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A Multi Response Optimization of Machining Parameters For Surface Roughness & MRR In High Speed CNC Turning of EN-24 Alloy Steel Using Response Surface Methodology

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Abstracts

In Manufacturing sector Turning is the most common process used to remove material from cylindrical workpiece & produce smooth surface finish on the workpiece. In turning process Material removal rate & Surface roughness are the important performance characteristics to be considered which is affected by several factors such as spindle speed, cutting tool material, feed rate, depth of cut, Nose radius cutting tool, coolant and work material characterstics. Alloy Steel EN-24 is a medium carbon steel which is used in manufacturing of aircraft Automotive & axles components, Heavy duty Gears, Shafts, Spindles, Studs, collets, Pins, bolts, sprockets, couplings, pinions & pinion arbors. In this research Response surface methodology (RSM) was applied to determine the optimum machining parameters leading to minimum surface roughness maximum MRR in turning process. In this research spindle speed, depth of cut & feed rate are considered to be main parameters for turning on Alloy Steel. Through multi response optimization the optimum value of the surface roughness (Ra) comes out to be 1.46389 µm for MRR is 403.458 mm3/sec. It is also concluded that feed rate & depth of cut are the major significant factor affecting surface roughness & MRR.

Keywords: En-24 Alloy Steel, Turning Process, Surface Roughness, MRR, Anova, Response Surface Methodology.

Introduction

Increasing productivity & Quality of product are considered to main challenging task for manufacturing industries. In manufacturing industries machining processes suffers various problems regarding optimum value of machining parameters for better surface finish & material removal rate. The work material selected for the present study is Alloy Steel EN-24 (Medium Carbon Steel) used in manufacturing of aircraft Automotive & axles components, Heavy duty Gears, Shafts, Spindles, Studs, collets, Pins, bolts, sprockets, couplings & pinion arbors . In this research spindle speed, depth of cut and feed rate are considered to be main parameters for turning on Alloy Steel.

Methodology

In this research Design Expert version 6.0.8 software with Box–Behnken approach was used to develop the experimental plan for multi response optimization. RSM was introduced by G.E.P.BOX and K.B.WILSON in 1951. It is a collection of mathematical and statistical technique that is useful for modeling and analysis of problems in which a response of interest is influenced by several variables and objective is to optimize this response. This experiment contains main three factors each at three levels. therefore total number of runs requirement is seventeen including five replications of centre point. The same software was also used to analyse the collected Result data. Desirability is an objective function that ranges from zero outside of the limits to one at goal. The numerical optimization finds a point that maximizes the desirability function.

Flow Process Chart

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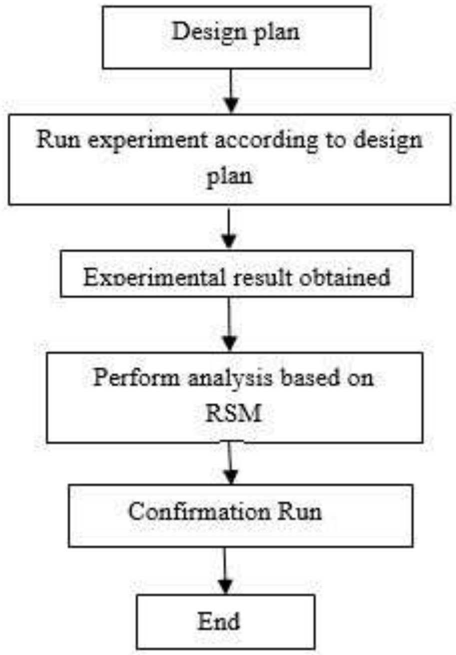

Experimental Setup

Work material

In this research, EN-24 alloy steel which is a medium carbon steel (Bars having diameter 34 mm and length 60 mm) is used as work piece for turning operation. It is used in manufacturing of aircraft Automotive & axles components, Heavy duty Gears, Shafts, Spindles, Studs, collets, Pins, bolts, sprockets, couplings & pinion arbors .

Chemical Composition of EN-24

Metal	Percentage
Fe	95.748
C	0.403
Si	0.185
Mn	0.606
S	0.019
P	0.0134
Cr	1.140
Mo	0.257
Ni	1.360

Cutting Tool

The Coated Tungsten Carbide Turning Insert (CNMG120408) is used
Tool material- Tungsten carbide
Tool Make- WIDIA
Tool Coating Material- TiN coating
C – Shape 80° diamond
N – clearance angleM – tolerance
G – insert type (pin type/top clamp)

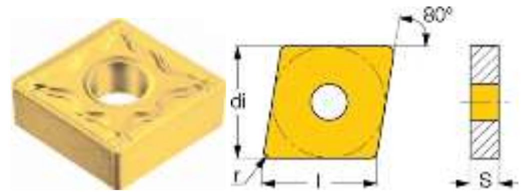

Figure 1: ***WIDIA Tool Bit for turning with geometry***

Experimental Machine

The experiments were conducted in R&D polytechnic Ludhiana. in CNC turning centre. EN-24 alloy steel (bars having diameter 34 mm and length 60mm) is used as work material for turning process in dry condition.

Figure 2: Stallion 100 HS CNC Lathe Machine for turning

Process variables & range

The working ranges of parameters for subsequent design of experiment based on Response Surface Methodology have been selected. In this experimental work, spindle speed, DOC and feed rate have been considered as main process variables. The process variables with their units (and notations) are listed in Table 1

Table 1: Process variables & working Range

Factors	**Units**	**Level-1**	**Level-2**	**Level-3**
Spindle speed(N)	Rpm	2400	2800	3200
Feed (F)	mm/rev	0.1	0.2	0.3
Depth of cut (DOC)	mm	0.5	1.00	1.50

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Figure 3: Turned work piece of Alloy Steel

Experimental design

The experimental designs based on Box–Behnken Design has been shown.
in This Table 2

			Factor 1	Factor 2	Factor 3
Std	**Block**	**Run**	**A:Speed**	**B:Feed**	**C:Depth of cut**
6	Block 1	1	3200.00	0.20	0.50
7	Block 1	2	2400.00	0.20	1.50
2	Block 1	3	3200.00	0.10	1.00
17	Block 1	4	2800.00	0.20	1.00
15	Block 1	6	2800.00	0.20	1.00
11	Block 1	7	2800.00	0.10	1.50
10	Block 1	8	2800.00	0.30	0.50
9	Block 1	9	2800.00	0.10	0.50
8	Block 1	10	3200.00	0.20	1.50
14	Block 1	11	2800.00	0.20	1.00
1	Block 1	12	2400.00	0.10	1.00
16	Block 1	13	2800.00	0.20	1.00
3	Block 1	14	2400.00	0.30	1.00
5	Block 1	15	2400.00	0.20	0.50
4	Block 1	16	3200.00	0.30	1.00
13	Block 1	17	2800.00	0.20	1.00
15	Block 1	6	2800.00	0.20	1.00

Roughness Measurement

Roughness measurement has been done using a portable stylus type profilometer named mitotoyo suftest-4 shown in figure 4.

Figure 4: Mitotoyo Suftest-4 Machine

Experimental result

Table 3: Experimental Result for Surface Roughness.

S.No.	**RUN 1 (µm)**	**RUN 2(µm)**	**Ra (µm)**
1	1.04	1.07	1.055
2	1.7	1.9	1.8
3	1.07	1.31	1.19
4	1.53	1.55	1.54
5	2.63	2.77	2.70
6	1.47	1.53	1.48
7	0.75	0.64	1.8
8	2.51	2.59	2.55
9	0.47	0.49	0.48
10	1.38	1.20	2.9
11	1.19	1.18	1.52
12	0.695	0.697	0.696
13	1.17	1.19	1.5
14	2.49	2.43	2.46
15	1.20	1.18	1.19
16	2.46	2.49	2.6
17	1 .32	1.34	1.3

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Table 4: Results of main experiments for MRR & average surface roughness values R_a

			Factor I	Factor II	Factor III	Response I	Response II
Std	**Block**	**Run**	**A:Speed**	**B:Feed**	**C:Depth of cut**	**Ra (µm)**	**MRR mm^3/sec**
6	Block 1	1	3200	0.2	0.50	1.055	152.86
7	Block 1	2	2400	0.2	1.50	1.8	413.15
2	Block 1	3	3200	0.1	1.00	1.19	280.25
17	Block 1	4	2800	0.2	1.00	1.54	350.31
12	Block 1	5	2800	0.3	1.50	2.7	618.74
15	Block 1	6	2800	0.2	1.00	1.48	407.64
11	Block 1	7	2800	0.1	1.50	1.8	305.73
10	Block 1	8	2800	0.3	0.50	2.55	222.93
9	Block 1	9	2800	0.1	0.50	0.48	127.38
8	Block 1	10	3200	0.2	1.50	2.9	621.02
14	Block 1	11	2800	0.2	1.00	1.52	407.64
1	Block 1	12	2400	0.1	1.00	0.696	209.38
16	Block 1	13	2800	0.2	1.00	1.5	389.24
3	Block 1	14	2400	0.3	1.00	2.46	382.17
5	Block 1	15	2400	0.2	0.50	1.19	152.86
4	Block 1	16	3200	0.3	1.00	2.6	541.40
13	Block 1	17	2800	0.2	1.00	1.3	467.09

ANOVA For R_a

ANOVA is performed using the Design-Expert 6.0.8. software. ANOVA for response R_a is given in Table 5

Table 5: ANOVA for Ra

Source	**Total Sum of Squares**	**DF**	**Mean Square**	**Total F Value**	**P- value Prob> F**	**Remarks**
Model	8.08	7	1.15	46.29	< 0.0001	Significant
A	0.32	1	0.32	12.81	0.0059	Significant
B	4.72	1	4.72	189.15	< 0.0001	Significant
C	1.93	1	1.93	77.19	< 0.0001	Significant
B^2	0.19	1	0.19	7.51	0.0229	Significant
C^2	0.19	1	0.19	7.49	*0.0230*	Significant
AC	0.38	1	0.38	15.29	0.0036	Significant
BC	0.34	1	0.34	13.72	0.0049	Significant
Residual	0.22	9	0.025			
Lack of Fit	0.19	5	0.037	4.02	0.1012	Insignificant
Pure Error	0.037	4	9.320E-003			
Core Total	8.31	16				
Std. Dev.	0.16	C.V.	9.34			
R-Squared	0.9730	Pred R-Squared	0.8084			

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Mean	1.69	PRESS	1.59			
Adj R-Squared	0.9520	Adeq Precision	23.233			

ANOVA For MRR

ANOVA is performed using the Design-Expert 6.0.8. software. ANOVA for response MRR is given in Table 6

Table 6: ANOVA for MRR

Source	**Total Sum of Squares**	**DF**	**Mean Square**	**Total F Value**	**P- value**	**Remarks**
Model	3.602E+005	6	60031.42	32.44	< 0.0001	Significant
A	23985.98	1	23985.98	12.96	< 0.0048	Significant
B	88742.63	1	88742.63	47.95	< 0.0001	Significant
C	2.121E+005	1	2.121E+005	114.60	< 0.0001	Significant
C^2	12736.11	1	12736.11	6.88	0.0255	Significant
AC	10802.48	1	10802.48	5.84	0.0363	Significant
BC	11822.21	1	11822.21	6.39	0.0300	Significant
Residual	1850.35	10	1850.74			
Lack of Fit	11400.77	6	1900.13	1.07	0.4970	Insignificant
Pure Error	7106.58	4	1776.65			
Core Total	3.787E+005	16				
Std. Dev	43.02	C.V.	12.09			
R-Squared	0.9511	Pred R-Squared	0.8665			
Mean	355.87	PRESS	50544.49			
Adj R-Squared	0.9218	Adeq Precision	19.427			

Regression Models.

The regression equations for the response characteristics as a function of input process parameters are given below in both coaded and actual factors.. The insignificant coeffiecients (investigated from ANOVA) are omitted from the total equations. & The developed statistical model for Surface roughness and Material removal rate is

Surface Roughness =1.49 + 0.20 * A + 0.77* B + 0.49 * C + 0.21 * A^2 + 0.21 * B^2 + 0.37 * C^2 + 0.31 *A * C -0.29 * B * C

Surface Roughness = 2.41360 -1.04406E-003 * speed + 5.10632 * feed -3.85399 * depth of cut + 21.05921 * $feed^2$ + 0.84137 * depth of cut^2 +1.54375E-003 *speed *depth of cut -5.85000*feed *depth of cut.

Material Removal Rate = +381.67 + 54.76 * A + 105.32 * B +162.83 * C – 54.84 * C^2 + 51.97 *A* C + 54.36 * B * C.

Material Removal Rate = +187.73542 -0.12295 * speed -34.07500 * feed- 180.65361* depth of cut -219.34944 * depth of cut^2 + 0.25984 * speed * depth of cut +1087.30000 * feed * depth of cut

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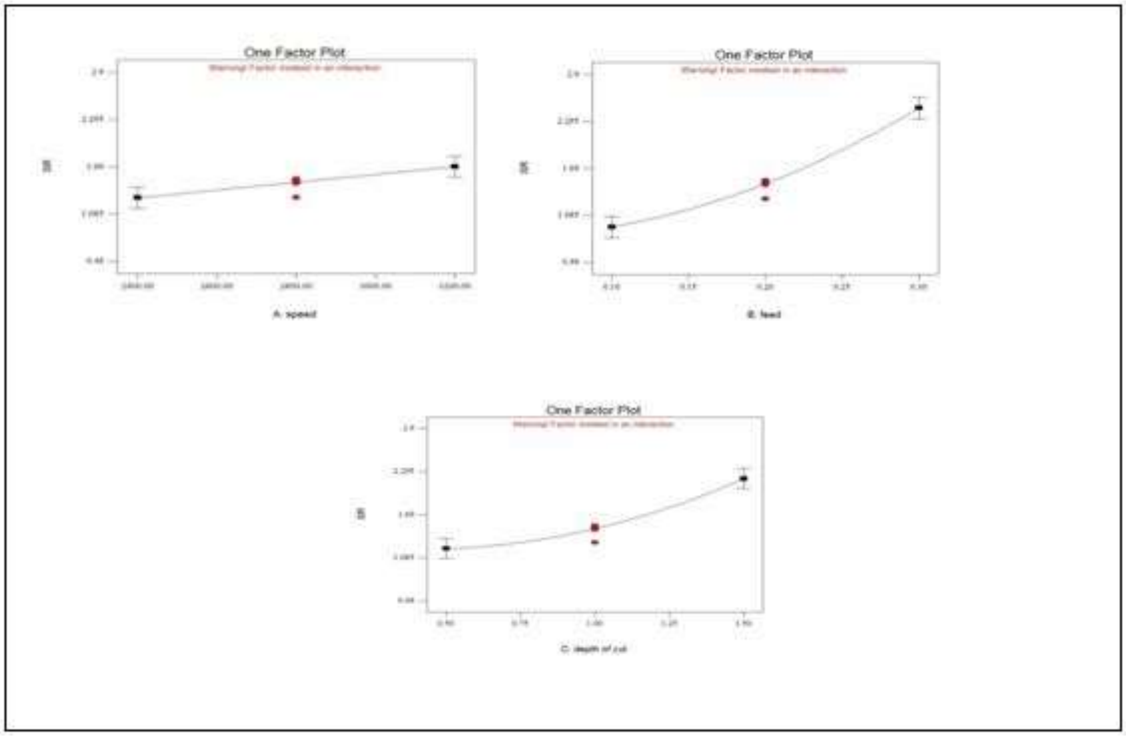

Figure 5: Effect of (A) speed, (B) feed, (C) depth of cut on Ra.

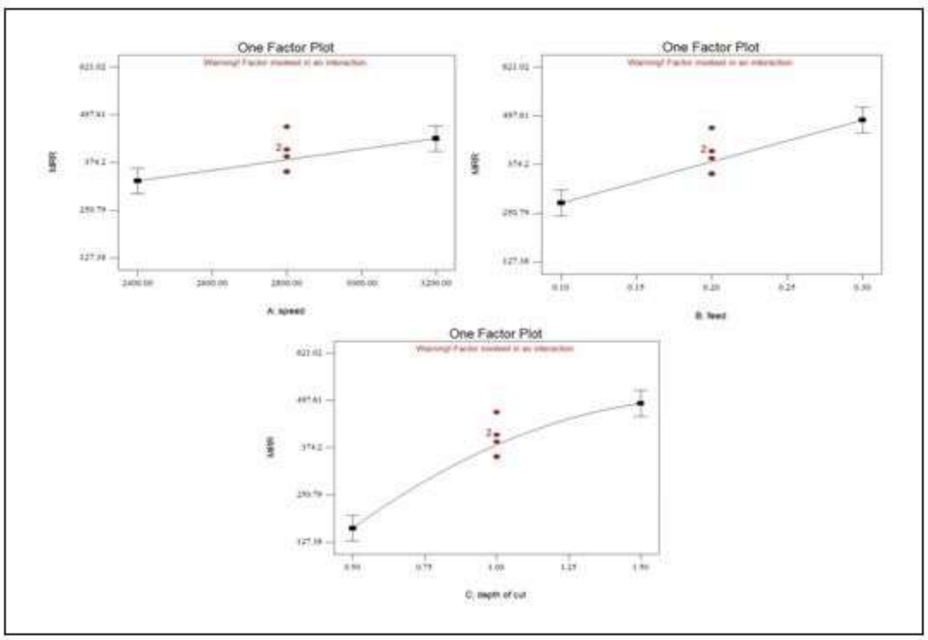

Figure 6: Effect of (A) speed, (B) feed, (C) depth of cut on MRR

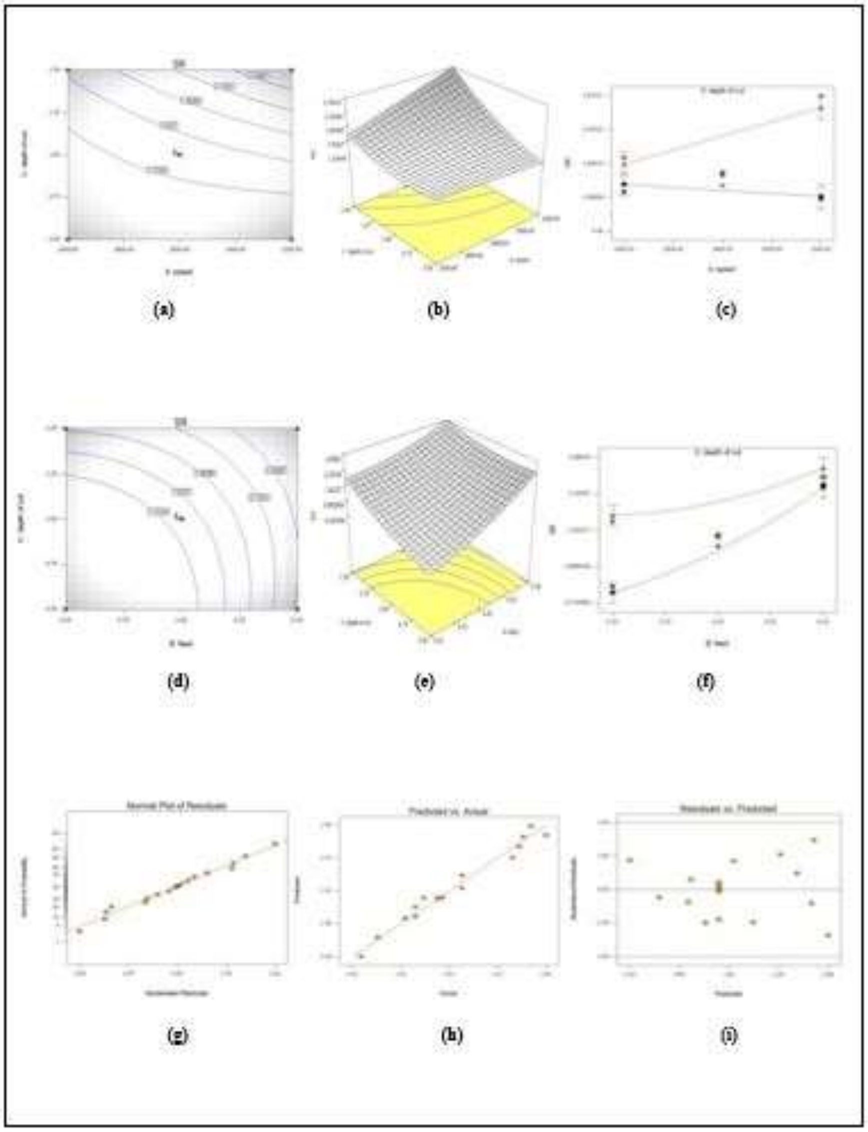

Figure 7: ***(a) Contour plot (b) response surface (c) Interaction plot at feed of 0.20mm. And (d) Contour plot (e) response surface (f) Interaction plot at speed of 2800 rpm (g) Normal probability plot of residuals (h) Actual Vs Predicted values (i) Residual Vs Run***

Figure 7: a-b-c shows the contour plot, 3D response surface and Interaction Graph for the response MRR in terms of speed and depth of cut at a feed of 0.20mm.Contour plot plays a very important role in the study of response surface method. with generating contour plot using Design of expert software for the response surface analysis, it is simple to characterize the shape of surface and locate the optimum with reasonable precision. By the examination of the contour plot and response surface, it is observed that SR increases from 1.37 to 2.46 with increase in speed from 2400RPM to 3200RPM with increase of depth of cut from 0.5mm to 1.5mm at a feed 0.20mm.

Figure 7: d-e-f shows the contour plot, 3D response surface and Interaction Graph for the response MRR in tergure 7: g-h-i displays the normal probability plot of residuals and predicted versus actual plots for Ra. It is observed that the residuals generally fall on the straight line implying that errors are normal distributed. The outlier points are then verified by checking for any points lying outside the red lines. It is evident from the fig.7(i), all points lie inside the red lines, which indicates that the model fit well.

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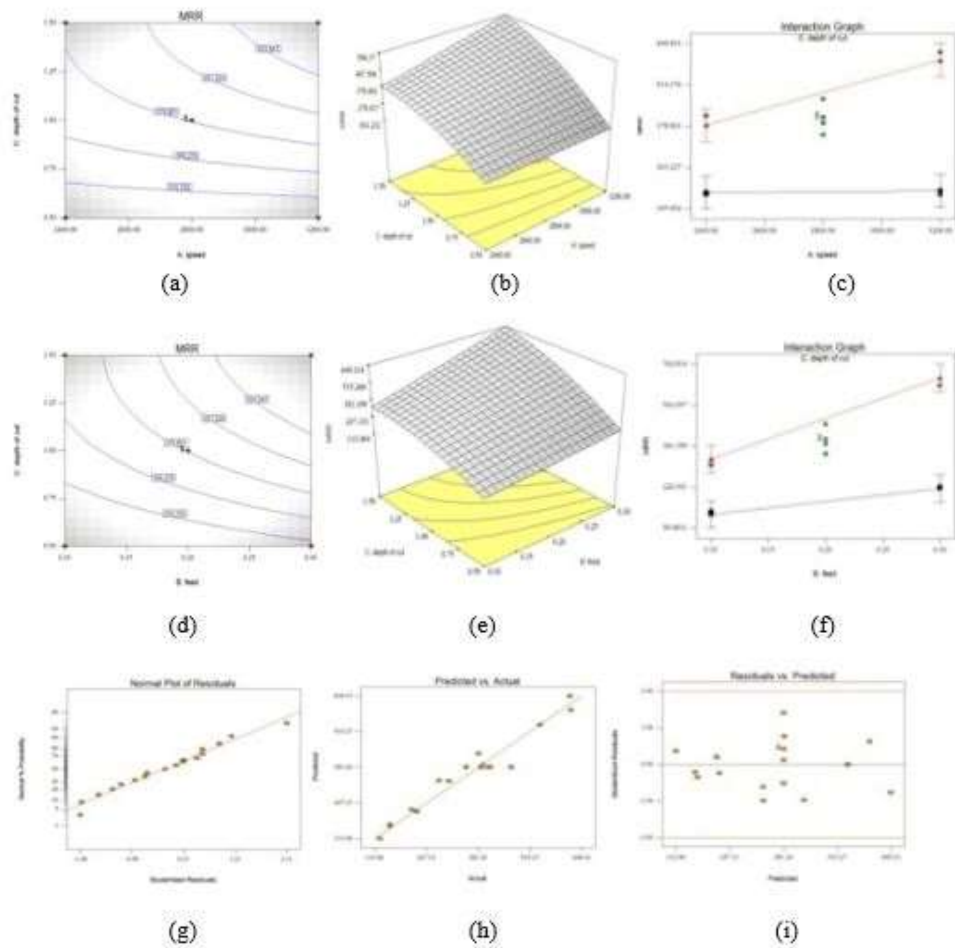

Figure 8: ***Estimated (a) contour (b) response surface (c) Interaction plot at a feed = 0.20mm, and (d) contour (e) response surface (f) Interaction plot at the speed of 2800RPM, (g) Normal probability plot residuals (h) Actual Vs Predicted values (i) Residual Vs Run***

Figure 8: a-b-c shows the contour plot, 3D response surface and Interaction Graph for the response MRR in terms of speed and depth of cut at a feed = 0.20mm.Contour plot plays a very important role in the study of response surface. with generating contour plot by Design of expert software for the response surface method, it is simple to characterize the shape of surface and locate the optimum with reasonable precision. By the examination of the contour plot and response surface, it is observed that MRR increases from 233.746 mm^3/sec to 523.856 mm^3/sec with increase in speed from 2400RPM to 3200RPM with increase of depth of cut from 0.5mm to 1.5mm at a feed 0.20mm.

Figure 8: d-e-f shows the contour plot, 3D response surface and Interaction Graph for the response MRR in terms of feed and depth of cut at a speed of 2800RPM.

Figure 8: g-h-i displays the normal probability plot of residuals and predicted versus actual plots for Ra. It is observed that the residuals generally fall on the straight line implying that errors are normal distributed. The outlier points are then verified by checking for any points lying outside the red lines. It is evident from the fig. 8(i), all points lie inside the red lines, which ensures easily that the model fit well.

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Table 7: Constraints for input parameters and responses.

Parameters	Target	Lower Limit	Upper Limit	Importance
Speed	Is in range	2400	3200	3
Feed	is in range	0.1	0.3	3
Depth of cut	is in range	0.5	1.5	3
Surface Roughness	minimum	0.48	2.9	3
MRR	Maximum	127.38	621.02	3

Table 8: Solutions for optimum settings of process inputs for confirmation experiment.

Exp no.	Speed	Feed	Depth of cut	Surface Roughness	MRR	Desirability	------------
1	3200.00	0.16	1.03	1.46389	403.458	0.576	Selected

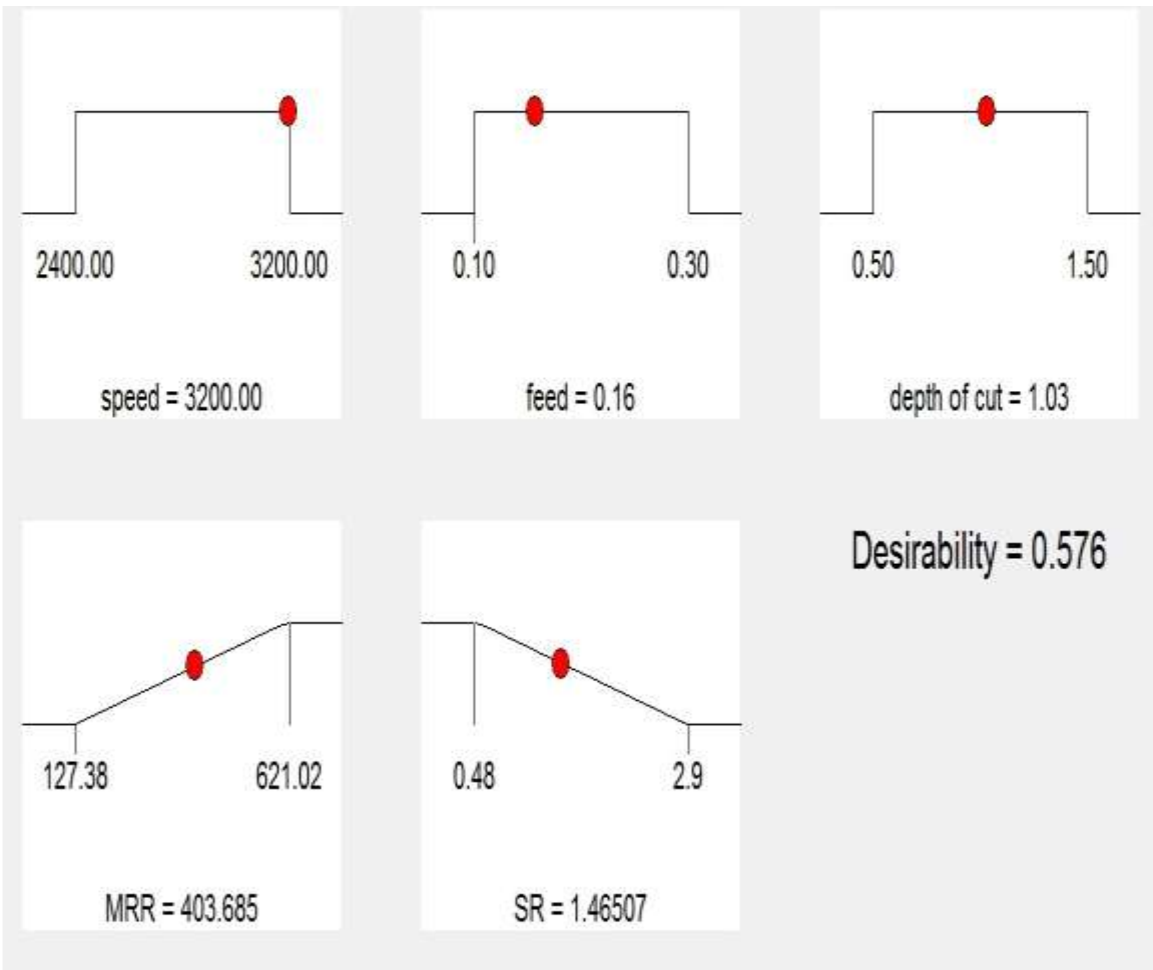

Figure 9: ***Multi response optimization results for maximum MRR and minimum Ra with ramp diagrams.***

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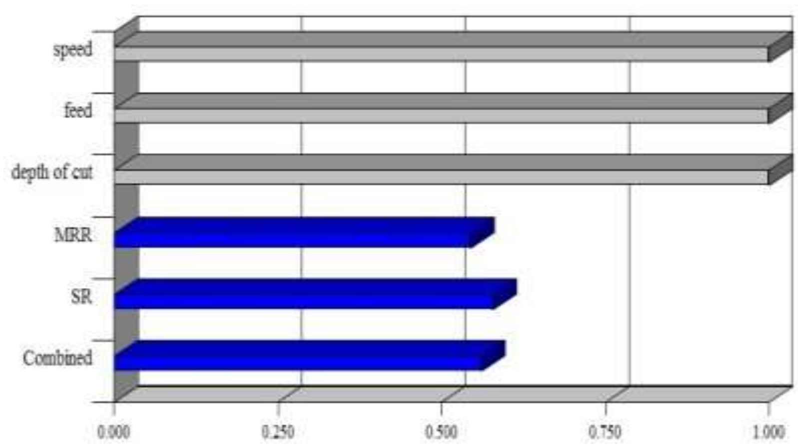

Figure10: ***Multi response optimization results for maximum MRR and minimum R_a with histograms results for maximum MRR and minimum R_a with histograms***

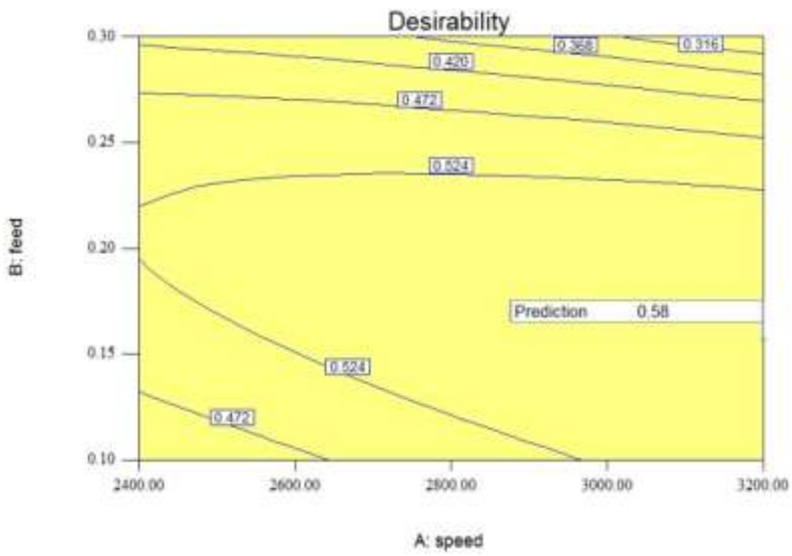

Figure 11: ***Contour plot for results of overall desirability functions (At speed = 3200 RPM, feed rate 0.16mm, depth of cut 1.03mm)***

Once the optimal level of the process inputs is selected, the final step is to predict and verifying the improvement of the performance characteristics using the optimal level of the machining parameters. Experiments performed to machine and verify the Turning at the above optimal input parametric setting for MRR and surface roughness were compared with optimal response values. The observed MRR and surface roughness of the experimental results are 403.458 mm^3/sec and 1.46389 µm respectively. Table 10 shows the error percentage for experimental validation of the developed models for the responses with optimal parametric setting during Turning of Alloy Steel EN-24. From the analysis of Table10, it can be observed that the calculated error is small. The error between experimental and predicted values for surface roughness and MRR lies within 5.48% and 1.04% respectively. Obviously, this confirms the excellent reproducibility for the experimental conclusions.

Table 9: Multi-optical parametric settings for surface roughness and MRR

Parameters	Units	Optical parameter setting
Speed	RPM	3200
Feed	mm/rev	0.16
Depth of cut	mm^3/sec	1.03

Table 10: Main Experimental validation of developed models with optimal parameter settings.

Responses	Predicted	Experimental	Error
Surface roughness	1.46	1.54	5.48%
MRR	403.45	407.64	1.04%

Conclusion

In this study, the surface roughness and MRR in the surface finishing process of EN24 alloy steel were modeled and analyzed through RSM. Spindle speed, feed and depth of cut have been employed to carry out the experimental study. Summarizing the main features, the following conclusion can be drawn.

1. Analysied with ANOVA the experimental results showed that the feed rate (the most significant factor) contributed 56.80 %, where as the depth of cut and spindle speed contribution was 23.22 % and 4 % for Ra.
2. The experimental results with ANOVA analysis showed that the Depth of cut (the most significant factor) contributed 56 %, where as the feed rate and spindle speed contribution was 23.43 % and 6.33 % for MRR.
3. The predicted values of R^2 are 0.8084 for surface roughness and 0.8665 for MRR are reasonably well.Its value greater than 70% and closest to one is the best value for fit the model.
4. The error between experimental and predicted values at the optimal combination of parameter setting for Ra and MRR lie with in 5.48 % and 1.03 % respectively. Obviosly,this confirms excellent reproducibility of the experimental conclusions.
5. From the multi response optimization, we obtain the optimal combination of parameters settings are speed of 3200 rpm, feed rate 0.16 mm/rev. and depth of cut 1.03 mm for achieving the required minimum surface roughness and maximum MRR.

Scope for future work

In this present research only three parameters have been studied in accordance with their effects. View of future scope, the further researches can be carried out as:
To study the effects of tool geometry like Nose Radius, Rake Angle on the surface roughness and MRR.

1. To analyses the effect of cutting forces exerted and tool wear rate during the cutting operation.
2. To study the other output factors like power consumption, tool life, etc. can be studied.
3. To study effect of response variables with different cutting tools.

To study and compare the differences in performance characteristics on same work sample after heat treatment.

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