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OPTIMIZATION OF MACHINING PARAMETERS IN TURNING OF EN-31 ALLOY STEEL USING RESPONSE SURFACE METHODOLOGY

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ABSTRACT

In this paper a detail study was performed on the CNC lathe machine for turning of the EN-31 alloy steel. Response surface methodology (RSM) is used for design of experiments which is based on second order face centred central composite design (CCD). The effect of process parameters viz. Spindle speed, feed rate and depth of cut on the surface roughness and material removal rate is carried out and optimize the response variables (for maximum material removal rate and minimum surface roughness). In present era the requirement of industries it may be micro, small and medium is mainly concerned with high quality products with minimum cost is desirable. So turning is the basic starting process for any product which came from casting, forging, extrusion and drawing process for remove the undesirable material in high quantity without compromising the quality of the product (Basic function) for which the product mainly design for intended purpose. In turning process the tool is moved parallel to the work piece axes or in linear direction and work piece is held fixed in the jaw of chuck and rotate together with the rotation of spindle which is attach to the chuck. The big challenge for any industry in India is to produce high quality products in large quantity with the same resources and within the time limit. So this is possible with the help of CNC machine which is desirable for automation and to achieve high accuracy, flexibility and saving of time and include lower production cost with increased productivity without compromising with quality of the product.

Keywords: CNC lathe, EN-31 alloy steel, Material removal rate, Response surface methodology (RSM), Surface roughness, Turning operation.

I. INTRODUCTION

For present thesis work EN-31 high carbon alloy steel is used as a material and CNC turning as a process for study. Design of experiments is done using the response surface methodology which is based on face centered second order central composite design (CCD). In the past many researcher made attempt the study on optimising process parameters for increasing tool life, minimum cutting forces, power with different coolant and different tools. Also the work is done on manual Lathe machine. Researchers mainly used the Taguchi method for design of experiments and grey relational analysis for optimization. But this research paper is mainly focused on dry turning of EN-31 alloy steel on the numerical control machine (CNC) without heat treatment of the material and study the effect of spindle speed, feed rate, and depth of cut on the surface roughness and material removal rate (MRR) using TIN (chemical vapour deposition) coated carbide insert of korloy make is used. In this study, Response surface methodology is used to develop mathematical modelling and ANOVA is used to check the significance of the develop model and also to verify the effect of process parameters whether it is significant or not. Optimization has been attempted for surface roughness and material removal rate for combination of process parameters spindle speed, feed rate and depth of cut. All experimental data analysis and plot is done using the design of expert software. Prediction of optimization value is done by the mathematical model using design of expert software and after that the selected combination of process parameters for optimization is used to perform set of confirmation runs. The difference between predicted and actual value is below the 5% or under the 95% confidence interval which is desirable. So the present thesis work result is useful for the industry it will show that material removal rate and surface finish can be predicted with the help of developed model and the predicted values are near to the actual values.

II. LITERATURE REVIEW

Ravinder Tonk, Jasbir Singh Ratol (2012) Investigated the effects of the parametric variations in turning process of En31 alloy steel. Taguchi's robust design methodology has been used for statistical planning of the experiments. Experiments were conducted on conventional lathe machine in a completely random manner to minimize the effect of noise factors present while turning EN31 under different experimental conditions. The analysis of results shows that input parameter setting of cutting tool as carbide, cutting condition as dry, spindle speed at 230 rpm, feed at 0.25mm/rev and depth of cut at 0.3 mm has given the optimum results for the thrust force and input parameter setting of cutting tool as HSS, cutting fluid as soluble oil, spindle speed at 230 rpm, feed at 0.25 mm/rev and depth of cut at 0.3 mm have been given the optimum results for the feed force when EN31 was turned on lathe.

Jitendra J. Thakkar et. al (2014) Study optimizes the process parameters for surface roughness and Material Removal Rate (MRR) in turning of SS 410 round bars on CNC machine. The experimentation was carried out with PVD-coated (WNMG) cutting tools; the multi response optimization problems i.e. Optimization of SR and MRR are solved by using Genetic Algorithm (GA). The optimization is done using twenty seven experimental runs based on L’27 orthogonal array.Feed rate is found the most significant effect on surface roughness. Increase in feed rate, value of surface roughness is increase. Increase in cutting speed, value of surface roughness is decrease. Increase in depth of cut value of surface roughness is increase .The percentage contribution of cutting speed is 12.01 %, feed of 78.45 % and depth of cut of 2.04 % on surface roughness for straight turning operation. Feed and Depth of cut are found the most significant effect on material removal rate. Increase in feed and depth of cut, value of material removal rate is increase.The percentage contribution of cutting speed is 14.67 %, feed of 18.14 % and depth of cut of 58.57 % on material removal rate for turning operation.

Richard Geo, Jose Sheril D’cotha (2014) Studied the effect of machining parameters (cutting speed, feed rate, depth of cut) on power consumption of the tool during turning of EN-24 alloy steel was studied. Tools considered in this experimental work are HSS and tungsten carbide tool. Comparison of power consumed by the tools was done. The power consumed by both tools is measured by measuring the forces acting on the cutting tool using a lathe tool dynamometer with a digital display for measuring the forces acting on three axes. From the model it was found that cutting speed is the most important factor that influences power consumed by the tool and feed rate has less influence. From the comparison of the tools it was found that during turning of EN-24 steel rod with both tools the HSS tool consumes more power than the carbide tool.

Poornima, Sukumar (2012) Study involves in identifying the optimized parameters in CNC turning of martensitic stainless steel. The optimization techniques used in this study are Response surface methodology, and Genetic algorithm. The results obtained from RSM are R-Sq obtained was 99.9% which indicates that selected parameters (speed, feed, depth of cut) significantly affect the response (surface roughness). The Best ranges obtained by using the genetic algorithm approach are Cutting velocity (speed) -119.93 m/min, Feed-0.15 m/min and Depth of cut -0.5mm. Hence the Optimal surface roughness from GA is 0.74 microns.

S.R. Das et. al (2012) Study on optimization method of the cutting parameters (cutting speed, depth of cut and feed) in dry turning of AISI D2 steel to achieve minimum tool wear and low work piece surface temperature. The experimental layout was designed based on the Taguchi's L9 (34) Orthogonal array technique and analysis of variance (ANOVA) was performed to identify the effect of the cutting parameters on the response variables. The results showed that depth of cut and cutting speed are the most important parameter influencing the tool wear. The minimum tool wear was found at cutting speed of 150 m/min, depth of cut of 0.5 mm and feed of 0.25 mm/rev. Similarly low work piece surface temperature was obtained at cutting speed of 150 m/min, depth of cut of 0.5 mm and feed of 0.25 mm/rev.

III. OBJECTIVES

The main objectives of this paper are:-

- To find out the effect of process parameters viz. spindle speed, feed rate, and depth of cut on the surface roughness and material removal rate.
- To develope the mathematical model for surface roughness and material removal rate for predicting the value of responses.
- To find out which process parameters are more significant and which is less significant to affect the material removal rate and surface roughness.
- To identify the non significant parameters which are to be removed from the mathematical model.
- Optimize the process parameters for minimum surface roughness and maximum material removal rate.
- To find out the combination of process parameters which is used to optimize the responses with the help of predicted value from the model and by performing confirmation run on same combination if error is less than 5% then optimization is confirmed because in this paper 95% confidence interval is used.

IV. RESEARCH METHODOLOGY

In this research paper for design of experiment Response surface methodology has been used for design the matrix to perform the experimental work. Response surface methodology (RSM) is a combination of various mathematical and statistical techniques in which modelling and analysis of problem is done. It is useful in the problems where response of the problem is directly influenced by the different variables in same manner or different manner. So there are three important terms related to response surface methodology which completely define its purpose to where it used in the problems for design of experiments. First the input parameters (x_1, $x_{2,\ldots}$) which are also called variables, second output or response (Y) of the experiment which is depend on the input parameters. So the input parameters are independent and response is dependent on the input parameters. Third is the error (e) which is occurred during the measurement of response.

$$Y = f(x_{1,}\, x_{2,\ \ldots\ldots\ldots\ldots}) + e$$

Disadvantage of first order model is that it is not used when the response surface having curvature effect. So that in present research paper second order model is used.

So the function with 3 variables having second order model is:

$$Y = \beta_0 + \beta_1X_1 + \beta_2X_2 + \beta_3X_3 + \beta_{11}X^2 + \beta_{22}X^2 + \beta_{33}X^2 + \beta_{12}\, X_1\, X_2 + \beta_{13}\, X_1\, X_3 + \beta_{23}\, X_2\, X_3 + \varepsilon$$

RSM is used to:-

- To determine the factor levels that will simultaneously satisfy a set of desired specifications,
- To determine the optimum combination of factors that yields a desired response and describes the response near the optimum,
- To determine how a specific response is affected by changes in the level of the factors over the Specified levels of interest,
- When response surface topography is studied like local minimum, ridge lines, local maximum etc.
- Find the region in response surface where the optimal solution occurs. The aim is to get a maximum or minimum response along a path with quick and efficient move so that response is optimized.

There are many designs available for fitting a second order model but in this research paper central composite design (CCD) is used. Face centred composite design having subdivided into three parts i) factorial points (2^k) ii) star points (2k) iii) centre points (n), where k is the number of input parameters or variables. So for this thesis work 3 variables spindle speed, feed rate and depth of cut is chosen.

Variables	Factorial points (2^k)	Star points (2k)	Centre points (n)	Total number of experiment (N)	Value of α
3	8	6	6	20	1.0

4.1 DESIGN OF EXPERIMENTS AND DATA ANALYSIS

Table 4.1: Input parameters and their levels

FACTORS	UNIT	TYPE	LEVEL 1	LEVEL 2	LEVEL 3
Spindle speed(N)	RPM	Numeric	1000	1500	2000
Feed rate (F)	mm/rev	Numeric	0.10	0.15	0.20
Depth of cut (D)	mm	Numeric	0.1	0.2	0.3

Table 4.2: Observed value for performance characteristics

Std. order	**Run order**	**Factor A**	**Factor B**	**Factor C**	**Response 1**	**Response 2**
		Spindle speed (N) (RPM)	**Feed rate (F) (mm/rev)**	**Depth of cut (D) (mm)**	**Surface roughness (Ra) (µm)**	**Material removal rate (MRR) (mm^3/sec)**
6	1	2000	0.1	0.3	0.84	63.10
14	2	1500	0.15	0.3	0.97	80.13
11	3	1500	0.1	0.2	0.81	19.72
9	4	1000	0.15	0.2	1.23	29.59
7	5	1000	0.2	0.3	1.42	38.46
16	6	1500	0.15	0.2	0.86	48.08
3	7	1000	0.2	0.1	1.3	14.25
13	8	1500	0.15	0.1	0.79	32.05
2	9	2000	0.1	0.1	0.67	12.82
1	10	1000	0.1	0.1	1.15	6.75
18	11	1500	0.15	0.2	0.9	64.10
15	12	1500	0.15	0.2	0.86	32.05
4	13	2000	0.2	0.1	0.73	25.64
5	14	1000	0.1	0.3	1.22	12.82
17	15	1500	0.15	0.2	0.85	16.03
10	16	2000	0.15	0.2	0.72	64.10
8	17	2000	0.2	0.3	0.85	64.10
20	18	1500	0.15	0.2	0.85	48.08
12	19	1500	0.2	0.2	0.92	42.74
19	20	1500	0.15	0.2	0.82	16.03

4.2 RESULTS

4.2.1 MATHEMATICAL MODEL

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i) Mathematical model for surface roughness:

Final equation in terms of coded factors:

$$Ra = +0.86 - 0.25*A + 0.053*B + 0.066*C - 0.035*AB + 0.13*A^2 + 0.034*C^2$$

Final equation in terms of actual factors

$$Ra = +2.30500 - 1.84450E - 003*RPM + 3.16000*feed - 0.71500*DOC - 1.40000E - 003*RPM*feed + 5.17500E{-}007*RPM^2 + 3.43750*DOC^2$$

ii) Mathematical model for material removal rate

Final equations in terms of coded factors:

Final equation in terms of coded factor

$$MRR = +36.53 + 12.79*A + 16.71*C$$

Final equation in terms of actual factor

$$MRR = -35.25500 + 0.025578*RPM + 167.10000*DOC$$

4.2.2 GRAPHICAL PLOTS

I) plots for surface roughness

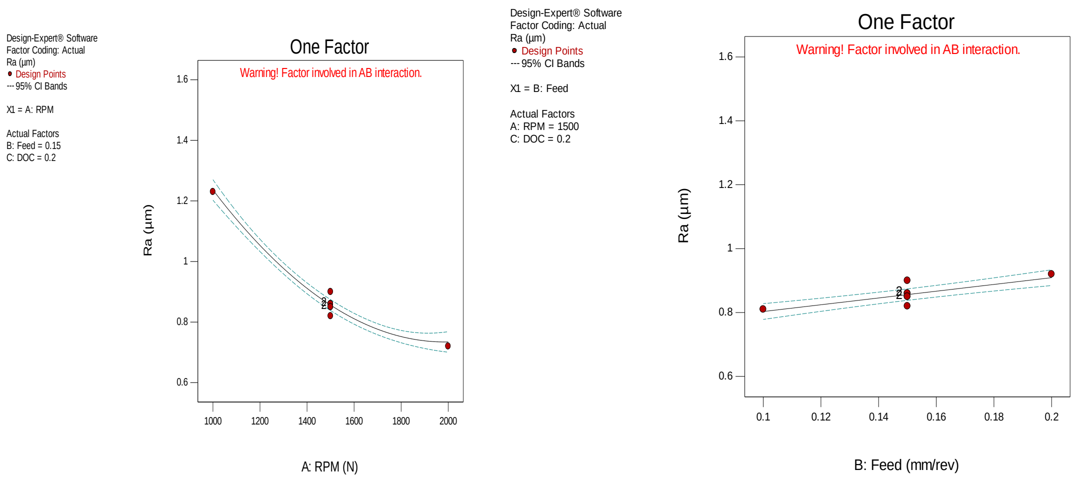

Figure 4.1: Effect of spindle speed and feed rate on surface roughness

- Surface roughness decreases as the spindle speed increases i.e. surface roughness is inversely proportional to the spindle speed.
- Surface roughness increases as the value of feed rate increase i.e. surface roughness is directly proportional to feed rate.

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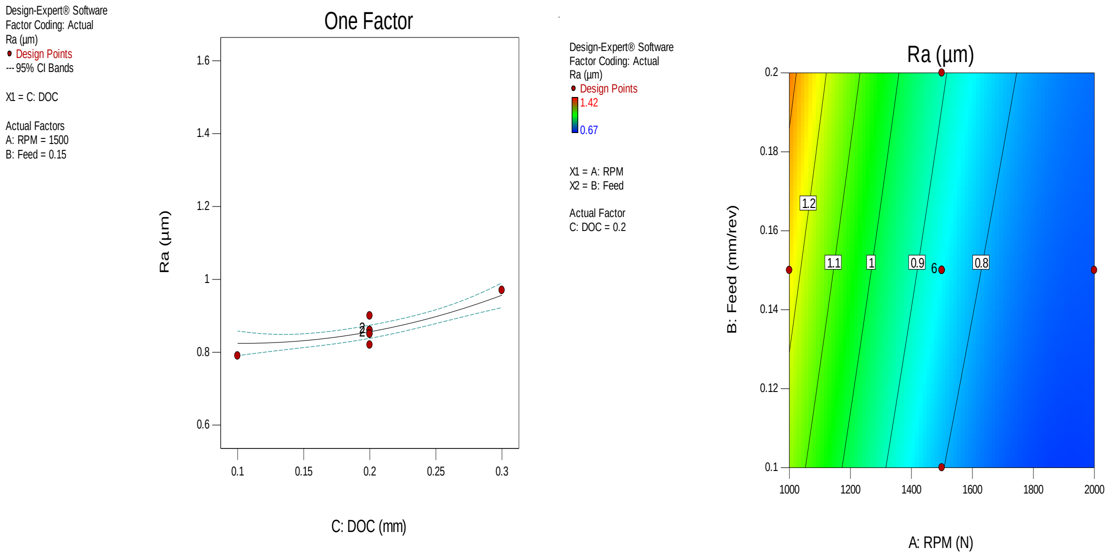

Figure 4.2: Effect of depth of cut on surface roughness and contour plot for surface roughness

- Surface roughness increases as the value of depth of cut is increases.

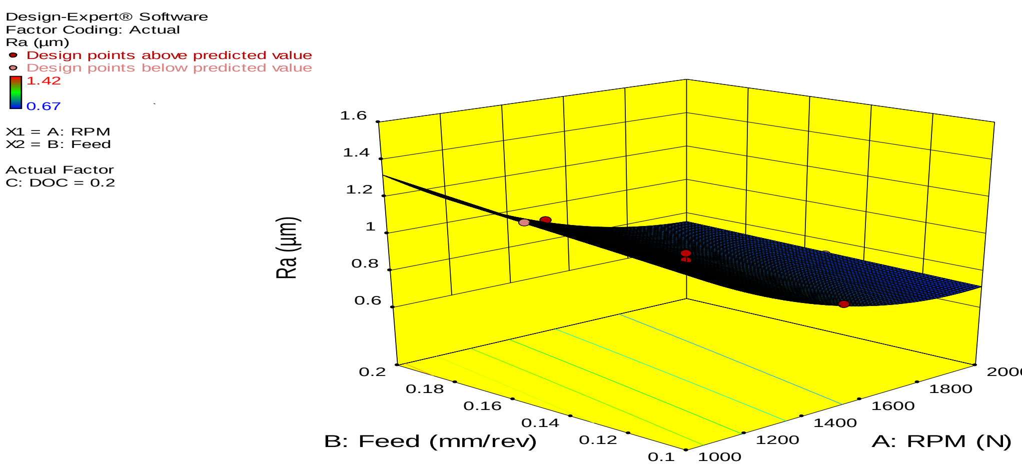

Figure 4.3: 3D plot for combined effect of feed & RPM on surface roughness.

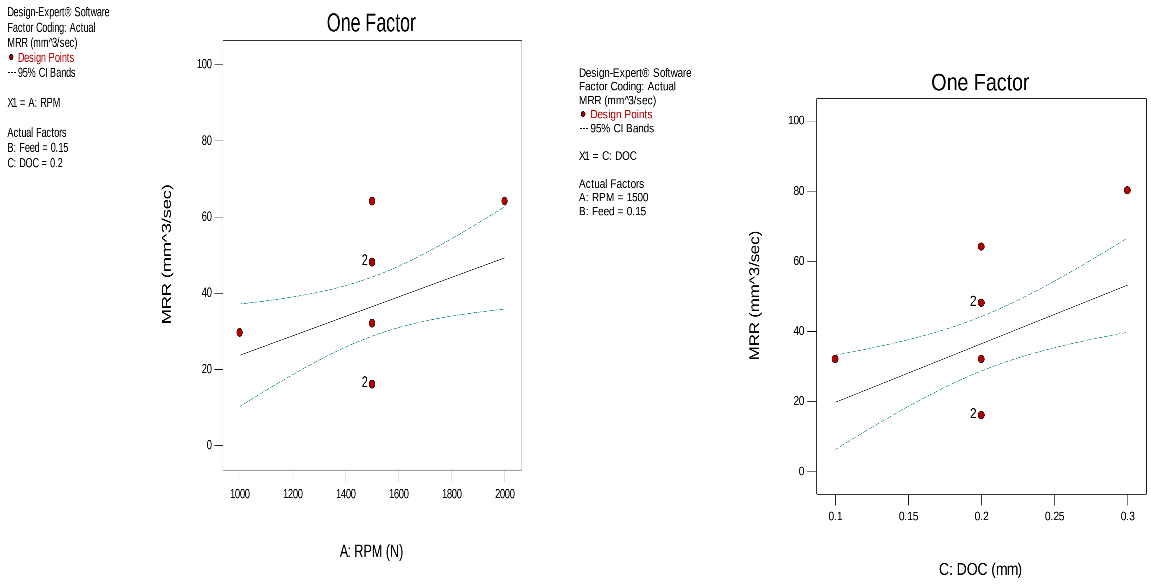

Figure 4.4: Effect of spindle speed and depth of cut on material removal rate

- Material removal rate is increases as the value of spindle speed and depth of cut is increases.
- Feed rate has insignificant effect on material removal rate.

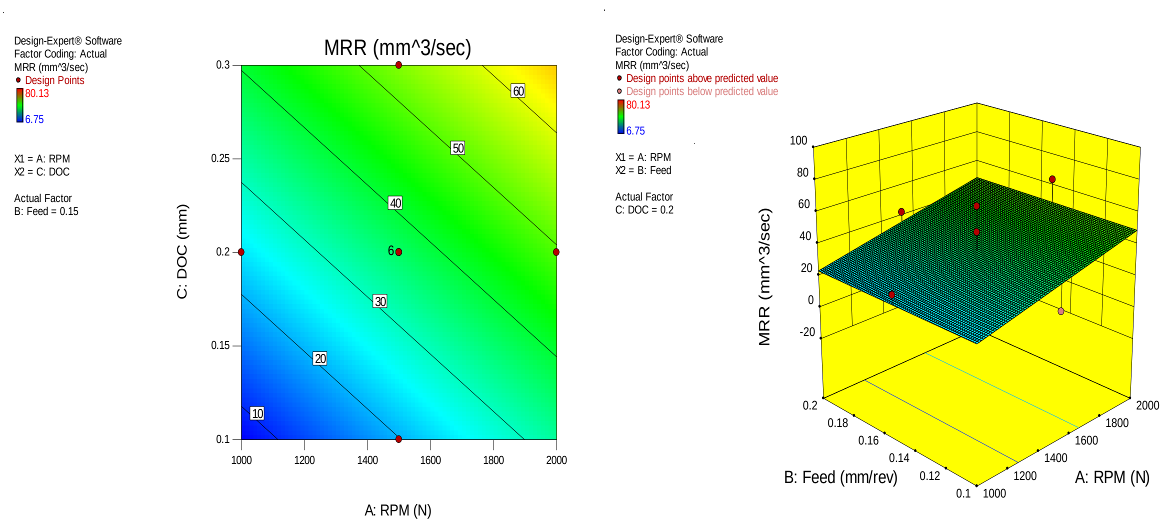

Figure 4.5: contour plot and 3D plot for surface roughness

Table 4.3: ANOVA tables [partial sum of squares –Type III] for surface roughness

Source	**Sum of squares**	**Df**	**Mean square**	**F value**	**p-value prob>F**	
Model	0.83	6	0.14	224.78	<0.0001	Significant
A-RPM	0.63	1	0.63	1026.49	<0.0001	
B-Feed	0.028	1	0.028	45.77	<0.0001	
C-DOC	0.044	1	0.044	70.97	<0.0001	
AB	9.800E-003	1	9.800E-003	15.97	0.0015	
A^2	0.054	1	0.054	87.27	<0.0001	
C^2	3.781E-003	1	3.781E-003	6.16	0.0275	
Residual	7.979E-003	13	6.138E-004			
Lack of fit	4.645E-003	8	5.807E-004	0.87	0.5904	Not significant
Pure error	3.333E-003	5	6.667E-004			
Cor total	0.84	19				

Table 4.4: ANOVA tables [partial sum of squares –Type III] for MRR

Source	**Sum of squares**	**Df**	**Mean square**	**F-value**	**p-value prob>F**	
Model	4427.83	2	2213.91	8.17	0.0033	Significant
A-RPM	1635.59	1	1635.59	6.04	0.0251	
C-DOC	2792.24	1	2792.24	10.31	0.0051	
Residual	4606.05	17	270.94			
Lack of fit	2723.06	12	226.92	0.60	0.7814	Not significant
Pure Error	1882.99	5	376.60			
Cor total	9033.88	19				

Table 4.5: Constraints for optimization of cutting conditions

Condition	**Goal**	**Lower limit**	**Upper limit**
Spindle speed (RPM)	Is in range	1000	2000
Feed rate (mm/rev.)	Is in range	0.10	0.20
Depth of cut (mm)	Is in range	0.10	0.30
Surface roughness (µm)	Minimize	0.67	1.42
Material removal rate (mm^3/sec)	Maximize	6.75	80.13

Table 4.6: Predicted value for optimization of responses

sr. no.	Spindle speed (RPM)	Feed rate (mm/rev)	Depth of cut (mm)	Surface roughness (µm)	Material removal rate (mm^3/sec)	Remarks
1.	2000	0.10	0.3	0.817	66.03	Selected

***desirability 0.806**

Table 4.7: Plan of confirmation experiments and optimization results

Test no.	**Cutting conditions**			**Response**		
1.	**Spindle speed (RPM)**	**Feed rate (mm/rev)**	**Depth of cut (mm)**	**Results**	**Surface roughness (µm)**	**Material removal rate (mm^3/sec)**
	2000	0.10	0.3	Predicted	0.817	66.031
				Experimental	0.84	63.10
				Error (%)	2.74	4.65

V. CONCLUSIONS AND FUTURE SCOPE OF WORK

A three level three numeric factors response surface methodology based on face centered central composite design technique has been used for the development of mathematical models to predict the surface roughness and material removal rate.

The important conclusions drawn from the present work has been summarized as follows:-

1. SURFACE ROUGHNESS

- Surface roughness increases as the cutting speed decreases and surface roughness decreases as the cutting speed increases.
- Surface roughness increases as the level of feed rate increases i.e. surface roughness is proportional to the feed rate.
- Surface roughness decreases as the depth of cut decreases or vice versa.
- In concerned with the surface roughness spindle speed seems to be the most significant and influential parameter followed by depth of cut. The feed rate has the least effect on the surface roughness.

2. MATERIAL REMOVAL RATE

- Material removal rate is increased with the increment of spindle speed and depth of cut and vice versa.
- Out of three process parameters depth of cut seems to be the most significant and influential parameter followed by spindle speed.
- The feed rate has insignificant influence on the material removal rate.

3. The results of ANOVA and the confirmation runs verify that the developed mathematical model for surface roughness and material removal rate show excellent fit and provide predicted values of surface roughness and material removal rate that are close to the experimental values, with a 95% confidence level.

4. The percentage error between the predicted and experimental values of the response factor during the confirmation experiments are within 5 percent.

5. The developed mathematical model can be used for direct evaluation or surface roughness and material removal rate under various combinations of machining parameters during the turning process.

6. The optimal sets of process parameters have been obtained for various performance measures using response surface methodology (RSM) based on face centered central composite design of experiment methodology. The summary results of predicted optimal values of the responses and their confidence intervals (both for confirmation experiment and prediction) are given as under:

Test no.	**Cutting conditions**			**Response**		
1.	**Spindle speed (RPM)**	**Feed rate (mm/rev)**	**Depth of cut (mm)**	**Results**	**Surface roughness (µm)**	**Material removal rate (mm^3/sec)**
	2000	0.10	0.3	Predicted	0.817	66.031
				Experimental	0.84	63.10
				Error (%)	2.74	4.65

5.1 Future scope of work

Although the CNC turning has been thoroughly investigated for EN-31 alloy steel work piece, still there is a scope for further investigation. This paves a way for following future work:

- To study the effect of cutting fluids and tool geometry on the surface roughness and material removal rate.
- To analyze the effect of these three input parameters on response chip - tool interface temperature.
- In this study, mathematical modelling and optimization has been attempted only for surface roughness and material removal rate. The work can be extended to consider more response variables like chip –

tool interface temperature, machining time, tool wear, different coolant, nose radius and tool geometry etc.

- In the present work Ra value (arithmetic average of absolute values) have been measured for surface roughness. However R_t (maximum height of profile) can also be considered for measuring surface roughness in case of die steels.

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