International Journal of Advance Research in Science and Engineering
Vol. No.6, Issue No. 08, August 2017
www.ijarse.com
IJARSE
ISSN (O) 2319 - 8354
ISSN (P) 2319 - 8346

"EXPERIMENTAL ANALYSIS AND OPTIMIZATION OF SURFACE ROUGHNESS, MATERIAL REMOVAL RATE FOR VARIOUS PROCESS PARAMETERS IN CNC MILLING"

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ABSTRACT

CNC machine tool is generally used by production engineers and personnel to quickly and effectively set up manufacturing processes for new products. CNC milling is a unique adaption of the conventional milling process which uses an end mill tool for the machining process. Surface roughness and Material removal rate are two important parameters which affect the quality of the component which indirectly affect the component cost. In order to build up a bridge between quality and productivity, the present study highlights optimization of CNC vertical end milling process parameters to provide good surface finish as well as high material removal rate (MRR).

In this thesis, the effect of machining parameters like spindle speed, feed rate & depth of cut on Material removal rate and surface roughness has been investigated during end milling of EN31 alloy steel. This study discusses an investigation into the use of Response surface methodology design for Parametric Study of CNC milling operation for Surface Roughness and Material Removal Rate as a response variable. A total of 20 experimental runs were conducted using an orthogonal array, and the ideal combination of controllable factor levels was determined for the surface roughness and material removal rate. A verification run was used to confirm the results, which indicated that this method was both efficient and effective in determining the best milling parameters for the surface roughness & material removal rate. Verification test result describes that the mathematical models are appropriate for effectively representing machining performance criteria.

Keywords: CNC end milling, RSM, MRR, SR, orthogonal arrayL_{20}, EN31alloy steel, Optimization, Machining parameters and performance characteristics

I. INTRODUCTION

CNC milling or computer numerically controlled milling (CNC) is the process of machining physical objects from 2D or 3D digital information, which is imported from CAD or other design programs converted to a specific language understood by the machine. CNC milling machines are machine tools which are used for the shaping of metal and other solid materials. These machines exist in two basic forms horizontal or vertical. This refers to the orientation of the cutting tool spindle. Early milling machines were manually or mechanically automated, but technological advances have lead to the development of computer numeric control, such as CNC

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ISSN (O) 2319 - 8354
ISSN (P) 2319 - 8346

machining centre.CNC refers to a computer ("control") that leads and stores instructions. This numerical information generally "G and M " codes (a programming language) is then used to control and drives a machine tool a powered mechanical device ("machining centre").

Programming of HEIDENHAN TNC 530: Programming of the slot milling which is presently used in this project-

```
*BEGIN PGM
 *PROJECT SUNNY KUMAR
*BLKFORM0.1ZX+0Y+0Z-20
*BLKFORM0.2X+64Y+207Z+0
*TOOLCALL1ZS1000M08
*LZ+100R0FMAXM3
*LZ+10R0FMAX
*CYCLEDEF3.0SLOTMILLING
*CYCLEDEF3.1SETUP10
*CYCLEDEF3.2DEPTH-2
*CYCLEDEF3.3PLNGNG0.1FEED150
*CYCLEDEF3.4X+76
*CYCLEDEF3.5Y+12
*CYCLEDEF3.6F500
*LX+0Y+18R0F5000M99
*LX+0Y+32R0F5000M99M30
```

II. LITERATURE SURVEY

Amit Joshi et al.[2012] investigated the Surface roughness response on CNC milling by Taguchi technique. Analysis of variance (ANOVA) was taken in this analysis. The material was used for this experiment is (100 x 34 x 20 mm) 5 rectangular blocks of Al cast heat-treatable alloy. The response parameter surface roughness is analysed by software Minitab 15 and ANOVA is used to check the adequacy of model which shows the percentage contribution of each machining parameter on surface roughness.

Abraham pinni et.al[2013] our work focuses on the Optimization of cutting tool life of a CNC milling machine and end milling operation is performed on it by using cubic Boron Nitride (CBN) as the cutting tool material and En31 steel (RC 46) as work piece material to predict the Tool life.

Sukhdev.S.Bhogal, Charanjeet Sindhu, Sukhdeep S.Dhami, and B.S.Pabla et al [2015] has analyzed that, the effect of cutting parameters on tool vibration, and surface roughness during end milling of EN-31 alloy steel. Response surface methodology (RSM) has been used to develop mathematical model for predicting surface finish, tool vibration and tool wear with different combinations of cutting parameters. The experimental results show that feed rate is the most dominating parameter affecting surface finish, whereas cutting speed is the major factor effecting tool vibration. The results of mathematical model are in agreement with experimental investigations done to validate the mathematical model.

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ISSN (O) 2319 - 8354
ISSN (P) 2319 - 8346

III. OBJECTIVE OF THE RESEARCH WORK

In the present study there is an attempt to evaluate the machining parameters for maximum material removal rate and minimum surface roughness. The machining of EN-31 alloy steel has been conducted at higher level of three machining parameters like spindle speed, Feed rate and depth of cut for two responses such as material removal rate and surface roughness in CNC vertical milling process by using response surface methodology. After performing this research work, we will able to decide the optimal machining condition as well as influence of machining parameters on performance characteristics like material removal rate and surface roughness.

IV. EXPERIMENTAL SETUP

CNC Vertical milling machine

Brand:-DMG (Deckel maho guildmeister)

Controller:-HEIDENHAIN

Number of axes movement:-5

Fig1:-CNC Milling Machine

Selection of Workpiece material

Fig2:- Rectangular plate (207×64×20)mm^3 of EN-31 Alloy steel after slot milling

Chemical composition of EN-31 alloy steel

Element	% Chemical composition
C	0.91
Si	0.26
Mn	0.30
Cr	1.20
S	0.03
P	0.04

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ISSN (O) 2319 - 8354
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Fe	97.26

Cutting tool material:

Fig3:- coated carbide end mill cutter

Table: Technical description of cutting tool material.

Cutting tool material	Coated carbide
Cutting tool type	End mill cutter
Diameter	12mm
No of Flutes	4

V. RESPONSE PARAMETERS

(a) Material removal rate (MRR)

(b) Surface roughness (SR)

Measurement of MRR & SR:-

Material removal rate is selected as response variable which defines the machining efficiency of CNC vertical milling process. The weight of workpiece material has been taken by electronic weighing machine. The workpiece is soaked from cloth to prevent extra weight measurement.

$$MRR=\frac{\text{Final weight}-\text{initial weight}}{\text{Density}\times\text{Machining Time}}$$

Surface roughness tester SJ-201 was used for the measurement of surface roughness. The Surface test SJ-201 (Mitutoyo) is a shop–floor type surface-roughness measuring instrument, which traces the surface of various machined parts and calculates the surface roughness based on roughness standards, and displays the results. The work piece is attached to the detector unit of the SJ-201 will trace the minute irregularities of the work piece surface. The vertical stylus displacement during the tracing is processed and value is digitally displayed on the liquid crystal display of the SJ-201.

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ISSN (O) 2319 - 8354
ISSN (P) 2319 - 8346

Fig4:- : surface roughness tester (SJ 201)

VI. RESPONSE SURFACE METHODOLOGY

Response Surface Methodology (RSM) is collection of mathematical and statistical methods for building experimental model and analysis of problems. By careful design of experiments, the objective is to optimize a response (output variable) which is influenced by several independent variables (input variables) with a goal to find the correlation between the response and the variables. A Central Composite Design (CCD) predicts the performance characteristic at high degree of accuracy during experimentation. Therefore, RSM using CCD with three variables yield a total of 20 runs in three blocks, where the cardinal points used 30 are; 8 cube points, 6 axial points and centre points [Minitab17, 2017]. Spindle speed, Feed rate and Depth of cut were the three experimental factors capable of influencing the process responses, namely, Material removal rate, Surface Roughness. Hence, these factors were considered for exploration.

Central Composite Design

The central composite design (CCD) is the most popular class of designs. It provides second order polynomial for the response variables in response surface methodology without using a complete full factorial design of experiments. It was proposed by Box and Wilson in 1951.It can be used for the experimental designs, which must have at least three levels of each factor. CCD has three different points, factorial points, central points and axial points. The vertices of the cube represent factorial points. The factor levels of these points are coded to -1 and +1. Central points are located at the centre of the design space. Axial points can be represented by the axes of the coordinate system symmetrically with respect to the central point at a distance α from the design centre.

ANOVA (Analysis of Variance)

Analysis of variance (ANOVA) is helpful to check the adequacy of the model for the responses. The distance between any point in a set of data and the mean of the data is known as deviation. The sum of all such squared deviations is called sum of square. The total variation in the data is represented by SS_{Total}. Degree of freedom is the number of independent variables required to calculate the sum of squares of the response data. In ANOVA, the ratio of the regression mean square to the mean square error is called F-ratio. It is also known as variance ratio, The higher value of F-ratio represents that the model is adequate at desired α level to provide the relationship between machining response and machining parameters. P-value or probability of significance represents whether the independent variable in the model is significant or not.

VII. RESPONSE SURFACE METHODOLOGY IN MINITAB

MINITAB 17 offers a number of different ways of design in which the experiments can be conducted. I have used face centred CCD in response surface methodology for the experimentation. It has 8 cube points, 6 centre

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ISSN (O) 2319 - 8354
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points in cube, 6 axial points and 0 centre points in axial position. There are 3 machining factors, 1 replicate, 3 blocks and total 20 experiments in the design.

Machining parameters and their levels:-

Machining parameters	Symbol	Unit	Levels	
			Low level	High level
Spindle Speed	N	RPM	1000	1500
Feed rate	f	mm/min	500	700
Depth of cut	d	mm	0.1	0.3

Experimental observations:-

Spindle speed (RPM)	Feed rate (mm/min)	Depth of cut (mm)	Machin-ing time(min)	MRR mm^3/min)	SR (µm)
1000	500	0.1	3.12	408.29	1.12
1000	600	0.1	2.42	526.39	1.49
1000	700	0.1	2.20	579.03	1.72
1000	500	0.2	1.40	909.91	1.68
1000	600	0.2	1.25	1019.10	1.89
1000	700	0.2	1.14	1117.44	2.03

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ISSN (O) 2319 - 8354
ISSN (P) 2319 - 8346

1000	500	0.3	1.13	1127.33	1.76
1200	500	0.1	3.12	408.29	1.03
1200	600	0.1	2.42	526.39	1.47
1200	700	0.1	2.20	579.03	1.85
1200	500	0.2	1.40	909.91	1.46
1200	600	0.2	1.25	1019.10	1.73
1200	700	0.2	1.14	1117.44	1.96
1200	500	0.3	1.13	1127.33	2.45
1500	500	0.1	3.12	408.29	1.67
1500	600	0.1	2.42	526.39	1.85
1500	500	0.2	1.40	909.91	1.89
1500	600	0.2	1.25	1019.10	2.21
1500	500	0.3	1.13	1127.33	2.93
1500	700	0.3	0.92	1389.69	3.50

Analysis of Material removal rate: The fit summary describes that the quadratic model is statistically significant for analysis of MRR. The results of the quadratic model for MRR are given in. The value of $R^2$and adjusted R^2 99.96% and 99.92%. This means that regression model provides an excellent explanation of the relationship between the independent variables (factors) and the response (MRR). The associated p-value for the model is lower than 0.05 (i.e. α = 0.05, or 95% confidence) indicates that the model is considered to be statistically significant. The standard percentage point of F distribution for 99%confidence limit is 15.68. As shown in Table4.2 the F- value 13.87 for 2-Way interaction is smaller than the standard value. Thus the 2-way interaction term is significant. In the same manner, the main effect of X_2 (Feed rate), X_3 (depth of cut), second order effect of X_1 (Spindle speed), X_2 (Feed rate) and X_3 (Depth of cut) are significant model terms. The other model terms N, N*N, N*f and N*d terms are can be regard as not significant effect due to their "P value greater than 0.05.It means that spindle speed, second order of spindle speed have almost negligible contribution on material; removal rate.

Table1:- Analysis of variance for Material removal rate

Source	DF	Adj SS	Adj MS	F-value	P-Value	% contribution
Model	9	1804194	200466	2618.54	0.000	99.95

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ISSN (O) 2319 - 8354
ISSN (P) 2319 - 8346

Linear	3	1039393	346464	4525.60	0.000	57.58
N	1	22	22	0.29	0.010	0.001
f	1	123005	123005	1606.72	0.000	6.81
d	1	708030	708030	9248.46	0.000	4.32
Square	3	68613	22871	298.75	0.000	3.80
N*N	1	4	4	0.06	0.815	0.0002
f*f	1	1027	1027	13.41	0.004	0.056
d*d	1	56230	56230	734.49	0.000	3.115
2-way interaction	3	3185	1062	13.87	0.001	0.176
N*f	1	26	26	0.33	0.576	0.0014
N*d	1	1	1	0.01	0.911	0.000
f*d	1	1870	1870	24.42	0.001	0.0010
Error	10	766	77			0.042
Total	19	1804960				100

Table2:- Regression coded coefficients for Material removal rate (MRR)

Term	**Coef.**	**SE Coef**	**T-Value**	**P-Value**	**Remarks**
Cons-tan	1027.16	5.21	197.00	0.000	significant

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ISSN (O) 2319 - 8354
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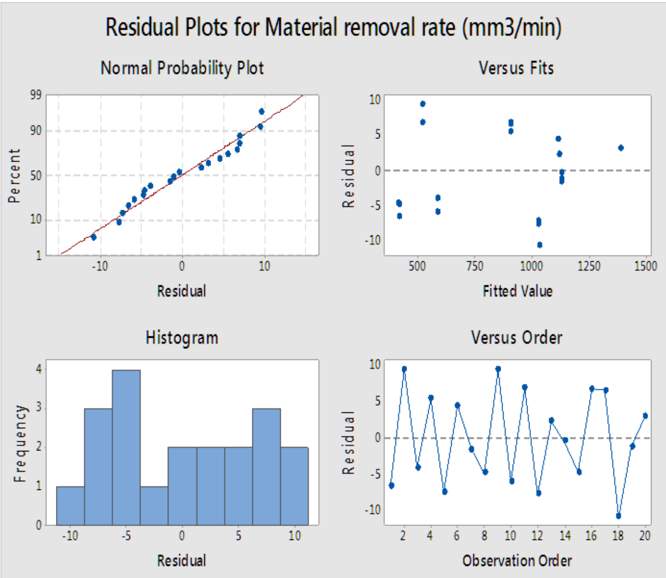
t					
N	1.73	3.25	0.53	0.605	Non-significant
f	106.57	2.66	40.08	0.000	significant
d	377.55	3.93	96.17	0.000	significant
N*N	1.07	4.47	0.24	0.815	Non-significant
f*f	-17.83	4.87	-3.66	0.004	significant
d*d	-132.53	4.89	-27.10	0.000	Significant
N*f	2.34	4.04	0.58	0.576	Non-significant
N*d	0.39	3.44	0.11	0.911	Non-significant
f*d	20.17	4.08	4.94	0.001	significant

Residual plot of material removal rate:-



Graph1: Residual plot of MRR

The residual plot of MRR is shown in figure Normal probability plot shows that the data are not normally distributed and the variables are influencing the response. A standardized residue ranges from -10 and 10. Residuals versus fitted values indicate the variance is constant and a

International Journal of Advance Research in Science and Engineering
Vol. No.6, Issue No. 08, August 2017
www.ijarse.com
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ISSN (O) 2319 - 8354
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nonlinear relationship exists as well as no outliers exist in the data. Histogram proves the data are almost normally distributed it may be due to the fact that the number of points are very less. Residuals versus order of the data indicate that there are nearly systematic effects in the data

Table3:- Analysis of variance for surface roughness (SR)

Term	Coef	SE Coef	T-Value	P-Value	Remarks
Constant	1.8550	0.0969	19.15	0.000	Significant
N	0.2846	0.0604	4.71	0.001	Significant
f	0.2934	0.0494	5.94	0.000	Significant
d	0.5786	0.0729	7.93	0.000	Significant
N*N	0.1514	0.0831	1.82	0.099	Non-significant
f*f	-0.0420	0.0905	-0.46	0.652	Non-significant
d*d	0.2390	0.0909	2.63	0.025	Non-significant
N*f	-0.0437	0.0751	-0.58	0.573	Non-significant
N*d	0.1258	0.0639	1.97	0.078	Non-significant
f*d	0.0158	0.0758	0.21	0.839	Non-significant

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Source	DF	Adj SS	Adj MS	F-Value	P-Value	% contribution
Model	9	5.95295	0.66144	25.03	0.000	95.74
Linear	3	5.04814	1.68271	63.67	0.000	81.20
N	1	0.58718	0.58718	22.22	0.001	9.45
f	1	0.93216	0.93216	35.27	0.000	14.99
d	1	1.66296	1.66296	62.93	0.000	26.74
Square	3	0.31775	0.10592	4.01	0.041	5.11
N*N	1	0.08763	0.08763	3.32	0.099	1.40
f*f	1	0.00570	0.00570	0.22	0.652	0.10
d*d	1	0.18285	0.18285	6.92	0.025	2.94
2-Way Interaction	3	0.12002	0.04001	1.51	0.270	1.93
N*f	1	0.00895	0.00895	0.34	0.573	0.14
N*d	1	0.10224	0.10224	3.87	0.078	1.64
F*d	1	0.00115	0.00115	0.04	0.839	0.01
Error	10	0.26427	0.02643			4.21
Total	19	6.21722				100

International Journal of Advance Research in Science and Engineering
Vol. No.6, Issue No. 08, August 2017
www.ijarse.com
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ISSN (O) 2319 - 8354
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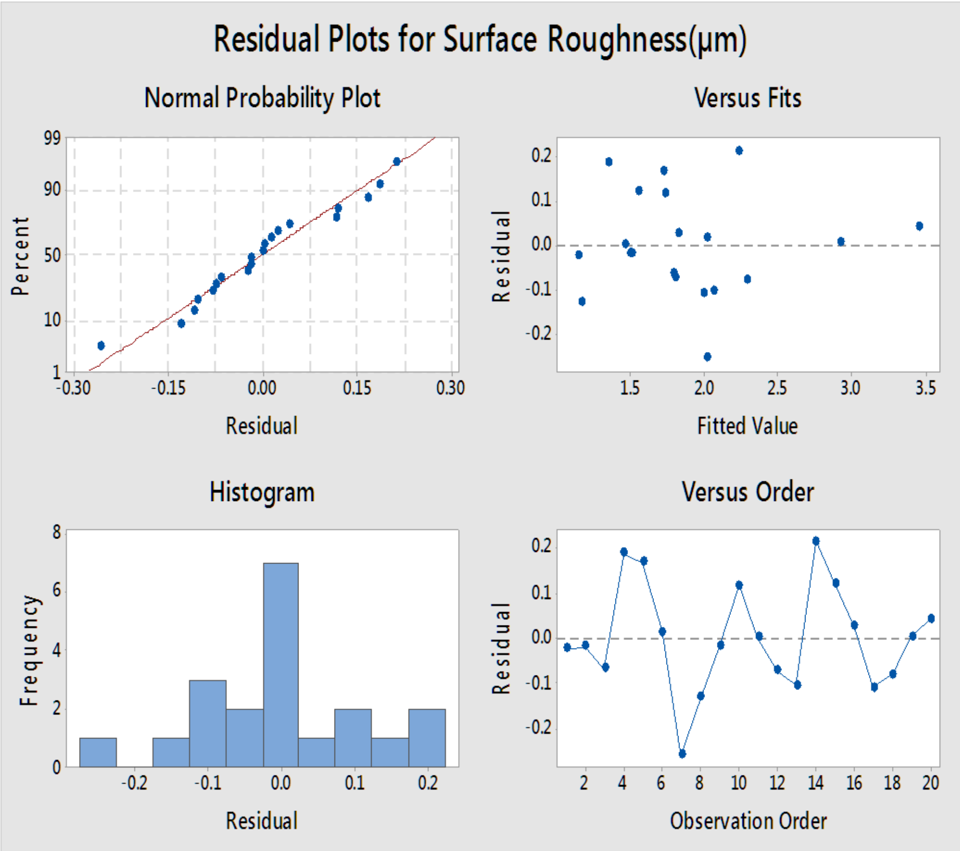
Table4:- Regression coded coefficients for Surface roughness (SR)

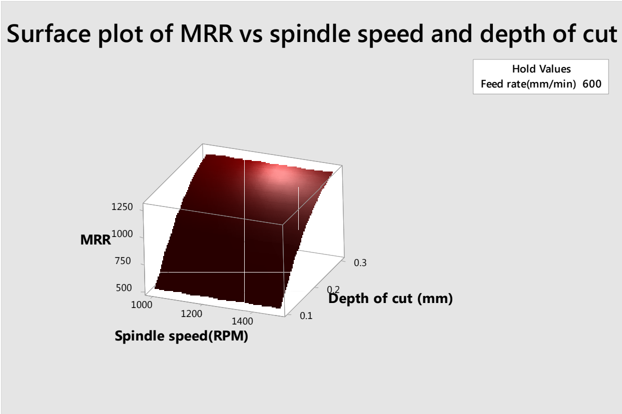


Graph2: Residual plot of surface roughness (SR)

Analysis of Surface Roughness:- Table 4shows the Estimated Regression Coefficients for Surface roughness. R^2 =95.25% indicates that the model is able to predict the response with good accuracy. The value of R^2 (adj) = 91.92%. The standard deviation of errors in the modelling, S= 0.162565, Spindle speed (N), Feed rate (f), Depth of cut (d) is significant. Squares N*N, d*d and f*fare non-significant and squares and interactions N*f, N*d and f*d are non -significant. The residual plot of Surface roughness is shown in graph 2. Normal probability plot shows that the data are almost normally distributed and the variables are influencing the response. A standardized residue ranges from -0.2 and 0.2. Residuals versus fitted values indicate the variance is constant and a nonlinear relationship exists as well as no outliers exist in the data. Histogram proves the data are almost normally distributed it may be due to the fact that the number of points are very less. Residuals versus order of the data indicate that there are nearly systematic effects in the data. Graph 2 displays the normal probability plot of the residuals for MRR. It shows the regression model is fairly well fitted with the observed values.

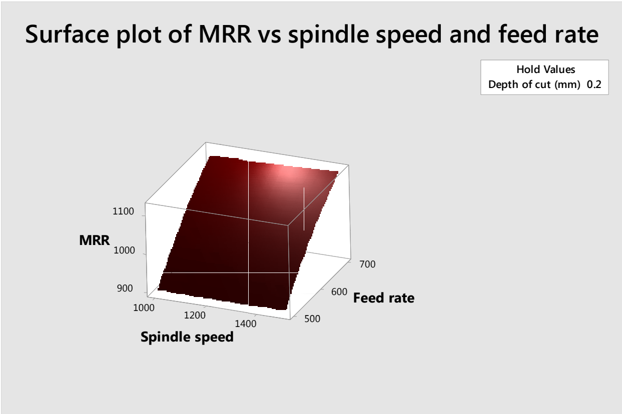
Analysis of Machining Parameters on MRR

(a) Effect of Spindle speed. Depth of cut on Material removal rate:



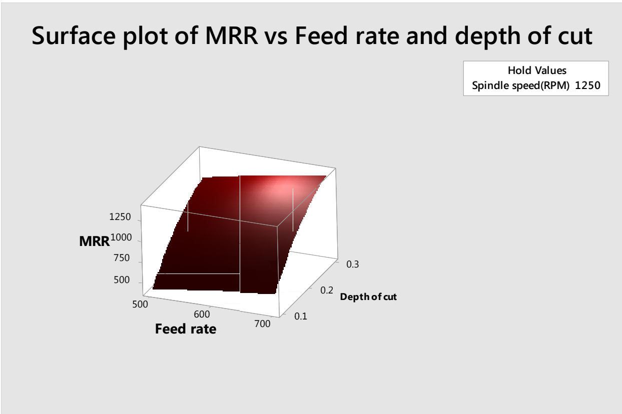
Graph3: Surface plot of MRR vs. Spindle speed and depth of cut

(b) Effect of spindle speed, Feed rate on material removal rate:



Graph4: Surface plot of MRR vs. Spindle speed and feed rate

(c) Effect of feed rate, depth of cut on material removal rate:



Graph5: Surface plot of MRR vs. Feed rate and depth of cut

Analysis of Machining Parameters on SR: (a) Effect of spindle speed, depth of cut on surface roughness:

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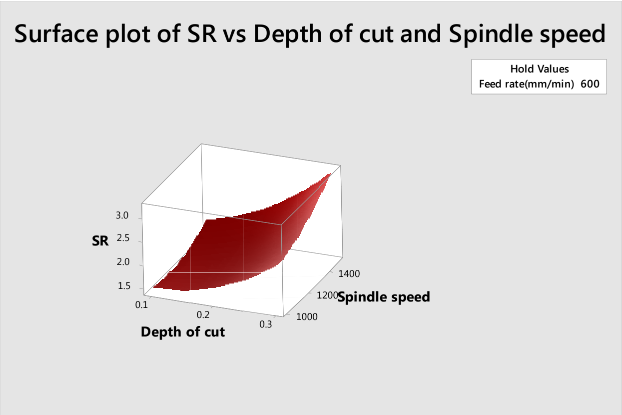
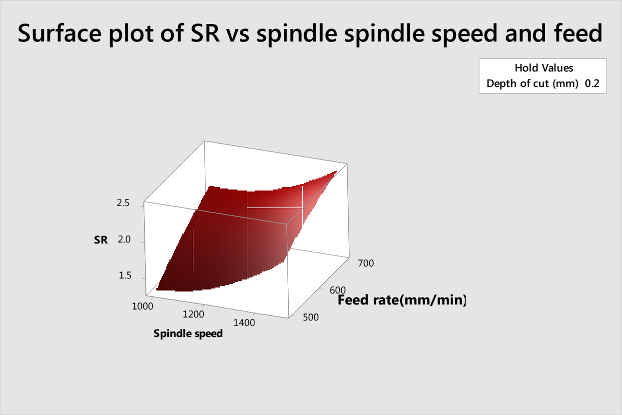
ISSN (O) 2319 - 8354
ISSN (P) 2319 - 8346



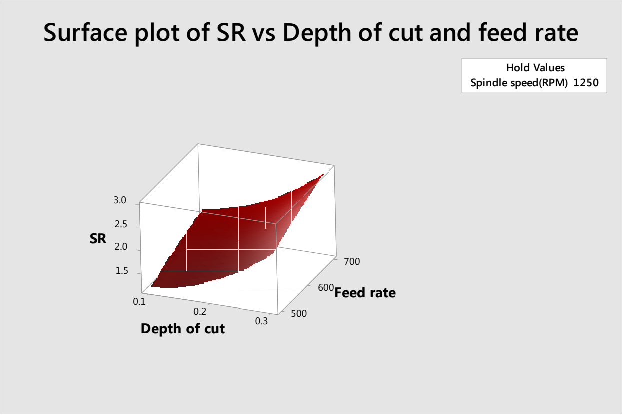
Graph6: Surface plot of SR vs. Depth of cut and spindle speed

(b)Effect of spindle speed, feed rate on surface roughness:



Graph7: Surface plot of SR vs. spindle speed and feed rate

(c) Effect of feed rate, depth of cut on surface roughness:-



Graph8: Surface plot of SR vs. Depth of cut and feed rate

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ISSN (O) 2319 - 8354
ISSN (P) 2319 - 8346

VIII. RESULT & CONCLUSION

The experiment has been performed by using RSM. The response optimizer has been applied for the optimization of CNC milling process parameters for EN-31 tool steel. The optimal machining parameters have been determined with the help of response optimizer. The following conclusion can be drawn from this study:

- Spindle speed has almost non-significant effect on MRR, while Feed rate, depth of cut has significant effect on MRR. Depth of cut has more percentage contribution on MRR. Second order of spindle speed is the most non-significant factor for MRR. MRR increases linearly with respect to feed rate when spindle speed is constant While, MRR increase non-linearly with respect to depth of cut when spindle speed is constant. The MRR increases with feed rate and depth of cut.MRR varies non-linearly with feed rate and depth of cut. At lower depth of cut when feed rate increases MRR increases but lesser value with comparison to higher depth of cut when feed rate increases.
- Spindle speed, Feed rate, Depth of cut all three machining parameters have significant effect on SR. But depth of cut has more contribution on SR with comparison to feed rate and spindle speed. All machining parameters of second order have non-significant effect on surface roughness.
- SR varies non-linearly with all three machining parameters. From the surface plot of SR vs. depth of cut & spindle speed it can be concluded that at higher depth of cut when spindle speed increases SR increases more rapidly with comparison to lower depth of cut. At higher feed rate when spindle speed increases SR initially decreases but after spindle speed 1250 RPM SR increases. From the surface plot of SR vs. depth of cut& feed rate SR increases more rapidly when feed rate is constant &depth of cut increases with comparison to when depth of cut is constant feed rate increases.

Table5:- Response optimization:-surface roughness (μm) and material removal rate (mm^3/min)

Response	Goal	Lower	Target	Upper	weight	importance
Surface roughness(μm)	Minimum	1.03	1.03	3.5	1	1
Material removal rate (mm^3/min)	Maximum	408.29	1389.69	1389.69	1	1

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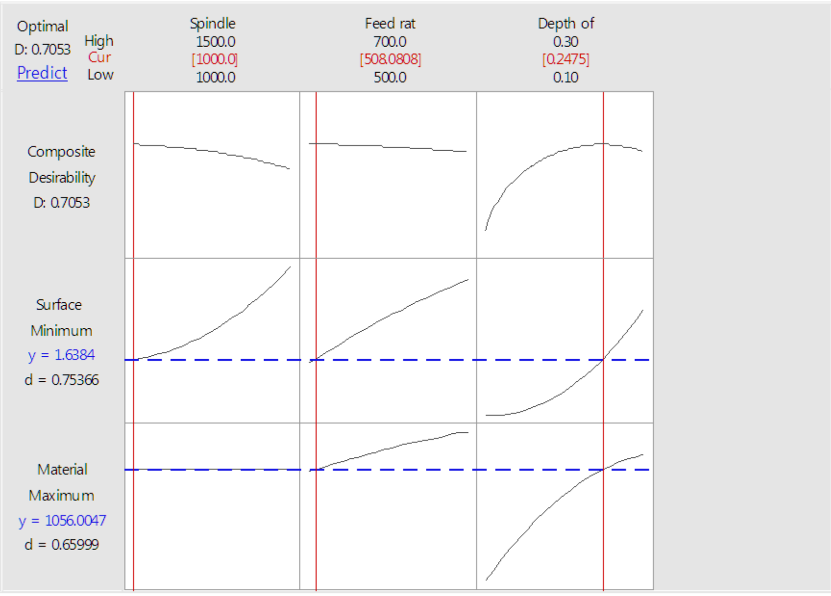
Table6:-Response optimized solution

Solution	Spindle speed (RPM)	Feed rate (mm/min)	Depth of cut (mm)	Surface Roughness (µm) Fit	Material removal rate (mm^3/min)	Composite desirability
1	1000	508.081	0.247	1.6384	1056.0047	0.7053

Response optimization plot:



Graph9: optimization plot of machining parameters and response parameters

Exploring solutions via optimization plot:-

Graph 9 shows the ramp display of machining parameters for interpolation of optimum solution parameters. The optimum results are obtained to achieve the objective of the study, that is, to minimize the surface roughness and maximum material removal rate. An intersection point on each optimization plot reflects the factor setting or response prediction for that solution. The height of the intersection point shows the composite desirability. Best optimizing solution occurs where composite desirability is 1.

Validation of model:-Mathematical model of a process has an advantage that we can experiment with the model rather than the process. Invariably the process can be simulated by using the mathematical model with simulation software. The results can often be used for refining an existing model to make it more realistic and more useful. The validity of the model is checked for the levels of the parameter, which has not been included in the experimental design.

Confirmation of result:-Finally, the confirmation test is conducted at optimal machining condition to validate the analysis. Table 7 represents response table for comparison of performance characteristics. The initial nearer level of machining condition is assumed to be N=1000, f=500, d=0.2

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Table7:- Response table for comparison of performance characteristic

Responses	Initial Nearer machining condition	Prediction	Experimental result	Confirmation test result
Level	N=1000, f=500,d=0.2	N=1000	f=508.08	d=0.24
MRR	909.91		1055.13	1056.00
SR	1.68		1.65	1.63

The material removal rates for experiment and confirmation test are 1055.13mm^3/min and 1056.00mm^3/min. The error is 0.87mm^3/min. The error in surface roughness for experimental and confirmation test are 0.02µm.Experimental and confirmation test for material removal rate are increased by 15.96% and 16.05%.respectively from initial machining condition. Experimental and confirmation test for surface roughness are decreased by 1.81% and3.06%. Composite desirability for predicted response are more than experimental response. Optimization was done to maximize MRR and minimize SR. Predicted properties at optimum condition are verified with a confirmation test and are found within limits.

IX. FUTURE SCOPE

The present study is useful to maximize material removal rate and minimize surface roughness. The proposed modelling technique can be utilized for advanced conventional as well as non-conventional machining process.

Future study may evaluate the following aspects:

The optimization of machining parameters of different grades of tool steels may be used for the interest of industries.

In this study only three parameters are chosen. A detailed study may be carried out for other parameter also.

The responses other than MRR and SR like flatness and surface integrity may be studied for the different machining parameters.

There are several methodologies such as Taguchi, mixture design, factorial design and Grey relational analysis; Genetic algorithm may be employed for the optimization instead of Response surface methodology (RSM).

The optimization procedure of machining parameters may be used for other machining process like CNC turning, plasma cutting etc.

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