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Experimental Investigation of Machining Parameters For Surface Roughness In High Speed CNC Turning of EN-24 Alloy Steel Using Response Surface Methodology

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Abstract
Alloy Steel EN-24 (Medium Carbon Steel) used in manufacturing of Automotive & aircraft components, Axles & Axles components, Shafts, Heavy duty Gears, Spindles, Studs, Pins, collets, bolts, couplings, sprockets, pinions & pinion arbors. Turning is the most common process used in manufacturing sector to produce smooth finish on cylindrical surfaces. Surface roughness is the important performance characteristics to be considered in the turning process is affected by several factors such as cutting tool material, spindle speed, feed rate, depth of cut and material properties. In this research Response surface methodology (RSM) was applied to determine the optimum machining parameters leading to minimum surface roughness in turning process. The main purpose of this research is to study the effect of carbide inserts on EN-24 Alloy Steel surface by using three parameters (spindle speed, feed rate and depth of cut). This research was conducted by using 100 HS Stallion CNC Lathe machine. Seventeen sets of experiments were performed. In this work empirical models were developed for surface roughness by considering spindle speed, feed rate and depth of cut as main controlling factors using response surface methodology. The optimum value of the surface roughness (Ra) comes out to be 0.48 µm. It is also concluded that feed rate is the most significant factor affecting surface roughness followed by depth of cut. As Cutting speed is the less significant factor affecting surface roughness. Optimum results are finally verified with the help of confirmation experiments.

Keywords: EN-24 Alloy Steel, Response Surface Methodology, Anova, Machining Process, Surface Roughness,

I. Introduction

Surface finish play a significant role during machining of any of the component. Better finished components increase the productivity & economics of the industry. A Better machined surface surely improves fatigue strength, creep failure, corrosion resistance. As we know in actual machining, there are a number of factors which affect the surface roughness as cutting conditions, tool variables and work piece variables. Cutting conditions include speed, depth of cut and feed. tool variables include tool material, rake angle, nose radius, cutting edge geometry, tool overhang, tool point angle, tool vibration etc. and work piece variable include hardness of material and mechanical properties. As It is very difficult to take all parameters that control the surface roughness for a particular manufacturing process. In a turning operation, it is very difficult to select the cutting parameters to achieve the high surface finish. This study would help the operator to select the cutting parameters.

The work material used for the present study is Alloy Steel EN-24 (Medium Carbon Steel) used in manufacturing of Automotive & aircraft components, Axles & Axle components, Shafts, Heavy duty Gears, Spindles, Studs, Pins, collets, bolts, couplings, sprockets, pinions & pinion arbors.

II. Methodology

In this research Response surface methodology (RSM) was applied to determine the optimum machining parameters leading to minimum surface roughness in turning process. The main Experiments in the present work were designed by Box–Behnken approach with the help of software Design-Expert6.0.8. In the present work, experiments are designed accordingly to the Box-Behnken approach of Response Surface Methodology (RSM). Main experiment contains three factors each at three levels. So, total number of runs required is seventeen including five replications of centre point. The version 6 of the Design Expert software was used to develop the experimental plan for RSM. The same software was also used to analyse the collected data.

III. Experimental detail

3.1 Work material

In present study, EN-24 alloy steel (bars of diameter 34 mm and length 60 mm) is used as workpiece. It is Suitable for manufacturing of Automotive & aircraft components, Axles & Axle components, Shafts, Heavy duty Gears, Spindles, Studs, Pins, collets, bolts, couplings, sprockets, pinions & pinion arbors, extrusion liners, magneto drive couplings, studs.

Table 3.1:Chemical Composition of EN-24

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

3.2 Selection of cutting Tools & tool holder

The Coated Tungsten Carbide Turning Insert (CNMG120408) is used
Tool Make- WIDIA
Tool material- Tungsten carbide
Tool Coating Material- TiN coating
TiN is a hard ceramic material, coating to improve surface properties, harden, protect cutting and sliding surfaces. Coatings generally increase a tool's lubricity. A coating allows the cutting edge of a tool to cleanly pass through the material without having the material stick to it.It also help in decrease the temperature associated with the cutting process and increase the life of the tool.
C – Shape 80^o diamond
N – clearance angle
M – tolerance
G – insert type (pin type/top clamp)

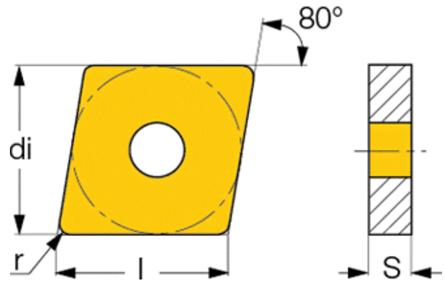

Figure 3.1 WIDIA Tool Bit for turning with geometry.

3.3 Experimental plan & cutting condition

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

Figure 3.2 Stallion 100 HS CNC Lathe Machine

Process variables and their levels

The working ranges of parameters for subsequent design of experiment based on Response Surface Methodology have been selected. In the present experimental work, spindle speed, feed rate and depth of cut have been considered as main process variables. The process variables with their units (and notations) are listed in Table 3.2

Table 3.2: Process variables and their levels

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

3.4 Experimental design

Experiments have been carried out using Response Surface Methodology experimental design which consists of 17 combinations of spindle speed, longitudinal feed rate and depth of cut. It consist three process parameters to be varied in three discrete levels. The experimental designs based on BBD has been shown in Table 3.3

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

3.5 Roughness Measurement

Roughness measurement has been done using a portable stylus type profilometer, mitotoyo suftest-4 shown in figure 3.3. The mitotoyo suftest-4 is a,self-contained, portable instrument used for the measurement of surface texture. The measurement results are displayed on an LCD screen and can be output to an optional printer or another computer for further evaluation. The instrument is powered by non-rechargeable alkaline battery (9V). It is equipped with a diamond stylus having a tip radius 5μm. For accurate measurement of surface roughness it is necessary to set the stylus on the top most position of the surface of the workpiece. So it is checked by marking centre lines at 90 degree on the cross section of the work piece. The measuring stroke always starts from the extreme outward position. At the end of the measurement sthe pickup returns to the position ready for the next measurement. Roughness measurements, in the transverse direction, on the work pieces have been repeated three times and average of four measurements of surface roughness parameter values has been recorded. Surface roughness measurement with the help of stylus has been shown in Figure 3.3.

figure 3.3 Mitotoyo Suftest-4 Machine

IV. Experimental Results For Surface Roughness

			Factor 1	Factor 2	Factor 3	
Std	Run	Block	A:Speed	B:Feed	C:Depth of cut	Ra (μm)
6	1	Block 1	3200.00	0.20	0.50	1.055
7	2	Block 1	2400.00	0.20	1.50	1.8
2	3	Block 1	3200.00	0.10	1.00	1.19
17	4	Block 1	2800.00	0.20	1.00	1.54
12	5	Block 1	2800.00	0.30	1.50	2.7
15	6	Block 1	2800.00	0.20	1.00	1.48
11	7	Block 1	2800.00	0.10	1.50	1.8
10	8	Block 1	2800.00	0.30	0.50	2.55
9	9	Block 1	2800.00	0.10	0.50	0.48
8	10	Block 1	3200.00	0.20	1.50	2.9
14	11	Block 1	2800.00	0.20	1.00	1.52
1	12	Block 1	2400.00	0.10	1.00	0.696
16	13	Block 1	2800.00	0.20	1.00	1.5
3	14	Block 1	2400.00	0.30	1.00	2.46
5	15	Block 1	2400.00	0.20	0.50	1.19
4	16	Block 1	3200.00	0.30	1.00	2.6
13	17	Block 1	2800.00	0.20	1.00	1.3

Table 4.1 Selection of Model for Ra

Sequential Model Sum of Squares:

Source	Sum of Squares	Df	Mean Square	F Value	P-value Prob > F	Remarks
Mean	48.66	1	48.66			
Linear	6.96	3	2.32	22.45	<0.0001	
2FI	0.75	3	0.25	4.27	0.0349	
Quadratic	0.41	3	0.14	5.41	0.0305	Suggested
Cubic	0.14	3	0.047	5.01	0.0767	Aliased
Residual	0.037	4	9.320 E-003			
Total	56.97	17	3.25			

Lack of fit test:

Source	Sum of Squares	Df	Mean Square	F Value	P-value Prob > F	Remarks
Linear	1.31	9	0.15	15.58	0.0089	
2FI	0.55	6	0.092	9.87	0.0220	
Quadratic	0.14	3	0.047	5.01	0.0767	Suggested
Cubic	0.000	0				Aliased
Pure Error	0.037	4	9.320 E-003			

Model Summary Statistics:

Source	Std. Dev.	R-Squared	Adjusted R-Squared	Predicted R-Squared	Press	Remarks
Linear	0.32	.08382	0.8009	0.6947	2.54	
2FI	0.24	0.9291	0.8865	0.7745	1.87	
Quadratic	0.16	0.9786	0.9512	0.7230	2.30	Suggested
Cubic	0.097	0.9955	0.9821		+	Aliased

4.1 ANOVA for R_a

ANOVA is performed using the Design-Expert 6.0.8. software. ANOVA for response R_a is given in Table 4. 2

Table 4.2 ANOVA for Ra

Source	Sum of Squares	DF	Mean Square	F Value	P-value	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
Residu	0.22	9	0.025			

al						
Lack of Fit	0.19	5	0.037	4.02	0.1012	Insignificant
Pure Error	0.037	4	9.320E-003			
Cor Total	8.31	16				
Std. Dev	0.16	C.V.	9.34			
R-Squared	0.9730	Pred R-Squared	0.8084			
Mean	1.69	PRESS	1.59			
Adj R-Squared	0.9520	Adeq Precision	23.233			

The model F value of 46.29 implies that the model is significant. There is only a 0.01% chance that a model F value this large could occur due to noise. Value of Prob. > F value less than 0.0500 indicate model terms are significant. In present experimentation A, B, C, B^2, C^2, AC and BC are significant model terms. Values greater than 0.1000 indicate the model terms are insignificant. If there are many insignificant model terms which are not counting to support hierarchy, model reduction may improve the model. The "Lack of Fit F-value" of 4.02 implies the Lack of Fit is not significant relative to the pure error. There is a 10.12% chance that a "Lack of Fit F-value" this large could occur due to noise. Non-significant lack of fit is good -- we want the model to fit.sThe "Pred R-Squared" of 0.8084 is in reasonable agreement with the "Adj R-Squared" of 0.9520. "Adeq Precision" measures the signal to noise ratio. A ratio greater than 4 is desirable. Here ratio of 23.233 indicates an adequate signal.This model can be used to navigate the design space.

4.2 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 equations.The developed statitical model for Surface roughness 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.

4.3 Discussions of Results of Main Experiment

4.4.1 Single Factor Effect on R_a: Fig. 4.1 show the effect of three process inputs i.e., speed, feed and depth of cut of turning on average surface roughness value.

Effect of speed: From the main effect plots based on the fig. 4.1a, it has been observed that whenever spindle speed is increased from 2400RPM to 2800RPM the value of Ra is increased from 1.19µm to 1.54µm and when again speed increased from 2800RPM to 3200RPM, the value of Ra is increased up to the value of 1.69µm.So result shows surface roughnesss is increased with speed.

Effect of feed: From the main effect plots based on the fig. 4.1b it has been observed that when feed rate is increased from 0.1mm/min to 0.3mm/min, the increment of Ra is 0.696µm to 2.46µm aproximately. So result shows that feed gives the main effect on Ra.

Effect of depth of cut: From the main effect plots based on the fig. 4.1c, it has been observed that whenever depth of cut is increased from 0.5mm to 1mm the value of Ra is very slightly increase from 1.19µm to 1.54µm approximately and when again depth of cut increases from 1mm to 1.5mm, the value of Ra is increased upto the value of 1.98µm approximately.So result shows that with increase in depth of cut value of R_a is increased.

Fig 4.1(a)

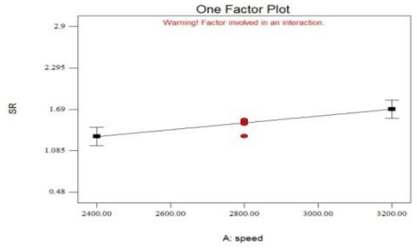

Fig 4.1(b)

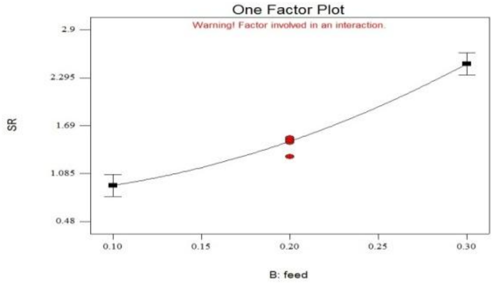

Fig 4.1(c)

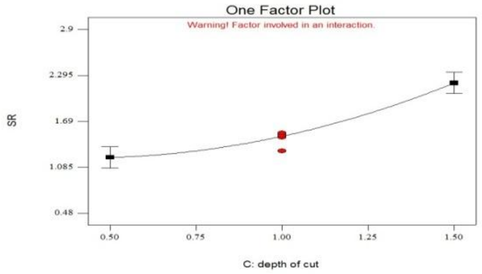

Fig 4.2(a)

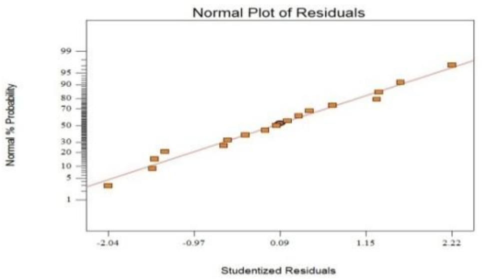

Fig 4.2(b)

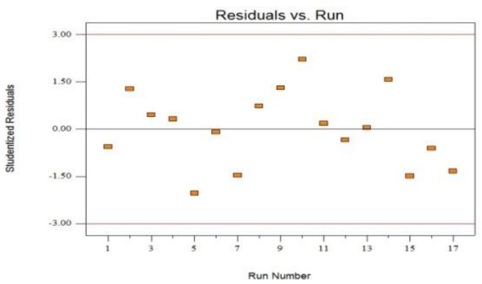

Fig 4.2(c)

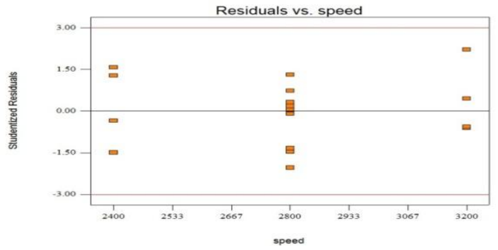

Fig 4.2(d)

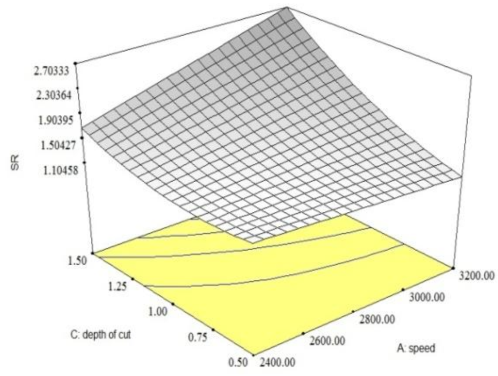

Fig 4.2(e)

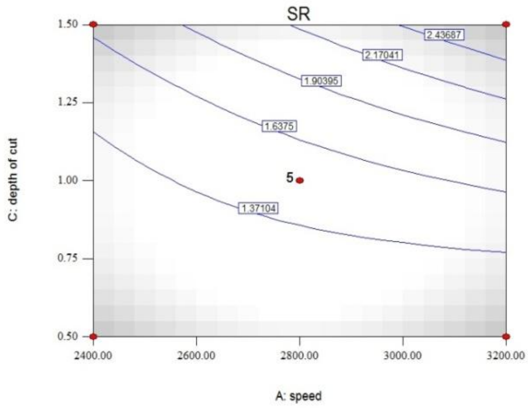

Fig. 4.2 Estimated contour and response surface for Ra

Fig.4.2 d-e shows the three dimensional interaction response surface and contour plot for the response Ra in terms of speed and feed & depth of cut. Contour plot plays a very important role in the study of response surface. By generating contour plot using Design expert software for the response surface analysis, it is easy to analyze the shape of surface and locate the optimum with reasonable precision. From the examination of the contour plot and response surface, it is observed that at feed 0.20mm/rev Ra increases from 1.37µm to 2.437µm with increase in speed from 2400RPM to 3200RPM with increase Depth of cut from 0.1mm to 1.5mm.Fig.4.2 a,b,c 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 normally distributed. The outlier points are verified by checking for any points lying outside the red lines. It is evident from all points lie inside the red lines area, which signifies that the model fit well.

V. Conclusion

The current Experiment has Performed to study the effect of Machining parameters on surface Roughness The following conclusions are drawn from the study:

1. The Surface roughness is mainly affected by feed rate and depth of cut. With the increase in feed rate & depth of cut the surface roughness increases
2.As the cutting speed increases there is slightly increase in Surface Roughness.
3. The optimum value of the surface roughness (Ra) comes out to be 0.48 µm.
4.The parameters taken in the experiments are optimized to obtain the minimum surface roughness possible. The optimum points of cutting parameters for better Quality Surface finish is as :-
i) Spindle speed = 2800rpm.
ii) Feed rate= 0.1 mm/min.
iii) Depth of cut =0.5 mm.

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