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Experimental Investigations to Determine Optimal Cutting Parameters in Grinding Operations by Design of Experiments

Bareddy Ramamohan Reddy
Indira Institute of Technology and Science,
JNTU, Kakinada,
Andhra Pradesh, India.

Sri P.Ch.Sreenivasababu
Indira Institute of Technology and Science,
JNTU, Kakinada,
Andhra Pradesh, India.

ABSTRACT:

In this thesis, different experiments are conducted by grinding Mild Steel pieces varying the cutting parameters table feed, depth of cut and speed for better surface roughness and material removal rates. The parameters considered for experimentation are feed 12.5mm/min, 17.25mm/min and 25.8mm/min, the Grinder speed 120rpm, 160rpm and 220rpm, the depth of cut 0.02mm, 0.04mm and 0.08mm. Different experiments are conducted by taking above values of parameters as per L9 orthogonal array. The optimization is carried out using Response Surface Methodology in Minitab 17 software.

THE GRINDING PROCESS

Grinding is a material removal and surface generation process used to shape and finish components made of metals and other materials. The precision and surface finish obtained through grinding can be up to ten times better than with either turning or milling.

LITERATURE SURVEY

The following works are done by some authors on grinding operations B. Dasthagiri, Dr. E. VenugopalGoud[1], mainly focuses on developing the empirical models using response surface methodology for surface roughness and metal removal rate by considering control factors as wheel speed, table speed and depth of cut. Kundan Kumar, Somnath Chattopadhyaya, Hari Singh[2], outlines the Taguchi's Parameter Design Approach, which has applied to optimize machining parameters in Cylindrical Grinding Process. The grinding parameters evaluated are cutting speed and depth of cut. An orthogonal array, signal-to-noise (S/N) ratio and analysis of variance (ANOVA) are employed to analyze the effect of these grinding parameters.

EXPERIMENTAL INVESTIGATION

The material Mild Steel is selected as work piece material having diameter 68.5 mm and length 180 mm round bar. The experiments are carried out by cylindrical grinding machine under wet condition mainly in respect of surface roughness. The machine used is shown.

Hydraulic Cylindrical Grinding Machine

EXPERMENTATION PROCEDURE

9 different experiments are conducted on three work pieces by varying the process parameters feed 12.5mm/min, 17.25mm/min and 25.8mm/min, the Grinder speeds 120rpm, 160rpm and 220rpm and the depth of cut 0.02mm, 0.04mm and 0.08mm as per L9 orthogonal array. The coolant flow rate is taken as 600ml/min.The process parameters as per L9 orthogonal array are shown in below.

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DESIGN OF EXPERIMENTS

The levels of input parameters are shown in below table.

FACTORS	PROCESS PARAMETERS	LEVEL 1	LEVEL2	LEVEL3
A	GRINDER SPEED(rpm)	120	160	220
B	FEED RATE (mm/min)	12.5	17.25	25.8
C	DEPTH OF CUT(mm)	0.02	0.04	0.08

Levels of Process Parameters considered for experimentation

L9 orthogonal array

JOB NO.	SPINDLE SPEED (rpm)	FEED RATE (mm/min)	DEPTH OF CUT (mm)
1	120	12.5	0.02
2	120	17.25	0.04
3	120	25.8	0.08
4	160	12.5	0.04
5	160	17.25	0.08
6	160	25.8	0.02
7	220	12.5	0.08
8	220	17.25	0.02
9	220	25.8	0.04

L9 Orthogonal Array based on Taguchi Method

Prepared Work pieces after cylindrical Grinding Process

RESULTS & DISCUSSIONS

SURFACE ROUGHNESS

After completing the experimental trails using L9 orthogonal array, the surface roughness values are measured using surface roughness tester of model Surftest 211/212 and the results are tabulated.

MATERIAL REMOVAL RATE RESULTS

Firstly the weight of the work piece is measured before the machining process with help of balance, the initial weight of the work piece is noted down. During the machining process the time taken for each job for grinding is measured and noted down. After the machining at one section the work piece is removed from the machine and the final weight of the work piece is measured. The MRR values are calculated by measuring the initial and final weights of the 9 jobs.

The weights before and after grinding and time taken for machining are specified in table 4.6. The MRR results obtained are given in Table 4.7.

Material removal rates are calculated using the formula

$$MRR= (Wb-Wa)/Tm$$

Wb =weight of work piece material before grinding (gms)

Wa = weight of work piece material after grinding (gms)

Tm = machining times (min/sec)

OPTIMIZATION OF MACHINING PARAMETERS USING MINITAB SOFTWARE RESPONSE SURFACE METHODOLOGY

To optimize parameters using Response surface Methodology, first the arrangement of L9 orthogonal array is done in Taguchi Method.

OPTIMIZATION FOR SURFACE ROUGHNESS

Enter Surface Roughness Values in the table

Worksheet 1 ***

↓	C1	C2	C3	C4
	GRINDER SPEED	FEED RATE	DEPTH OF CUT	SURFACE ROUGHNESS
1	120	12.50	0.02	0.895
2	120	17.25	0.04	1.498
3	120	25.80	0.08	1.920
4	160	12.50	0.04	1.451
5	160	17.25	0.08	1.706
6	160	25.80	0.02	1.234
7	220	12.50	0.08	1.687
8	220	17.25	0.02	1.349
9	220	25.80	0.04	1.746

Observed Surface Roughness Values

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Worksheet1 ***

↓	C1	C2	C3	C4	C5	C6	C7	C8
	GRINDER SPEED	FEED RATE	DEPTH OF CUT	SURFACE ROUGHNESS	StdOrder	RunOrder	Blocks	PtType
1	120	12.50	0.02	0.895	1	1	1	1
2	120	17.25	0.04	1.498	2	2	1	1
3	120	25.80	0.08	1.920	3	3	1	1
4	160	12.50	0.04	1.451	4	4	1	1
5	160	17.25	0.08	1.706	5	5	1	1
6	160	25.80	0.02	1.234	6	6	1	1
7	220	12.50	0.08	1.687	7	7	1	1
8	220	17.25	0.02	1.349	8	8	1	1
9	220	25.80	0.04	1.746	9	9	1	1

Design of Response Surface

Response Surface Regression: SURFACE ROUGHNESS versus GRINDER SPEED, FEED RATE, DEPTH OF CUT

The relationship between the input factors and output responses used to develop the empirical models. After machining parameter optimization the empirical models can be used. The MiniTab 17 software used to develop the second order models for the output responses.

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	3	0.65946	0.21982	9.41	0.017
Linear	3	0.65946	0.21982	9.41	0.017
GRINDER SPEED	1	0.03947	0.03947	1.69	0.250
FEED RATE	1	0.11737	0.11737	5.02	0.075
DEPTH OF CUT	1	0.50262	0.50262	21.51	0.006
Error	5	0.11683	0.02337		
Total	8	0.77629			

By observing P – value from above table, it can be found that the most important parameter is Depth of Cut.

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.152859	84.95%	75.92%	53.22%

The goodness-of-fit of the model was checked by the determination coefficient (R^2 – 84.95%). The adjusted determination coefficient (adj. R^2 =75.92%) was satisfactory for confirming the significance of the model.

Coded Coefficients

Term	Effect	Coef	SE Coef	T-Value	P-Value	VIF
Constant		1.5485	0.0519	29.83	0.000	
GRINDER SPEED	0.1611	0.0806	0.0620	1.30	0.250	1.00
FEED RATE	0.2760	0.1380	0.0616	2.24	0.075	1.00
DEPTH OF CUT	0.5684	0.2842	0.0613	4.64	0.006	1.00

The probability (p) values were used as a tool to check the significance of each of the coefficients. A smaller p-value denotes greater significance of the corresponding coefficient.

Regression Equation in Uncoded Units

SURFACE ROUGHNESS = 0.404 + 0.00161 GRINDER SPEED+ 0.02075 FEED RATE + 9.47 DEPTH OF CUT

The level of significance can be tested by using the analysis of variance (ANOVA). The surface roughness can be found in second order models were 84.95. The "Pred R-Squared “of is in reasonable agreement with the "Adj R-Squared" in case of surface roughness. F-value for surface roughness 9.41 is significant.

The 3D response surface plot is a graphical representation of the regression equation. It is plotted to understand the interaction of the variables and locate the optimal level of each variable for maximal response.

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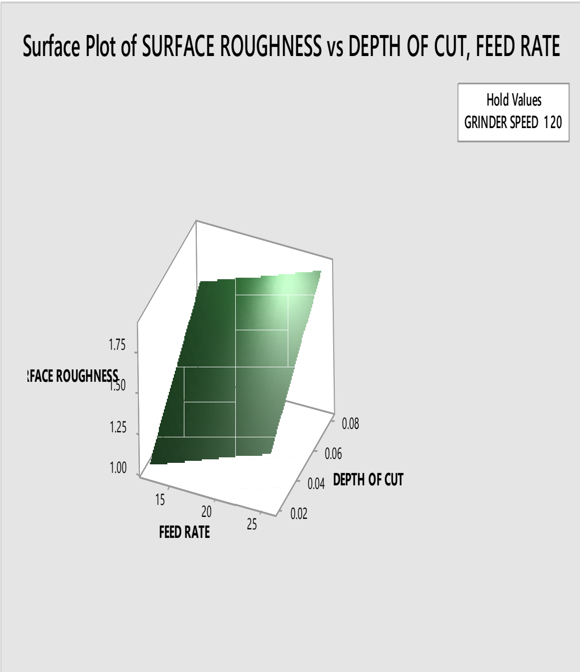
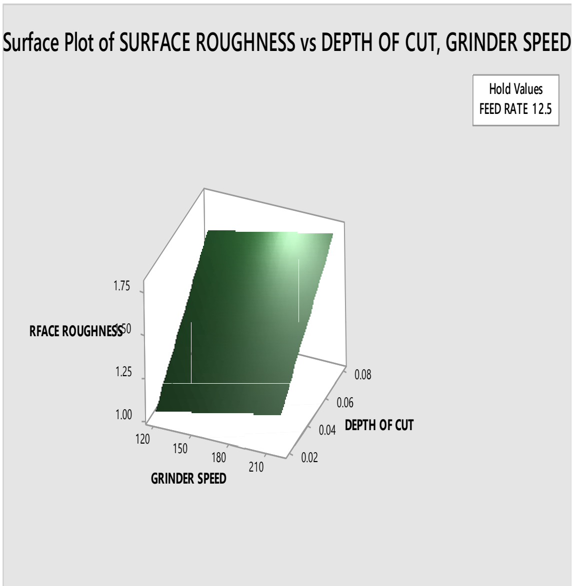


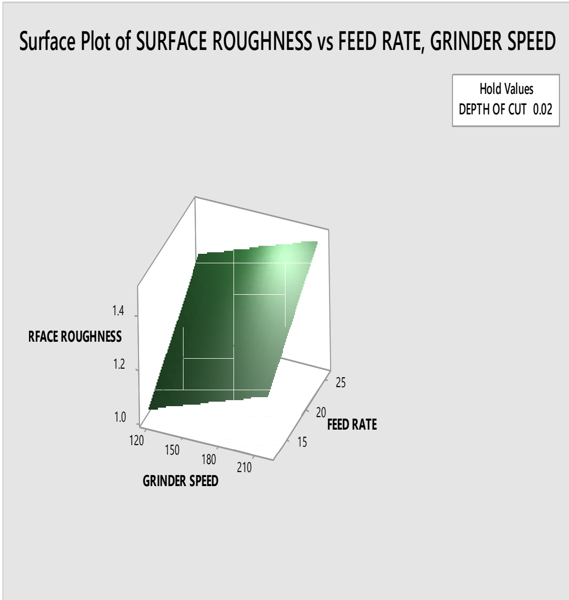
Graph – Surface Plot of Surface Roughness Vs Depth of Cut (mm), Feed Rate (mm/min)

By observing above graph, to minimize surface roughness, the Feed Rate should be set at 12.5mm/min and Depth of Cut at 0.02mm.



Graph – Surface Plot of Surface Roughness Vs Depth of Cut (mm), Speed (rpm)

By observing above graph, to minimize surface roughness, the Depth of Cut should be set at 0.02mm and Speed at 120rpm.



Graph – Surface Plot of Surface Roughness Vs Feed Rate (mm/min), Speed (rpm)

By observing above graph, to minimize surface roughness, the Feed Rate should be set at 12.5mm/min and Speed at 120rpm.

OPTIMIZATION FOR MATERIAL REMOVAL RATES

Worksheet 1 ***

↓	C1	C2	C3	C4	C5	C6	C7	C8
	GRINDER SPEED	FEED RATE	DEPTH OF CUT	MRR	StdOrder	RunOrder	Blocks	PtType
1	120	12.50	0.02	0.02660	1	1	1	1
2	120	17.25	0.04	0.02833	2	2	1	1
3	120	25.80	0.08	0.37330	3	3	1	1
4	160	12.50	0.04	0.02810	4	4	1	1
5	160	17.25	0.08	0.03100	5	5	1	1
6	160	25.80	0.02	0.02770	6	6	1	1
7	220	12.50	0.08	0.02900	7	7	1	1
8	220	17.25	0.02	0.02760	8	8	1	1
9	220	25.80	0.04	0.03550	9	9	1	1

Design of Response Surface

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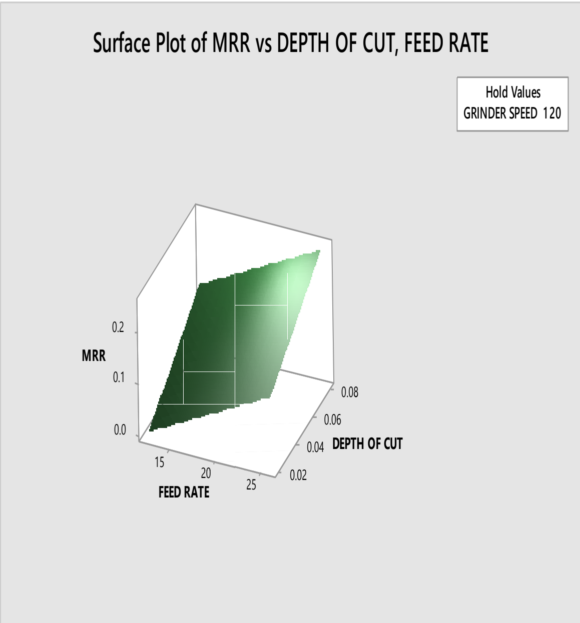
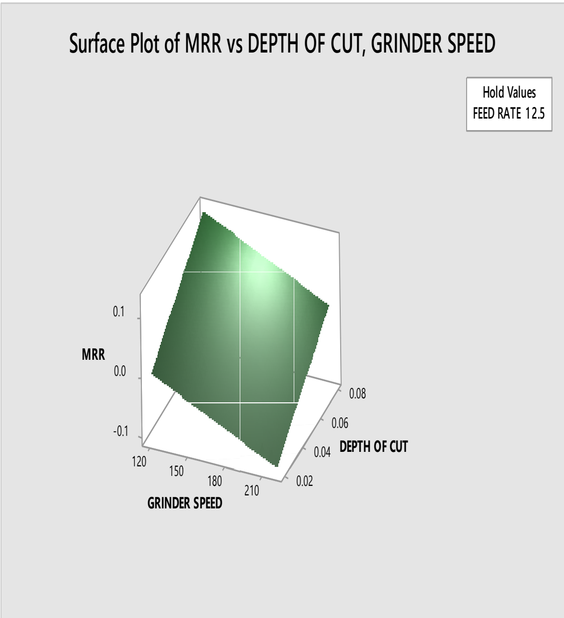


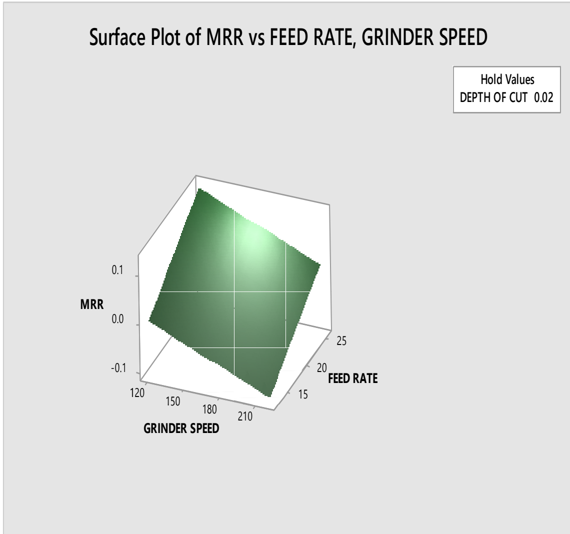
Graph – Surface Plot of Surface Roughness Vs Depth of Cut (mm), Feed Rate (mm/min)

By observing above graph, to maximize MRR, the Feed Rate should be set at 25.8mm/min and Depth of Cut at 0.08mm.



Graph – Surface Plot of Surface Roughness Vs Depth of Cut (mm), Speed (rpm)

By observing above graph, to maximize MRR, the Depth of Cut should be set at 0.08mm and Speed at 120rpm.



Graph – Surface Plot of Surface Roughness Vs Feed Rate (mm/min), Speed (rpm)

By observing above graph, to maximize MRR, the Feed Rate should be set at 25.8mm/min and Speed at 120rpm.

CONCLUSION

From the **Response surface,** the following conclusions can be made:

For better surface finish, by observing P – value, it can be found that the most important parameter is Depth of Cut. The optimization carried out is good as the R-Sq is 84.95%. The optimized process parameters are the Feed Rate – 12.5mm/min and Depth of Cut - 0.02mm and Grinder Speed - 120rpm.

For better MRR,by observing P – value from above table, it can be found that the most important parameters are Feed Rate and Depth of Cut. The optimization carried out is good as the R-Sq is 61.25%. The optimized process parameters are the Feed Rate – 25.8mm/min and Depth of Cut – 0.08mm and Spindle Speed - 120rpm.

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Author Details

Bareddy Ramamohan Reddy received the B.Tech degree in mechanical engineering from Indira Institute of technology and science, Jntu,Kakinada, Andhra Pradesh, India, in 2014 year, andpersuing M.Tech in CAD/CAM from Indira Institute of technology and science, Jntu, Kakinada, Andhra Pradesh, India.

Sri.P.Ch.Sreenivasababu, M.Tech, Assistant professor, Indira Institute of technology and science, Jntu, Kakinada, Andhra Pradesh, India.