 ISSN: 2454-4248
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Investigating the Effect of Process Parameters on Surface Roughness Indicators Produced by End Milling Operation When End Milling Solid Material AISI D3 Tool Steel

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Abstract:- Machining parameters such as speed, feed and depth of cut play a vital role in machining the given work piece to the required shape. These have a major effect on the quality as well as on quantity of production, cost of production and production rate; hence their judicious selection assumes significance. A study of surface roughness and cutting force during end milling on this material will be quite useful. In the present work the 2 level full factorial design has been selected for development of prediction models as well as for the optimization of milling parameters for minimum surface roughness and minimum cutting forces. An effort has also been made to investigate the effect of end milling parameters on surface roughness indicators end milling of AISI D3 tool steel.

This work concluded that feed is the most significant and influential machining parameter that affect the surface roughness indicator (Ra, Rq and Rt) followed by depth of cut. The cutting speed has insignificant influence on the surface roughness parameters. The mathematical models developed clearly show that surface roughness indicators increases with increasing the feed rate but decreases with increasing the cutting speed.

The results of ANOVA and the confirmation runs verify that the developed mathematical models for surface roughness parameters shows excellent fit and provide predicted values of surface roughness that are close to the experimental values, with a 95 per cent confidence level. The percentage error between the predicted and experimental values of the response factor during the confirmation experiments are within 5 per cent.

The study was undertaken to investigate the effect of process parameters on surface roughness indicators produced by end milling operation when end milling solid material AISI D3 tool steel. The end milling operation was carried out using various cutting parameters by using a cutting insert. Machining data of surface roughness indicators were tabulated by using surface roughness measurement apparatus. A Surface Roughness Tester (Stylus equipment) measuring instrument was used to process the measured profile data.

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I. INTRODUCTION

This chapter presents the importance of surface quality in metal machining. Machining parameters such as speed, feed and depth of cut play a vital role in machining the given work piece to the required shape. These have a major effect on the quality as well as on quantity of production, cost of production and production rate; hence their judicious selection assumes significance. The selected machining parameters should yield desired quality on the machined surface while utilizing the machining resources such as machine tool and cutting tool to the fullest extent possible, consistent with the constraints on these resources.

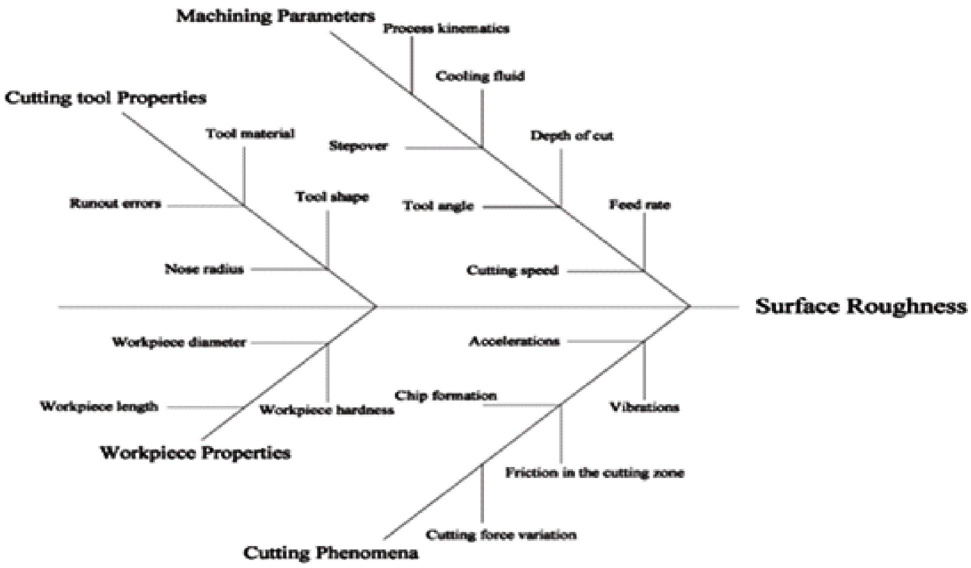
Machining is the most widespread metal shaping process used in manufacturing industry. Worldwide investment in metal-machining processes continues to increase year after years. The machining is more costly than other production process, viz. casting, molding, and forming etc, but it is often justified for precision requirement. Another reason for its popularity is the versatility complicated free-form shapes with many features, over a large size range, can be made more cheaply, quickly and simply by controlling the path of a standard cutting tool.

In the manufacturing industries, various machining processes are adopted for removing the material from the work piece to obtain finished product. Among various machining operations milling is widely used metal removal processes.

Milling is the basic machining process in which a surface is generated by progressive chip removal. The work piece is fed into a rotating cutting tool. Sometimes, the workpiece remains stationary and the cutter is fed into the work. Often, the desired surface is obtained in a single pass of the cutter or the work. This process is widely used for mass production because of its ability to produce a surface with good surface finish.

Surface finish is one of the most important parameters to determine the quality of product. It is the one of the critical performance parameter that has an appreciable effect on several mechanical properties of machined parts such as fatigue behaviour, corrosion resistance, creep life, etc. It also affects other functional attributes of machined parts like friction, wear, light reflection, heat transmission, lubrication, electrical conductivity, etc. Hence, achieving the desired surface quality is of great importance for the functional behaviour of the mechanical parts. The challenge in accurately modelling the surface roughness lies in the fact that the cutting process is very complex due to the many highly interlinked variables influencing the surface finish.

During the machining, machining conditions play a significant role in governing the performance of machining. Several factors influence the surface roughness during the milling operation. These can be categorized as controllable factors (spindle speed, feed rate, depth of cut and nose radius) and uncontrollable factors (tool geometry and material properties of both tool and work piece). Figure 1 shows the set of parameters that influence the surface roughness obtained on the workpiece during machining.



Fishbone diagram with the parameters that affect surface roughness

It has long been recognized that the machining conditions, such as feed rate, cutting speed and depth of cut affect the performance of the operation to a greater extent. These parameters should be selected to optimize the economics of machining operations. So it can be achieved by mathematical modelling of performance as a function of machining conditions using design of experiments (DOE).

II EQUIPMENTS AND TECHNIQUES

A. CNC End milling

End milling operation was carried out on a HMT VMC 400 Machining Centre, Make-India. The CNC Machining centre equipped with continuously variable spindle speed up to 6000 rpm, and 7.5kW motor drive was used for experimentation. The major machining operations that can be carried out are milling, drilling, boring etc. The cutter used in this study was end ball nose cutter having 18 mm diameter.

Table I Technical specification of LEADWELL V40 Machining Centre

Model No.	**VMC 400**
Spindle speed (Max)	6000
Spindle motor power	7.5 kW
X- axis	420 mm
Y- axis	400 mm
Z- axis	420 mm
Table size (L*W)	650 X400 mm
Rapid rate	20 m/min
Positioning accuracy	± 0.005mm
Repeatability	± 0.003mm

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B. Cutting inserts

Coated carbide tool performs better than uncoated carbide tools. On this basis, commercially accessible PVD coated carbide insert was used for end milling. The inserts were manufactured by Taegu Tec, India Pvt. Ltd. The ISO designation of cutting insert is AXMT0903R05 EML (85◦ rhombus-shaped insert with 0.5 mm nose radius).

C. Work piece

The machining experiments were performed on AISI D3 steel. All the pieces used in experimentation were Length: -200mm, Breadth: - 50mm, Thickness:-10mm as shown in

D. Coolant

Coolant has been used in all the experiments. SUPERCUT cutting oil by SHELL COMPANY has been used in the ratio of 20:1 i.e. 20 litres of water and 1 litre of cutting oil in it. Physical properties of cutting oil are summarized in Table.

Table II. Physical properties of SUPERCUT- cutting oil

Appearance	**Amber clear liquid**
Solubility in water	Soluble giving stable milky emulsion
Storage stability	Good
pH of 5% conc.	9.1

E. Design of Experiments

Number of experiments required, mainly depends on the approach adopted for design of experiment. Thus, it is important to have a well designed experiment so that number of experiments required can be minimized. In the present work, the design suggested by 2 level full factorial design has been implemented to analyze the effect of three independent parameters for end milling i.e. cutting speed, feed rate and depth of cut on surface roughness indicators.

The machining parameters and their levels are shown in Table. Complete design layout for experiments with experimental results is summarized in Table III. Total fourteen experiments constitute 23factorial point and six centre point.

Table III. Factors and levels of independent variables according to response surface methodology

Factors	**Symbol**	**Units**	**Levels**	
Feed rate	A	mm/tooth	0.05	1.5
Depth of cut	B	mm	0.1	0.5
Speed	C	m/min	100	200

Table IV. Complete design layout with measurement results

Std	**Run**	**A:Feed (mm/tooth)**	**B:Depth of cut (mm)**	**C:Speed (m/min)**	**Surface roughness indicators (microns)**		
					Ra	**Rq**	**Rt**
1	9	0.05	0.1	100	1.27	1.424	9.43
2	5	1.5	0.1	100	3.121	3.7452	10.5
3	7	0.05	0.5	100	1.62	1.944	10.12
4	1	1.5	0.5	100	3.696	4.6352	11.152
5	2	0.05	0.1	200	0.671	0.9052	7.82
6	11	1.5	0.1	200	1.983	2.5796	8.628
7	8	0.05	0.5	200	0.856	1.072	8.021
8	10	1.5	0.5	200	2.114	2.9368	9.651
9	14	0.775	0.3	150	1.762	2.2144	10.72
10	4	0.775	0.3	150	1.893	2.0716	10.186
11	6	0.775	0.3	150	1.713	2.1556	10.162
12	13	0.775	0.3	150	1.696	1.972	10.014
13	3	0.775	0.3	150	1.795	2.254	10.114
14	12	0.775	0.3	150	1.837	2.3044	10.211

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F. Surface Roughness Measurement

Surface roughness is defined as the finer irregularities of the surface texture that usually result from the inherent action of the machining process or material condition. There are many parameters used related to surface roughness in literatures. In this study, surface roughness of finish-turned work pieces was measured by making use of a portable surface roughness tester (Surf coder SE 1200) and the measurements were repeated three times. Cut-off length for roughness measurements was set to be 0.8 mm.

III. RESULTS AND ANALYSIS

Results and Analysis

The study was undertaken to investigate the effect of process parameters on surface roughness indicators produced by end milling operation when end milling solid material AISI D3 tool steel. The end milling operation was carried out using various cutting parameters by using a cutting insert. Machining data of surface roughness indicators were tabulated by using surface roughness measurement apparatus. A Surface Roughness Tester (Stylus equipment) measuring instrument was used to process the measured profile data.

For surface roughness analysis, the results from the performance of the end milling operation produced as per experimental plan was input into Design Expert 8.0.4 software for further analysis.

ANOVA Analysis for average surface roughness (Ra)

Analysis of variance (ANOVA) was conducted on the collected data to investigate the main effect of cutting speed, feed rate, depth of cut together with their two-level interaction effect on surface roughness as measured by surface roughness tester.

In order to provide a good model, test for significance of the regression model, test for significance on individual model coefficients and test for lack of fit need to be performed. An ANOVA table regularly used to conclude the tests performed. Table shows the ANOVA table for average surface roughness (Ra) in End milling operation after transformation by Box-Cox plot using natural log (generated by the Design Expert software). The variables from the model were chosen using half normal graph of effect.

Table V. ANOVA for selected factorial model

Analysis of variance table [Partial sum of squares - Type III]						
	Sum of		Mean	F	p-value	
Source	Squares	Df	Square	Value	Prob > F	
Model	7.829289	5	1.565858	121.9156	< 0.0001	significant
A-Feed	5.276376	1	5.276376	410.8115	< 0.0001	
B-Depth of cut	0.19251	1	0.19251	14.98858	0.0047	
C-Speed	2.083861	1	2.083861	162.2466	< 0.0001	
AC	0.230181	1	0.230181	17.92159	0.0029	
BC	0.04636	1	0.04636	3.609537	0.0940	
Residual	0.10275	8	0.012844			
Lack of Fit	0.074681	3	0.024894	4.434316	0.0712	not significant
Pure Error	0.028069	5	0.005614			
Cor Total	7.932039	13				
Std. Dev.	0.11333		R-Squared		0.987046	
Mean	1.859071		Adj R-Squared		0.97895	
C.V. %	6.096078		Pred R-Squared		0.936526	
PRESS	0.503479		Adeq Precision		39.83236	

As per the result in the Table the model F value of 121.91 depicts that the model generated is significant. Also the variables that are A, B, C, have certain values of P value. As per the rule if the P value of the parameters is less than 0.05,

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it is not significant and is negligible. This suggests that the effect on the average surface roughness of all parameters is significant.

The P value of Lack of fit is also not significant with a value of 0.0712. It implies that the chances that the model doesn't fit are insignificant. Also the predicted R value 0.9365 is also in agreement with the adjusted R value which is 0.9789. Also the adequate precision value is 39.832, which is greater than the desirable value of 4, which justifies the correctness of model. This model can be used to navigate the design space.

Mathematical models in terms of coded factors:

Ra = 1.86 + (0.81*A) + (0.16*B) – (0.51 * C) – (0.17 * A * C) + (0.076 *B * C) 4.1

Mathematical models in terms of actual factors

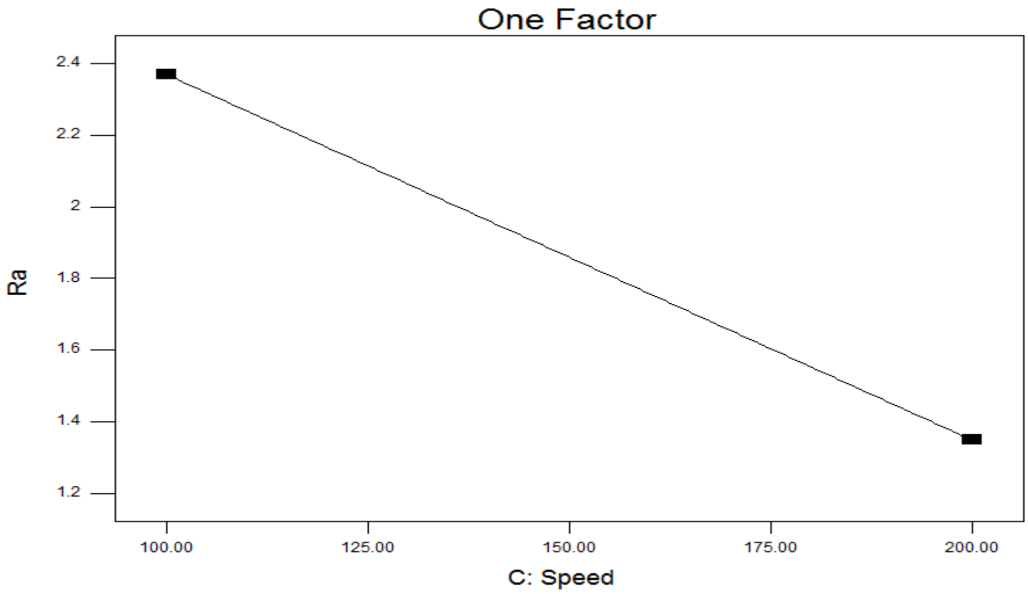
Ra = +1.40284 + 1.82207 * Feed + 1.91750 * Depth of cut - 4.29728E-003 * Speed - 4.67931E-003 * Feed * Speed - 7.61250E-003 * Depth of cut * Speed 4.2

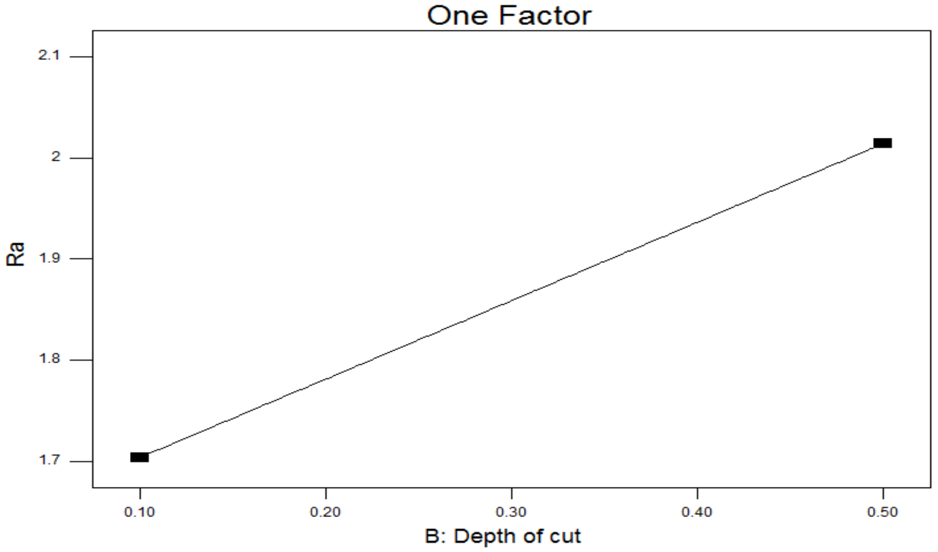
So, the above equation can be used to find out the value of the surface roughness and it also shows how the roughness is depending upon the various parameters. This model can be now used to study within the specified limits of the variables.

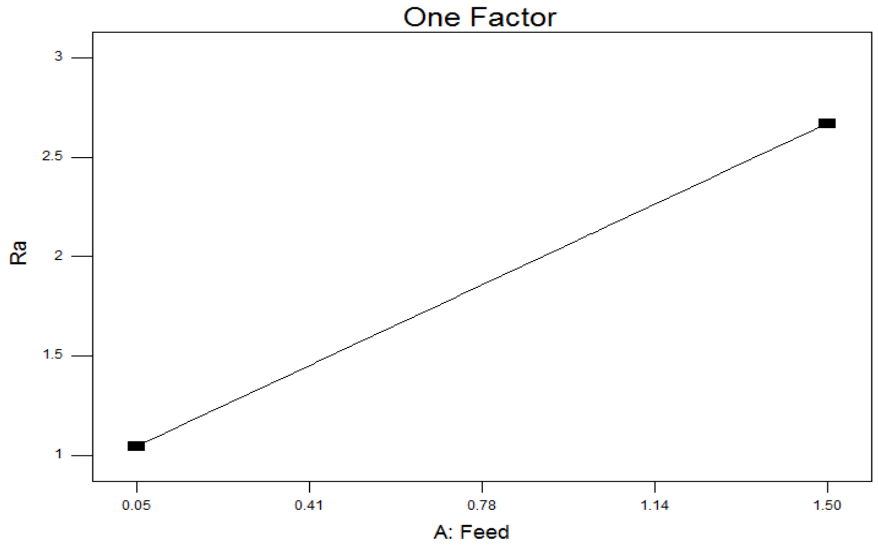
Now, we start doing the analysis of the average surface roughness value on the different factors.

Graphs show the behaviour pattern of average surface roughness with machining parameters. These figures are showing the sole effect of these factors on the average surface roughness.

It is seen that the average surface roughness decreases with the cutting speed and increases with the feed rate and depth of cut in end milling operation.

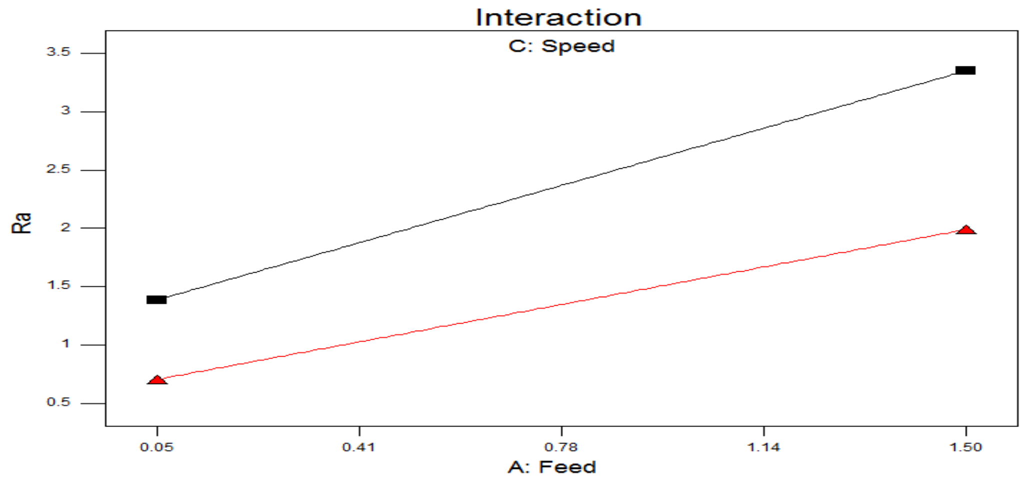


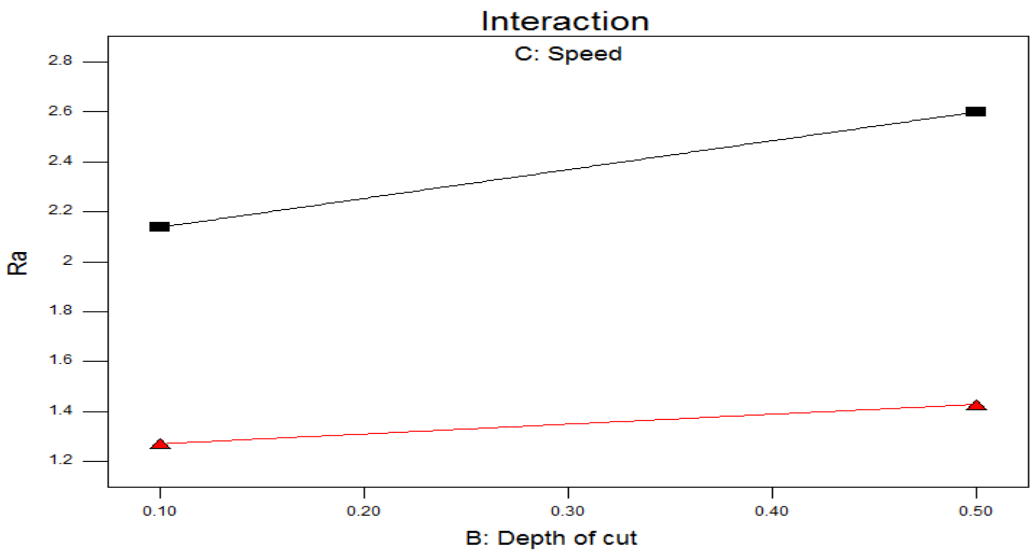




Graphs show the variation of average surface roughness when there is an interaction between the two factors i.e. A & C which are feed rate and cutting speed. When these two interact with each other what effect they have on the average surface roughness can be seen here. Here two curves can be seen. One is when the cutting speed is at low level (-1) with ■ mark and the other is at higher level (+1) with ▲ mark of the cutting speed. This figure shows that either it is low level or high level average surface roughness increases with the increasing of feed rate.

Even when the Feed rate is high then also the average surface roughness shows a decrease with increasing speed.





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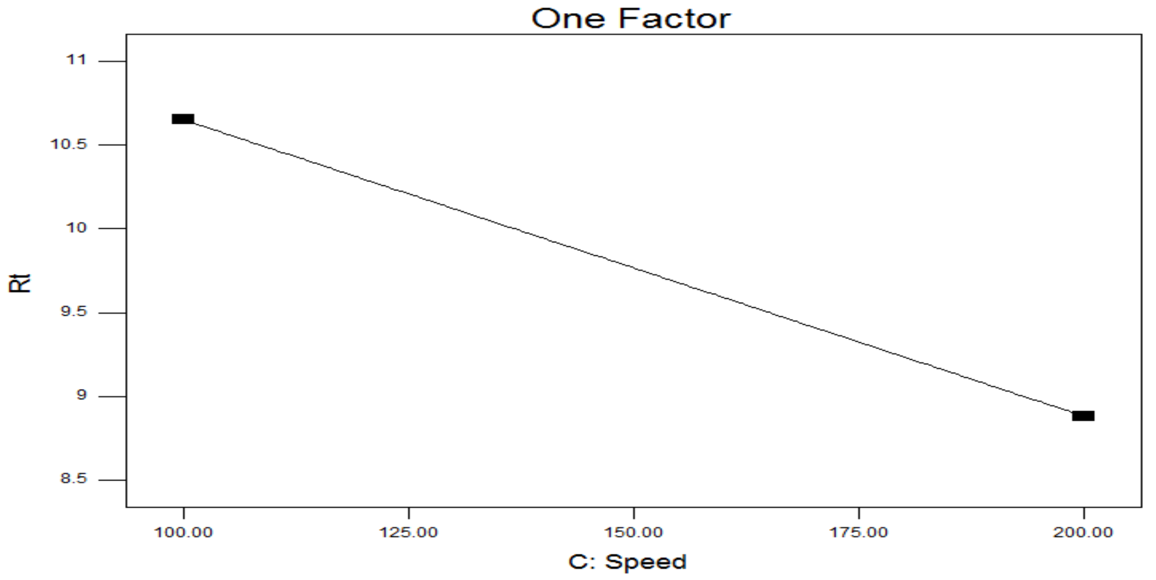
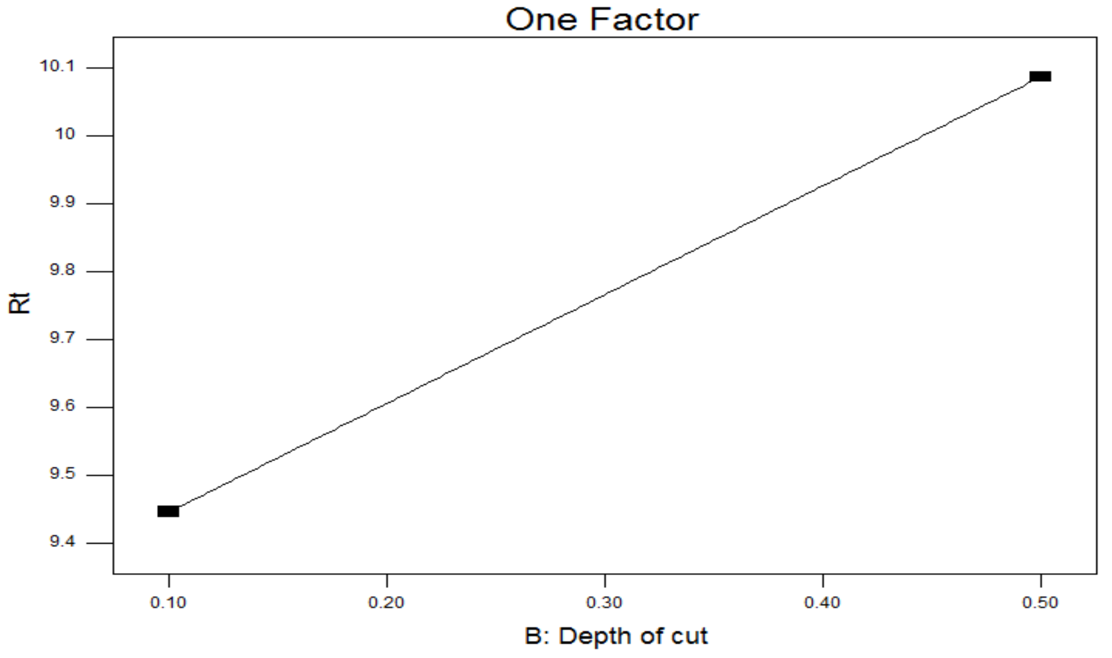
Graphs show the cubical graph that shows the effect on average surface roughness at a simultaneous time due to three major factors, which are:

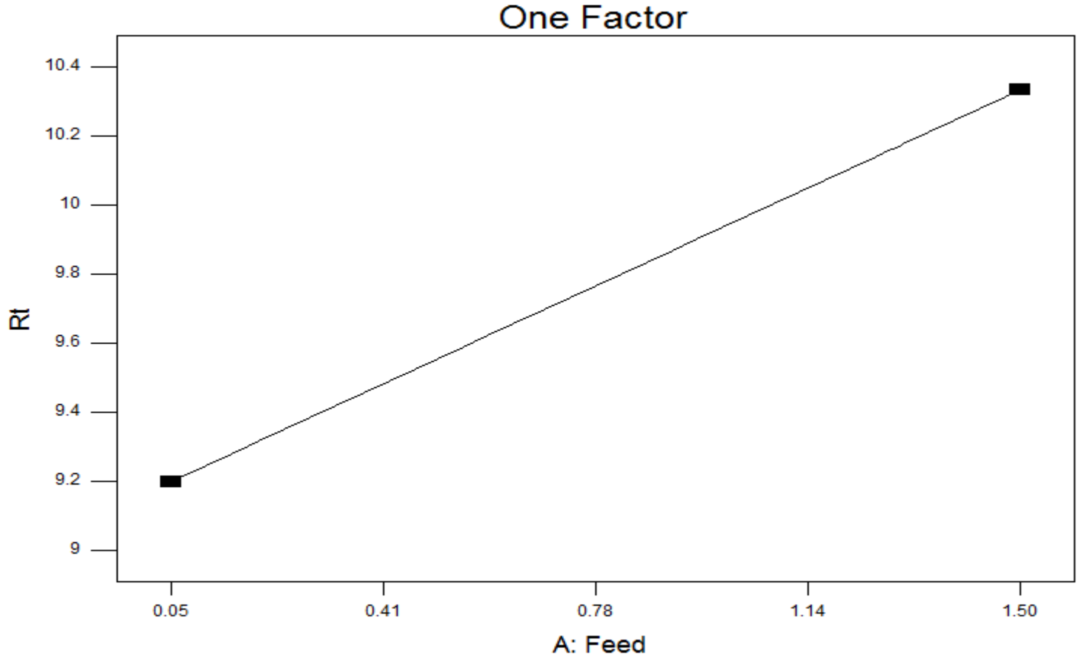
- Cutting speed (on the axis inside the plain of paper)
- Feed rate (on the horizontal axis)
- Depth of cut (on the vertical axis)

Graphs show the behaviour pattern of peak to valley height surface roughness with machining parameters. These figures are showing the sole effect of these factors on the peak to valley height surface roughness.

It is seen that the peak to valley height surface roughness decreases with the cutting speed and increases with the feed rate and depth of cut in end milling operation.







Graphs show the cubical graph that shows the effect on peak to valley height surface roughness at a simultaneous time due to three major factors, which are:

- Cutting speed (on the axis inside the plain of paper)
- Feed rate (on the horizontal axis)
- Depth of cut (on the vertical axis)

IV. CONCLUSIONS

From the analysis of all the graphs and models generated by the software Design Expert, we have to following conclusion:-

1. Out of three parameters, feed seems to be the most significant and influential machining parameter that affect the surface roughness indicator (Ra, Rq and Rt) followed by depth of cut.
2. The cutting speed has insignificant influence on the surface roughness parameters.
3. The mathematical models developed clearly show that surface roughness indicators increases with increasing the feed rate but decreases with increasing the cutting speed.
4. The results of ANOVA and the confirmation runs verify that the developed mathematical models for surface roughness parameters shows excellent fit and provide predicted values of surface roughness that are close to the experimental values, with a 95 per cent confidence level.
5. The percentage error between the predicted and experimental values of the response factor during the confirmation experiments are within 5 per cent.
6. The model can be used for direct evaluation of surface roughness indicators under
7. Various combinations of machining parameters during end milling of AISI D3 tool steel. The minimum surface roughness parameters Ra (0.6271 microns), Rq (0.8234microns), and Rz (7.9928 microns) have been obtained at cutting speed 200 m/ min and feed rate 0.05 mm/tooth and depth of cut 0.10 mm.
8. If the cutting speed is high then surface roughness indicators decreases at all the feed rate what we have taken in the model range and at all the depth of cut in our range.
9. If the feed rate is increased the surface roughness indicators are increase within all the permissible range of values of all the factors.
10. When we increase the depth of cut the surface roughness indicators also increases at all the values of factors within the permissible range of model.
11. In the interaction curve, it has been seen that roughness increases even when there is an interaction between the cutting speed and feed rate. It shows the dominance of speed factor.
12. When cutting speed and depth of cut interact together, the surface roughness also increases. It may be due to combined effect of the speed as well as depth of cut both alone also cause the roughness to increases.
13. When feed rate and depth of cut interact together the roughness tends to increase. However, at too low feed rate at 0.10 mm/rev the roughness is almost increasing with the depth of cut.

V FUTURE SCOPE

In this dissertation, mathematical modelling and optimization has been attempted for average surface roughness and material removal rate. The work can be extended to consider more response variables like cutting

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forces, tool wear etc. Also, more machining parameters such as coolant concentration, tool angles etc can be introduced to have a better insight in to the process. Response such as tool life, power consumption can be added in this work.

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