. The measured response surface roughness corresponding to the varying machine parameters is shown in table 2.The statistical analysis was done with the help of MINITAB 17 software for obtaining the main effects. The main objective of this research was to explain the use of RSM in order to find the optimum surface roughness with particular combination of cutting parameters .The equations for surface roughness Ra and Rz are given below

$$Ra=2.44+0.0416\ Speed-4.66\ Feed-4.473\ Depth-0.000133\ Speed*Speed+16.5\ Feed*Feed+1.662\ Depth*Depth \quad (1)$$

$$Rz=11.77+0.3560\ Speed-28.2\ Feed-30.91\ Depth-0.001123\ Speed*Speed+106.5\ Feed*Feed+11.51\ Depth*Depth \quad (2)$$

The above equations show depth of cut is the most dominant factor among the cutting parameters which affect the surface roughness .Hence larger values of depth of cut must be selected for better surface finish. This is because their P-values are higher than 5% at 95 % confidence level. After examining the experimental data, it can be seen that interaction terms of cutting speed, feed rate and depth of cut are significant at 95% confidence interval. The adequacy of first and second order model was verified using ANOVA as shown in the table 3 and 6. At a level of confidence of 95%, the model was checked for its adequacy .

Figure 3 shows the main effect plots for Ra .From the graph it is understood that when depth of cut increases surface roughness decreases. But when feed increases, surface roughness also increases and when speed increases, surface roughness decreases. Similarly figure 9 shows the interaction plots for Rz. From the graph it is understood that when depth of cut increases surface roughness decreases. But when feed increases, surface roughness also increases and when speed increases, surface roughness decreases.

The interactions between three significant cutting parameters and surface roughness ,Ra are shown in figure 4. Figure 5 shows counter plots of speed*feed, feed*depth and depth*speed. Surface plots of Ra against the cutting parameters are shown in figures 6, 7 and 8. Similarly the interactions between three significant cutting parameters and surface roughness Rz are shown in figure 10. Figure 11 shows counter plots of speed*feed, feed*depth and depth*speed. Surface plots of Rz against the cutting parameters are shown in figures 12,13 and 14.

Table 2: *Experiment results and their S/N ratios*

	Control factors			**Surface roughness**	
Sl no	**Speed**	**Feed**	**Depth of cut**	**Ra**	**Rz**
	m/min	mm/rev	mm	µm	µm
1	135	0.1	0.5	3.512	24.9735
2	135	0.2	1	2.647	19.003
3	135	0.3	1.5	2.65	19.599
4	180	0.1	1	2.409	17.899
5	180	0.2	1.5	2.38	17.549

6	180	0.3	0.5	3.984	28.426
7	225	0.1	1.5	1.897	13.214
8	225	0.2	0.5	2.878	20.644
9	225	0.3	1	2.348	16.67

Table 3: *Analysis of variance (Ra)*

Source	DOF	Adj SS	Adj MS	F value	P value
model	6	3.2243	0.53739	18.46	0.05
linear	3	2.67988	0.89329	30.68	0.03
Speed	1	0.47377	0.47377	16.27	0.05
Feed	1	0.22582	0.22582	7.76	0.10
Depth	1	1.9803	1.9803	68.02	0.01
Square	3	0.54445	0.18148	6.23	0.14
Speed*Speed	1	0.14472	0.14472	4.97	0.15
Feed*Feed	1	0.05445	0.05445	1.87	0.30
Depth*Depth	1	0.34528	0.34528	11.86	0.07
Error	2	0.05823	0.02911		
Total	8	3.28256			

Table 4: *Model Summary (Ra)*

S	R-sq	R-sq(adj)	R-sq(pred)
0.170625	98.23%	92.90%	91.08%

Table 5: *Coded Coefficients (Ra)*

Term	Effect	Coef	SE Coef	T value	P value	VIF
Constant			2.537	16.86	0.003	
Speed	-0.562	-0.532	-0.281	-4.03	0.056	1
Feed	0.388	0.388	0.194	2.79	0.108	1
Depth	-1.149	-1.149	-0.5745	-8.25	0.014	1
Speed*speed	-0.538	-0.269	-0.269	-2.23	0.156	1
Feed*feed	0.33	0.165	0.165	1.37	0.305	1
Depth*depth	0.831	0.416	0.416	3.44	0.075	1

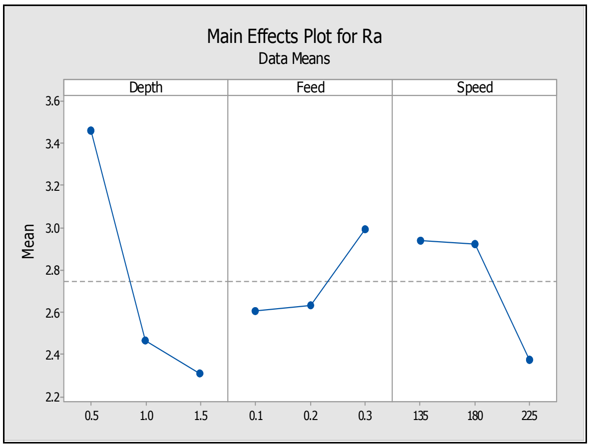

Figure 3: Main *Effects plot for Ra*

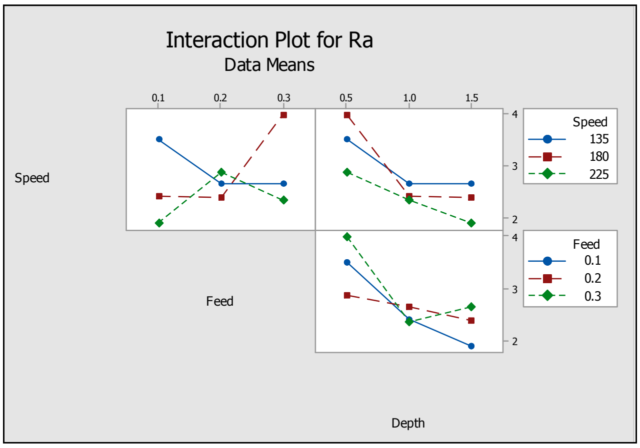

Figure 4: Interaction *plot for Ra*

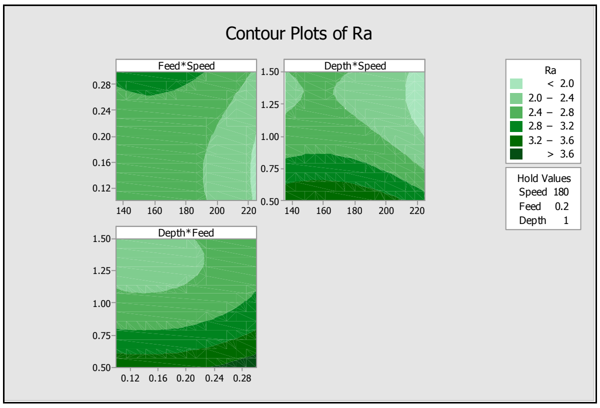

Figure 5: Counter *plots for Ra*

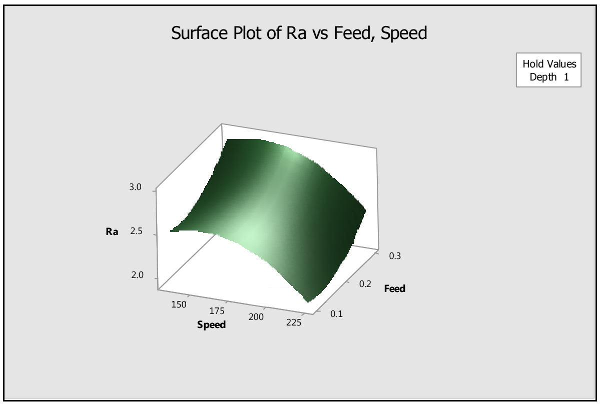

Figure 7: Counter *Surface plots of Ra vs. Feed, Speed*

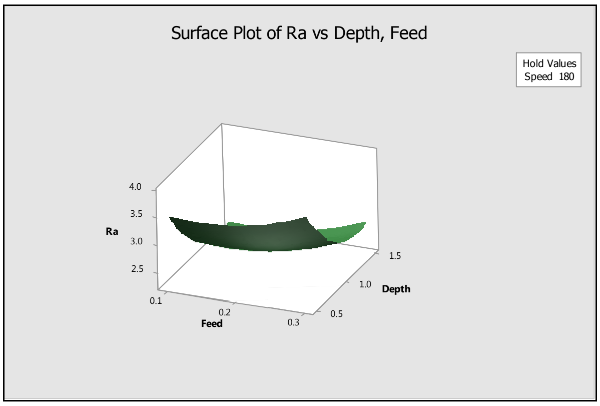

Figure 6: *Surface plots of Ra vs. Depth, Feed*

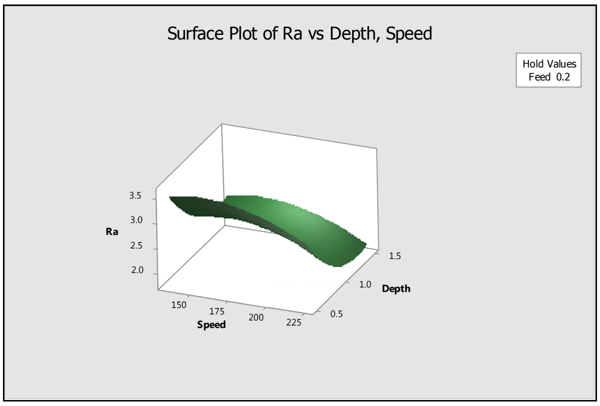

Figure 8: Surface *plots of Ra vs. Depth, Speed*

Table 6: *Analysis of variance (Rz)*

Source	DOF	Adj SS	Adj MS	F value	P value
Model	6	163.357	27.226	51.79	0.019
Linear	3	134.193	44.73	85.09	0.015
Speed	1	28.373	28.3729	53.97	0.018
Feed	1	12.351	12.341	23.49	0.04
Depth	1	93.469	93.468	177.8	0.006
Square	3	29.164	9.7214	18.49	0.052
Speed*speed	1	10.343	10.342	19.67	0.047
Feed*feed	1	2.268	2.2681	4.31	0.173
Depth*depth	1	16.553	16.553	31.49	0.03
Error	2	1.051	0.5257		
Total	8	164.409			

Table 7: *Model Summary (Rz)*

S	R-sq	R-sq(adj)	R-sq(pred)
0.725048	99.36%	97.44%	87.05%

Table 8: *Coded Coefficients (Rz)*

Term	Effect	Coef	SE Coef	T value	P value	VIF
Constant		18.663	0.639	29.19	0.001	
Speed	-4.349	-2.175	0.296	-7.5	0.018	1
Feed	2.869	1.435	0.296	4.85	0.04	1
Depth	-7.894	-3.947	0.296	-13.33	0.006	1
Speed*speed	-4.548	-2.274	0.513	-4.44	0.047	1
Feed*feed	2.13	1.065	0.513	2.08	0.173	1
Depth*depth	5.754	2.877	0.513	5.61	0.03	1

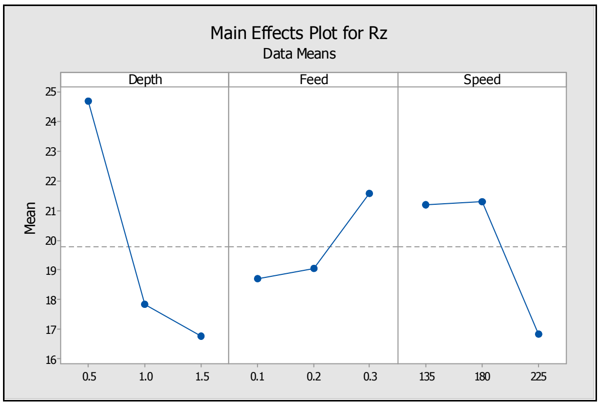

Figure 9: Main *affects plots for Rz*

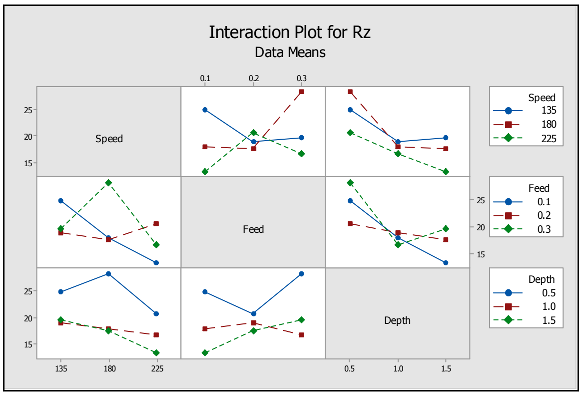

Figure 10: Interaction *plots for Rz*

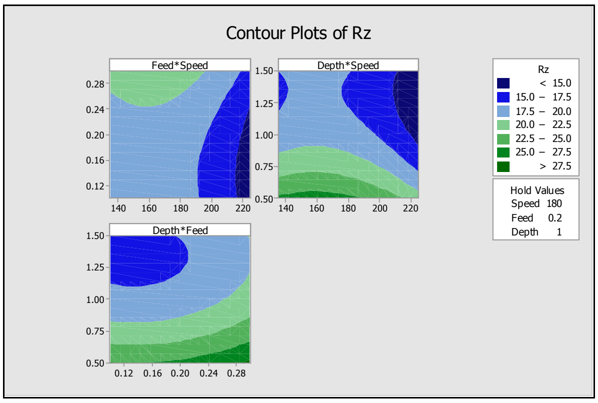

Figure 11: Counter *plots for Ra*

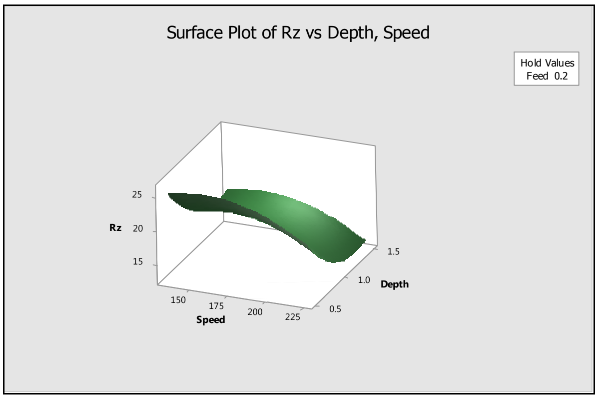

Figure 13: Surface *plots of Ra vs. Depth, Speed*

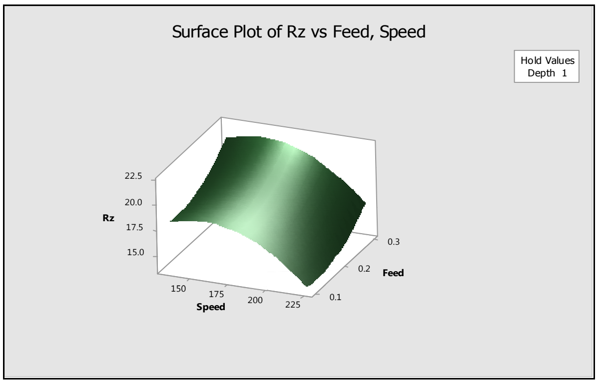

Figure 12: Surface *plots of Ra vs. feed, Speed*

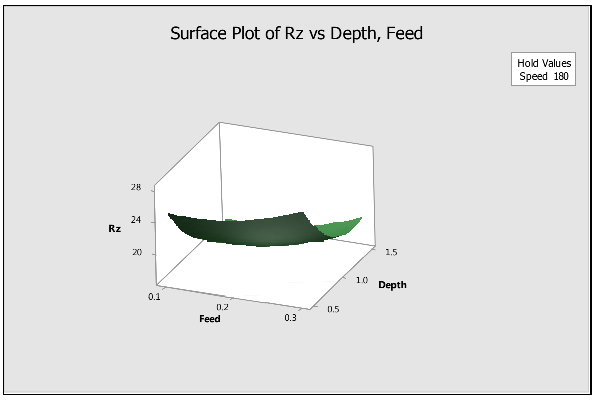

Figure 14: Surface *plots of Ra vs. Depth, Feed*

4. Confirmation experiments

To verify the fitness of the model developed, three confirmation run experiments are performed .the test conditions are within in the range of levels defined before. The percentage error is calculated based on the difference between the predicted value and the actual experimental value. The percentage error range between the actual and predicted value of Ra is as follows: Ra experimental predicted value ranges between 1.81% and 4.82%. The percentage error range between the actual and predicted value of Rz is as follows: experimental predicted value ranges between 1.17% and 4.72%.

Table 9: *Confirmation test for Ra*

SL no	Speed	Feed	Depth	Experimental value	Predicted Value	Error %
1	135	0.1	0.5	3.512	3.69	4.82
2	225	0..1	1.5	1.897	1.932	1.81
3	180	0.1	1	2.409	2.469	2.43

Table 10: *Confirmation test for Rz*

SL no	Speed	Feed	Depth	Experimental value	Predicted Value	Error %
1	135	0.1	0.5	24.9735	25.003	1.17
2	225	0..1	1.5	13.214	13.87	4.72
3	180	0.1	1	17.899	17.967	3.78

5. Conclusion

The present work shows the use of Response surface methodology to find out optimal machining parameter. Machining Parameters namely Cutting speed V, Feed rate f, depth of cut d were optimized to meet the objective .As a result of the study the following conclusions are drawn:

- The observation result shows that the primary factor affecting the surface roughness is depth of cut, subsequently followed by cutting speed and feed.
- The optimized control factors for minimizing the Surface roughness Ra were
  Cutting speed, V_3=225m/min, Feed rate f_1=0.1mm/rev, Depth of Cut d_3=1.5mm
- The optimized control factors for minimum Surface roughness Rz were
  Cutting speed, V_3=225m/min, Feed rate f_1=0.1mm/rev, Depth of Cut d_3=1.5mm
- From the RSM analysis it was found that the depth of cut is the most dominant factor affecting the surface roughness, Ra and Rz

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