Investigation of The Effect of Turning Parameters on Average Surface Roughness Using 2 Level Full Factorial Design of AISI 1019 Carbon steel

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ABSTRACT

Metal machining has a very important process in manufacturing. Machining Conditions play a vital role in estimating the performance of machining operations. It have long been recognized that the machining conditions, such as cutting speed, feed and depth of cut affect the performance of the operation in great extent. These parameters must be selected to optimize the quality of machining operations.

The objective of the present work is to analyze the effects of the machining parameters in turning on the surface roughness parameters of AISI 1019 carbon steel is suitable for manufacturing wire rods and many other products. The Design of experiments based on response surface methodology with three numeric factors (cutting speed, feed rate and depth of cut) five level central composite rotatable designs have been used to develop relationships for predicting surface roughness.

The surface roughness parameters were measured using surface roughness tester (Surf coder SE 1200) the design expert software has been used for the analysis. A quadratic model and linear Model have been developed which indicates that interaction is present between the machining parameters (speed, feed and depth of cut). Model adequacy tests were conducted using ANOVA table and the effects of various parameters were investigated and presented in the form of contour plots and 3D surface graphs. Numerical optimization was carried out considering all the input parameters within range so as to minimize the surface roughness.

The optimal values obtained are cutting speed 259.46 m/min, feed 0.20mm/rev, depth of cut 0.35 mm. The findings of this study would be beneficial to manufacturing industries where surface finishing plays very important role

INTRODUCTION

1.1 Background

In machining operation, the quality of surface finish is an important requirement in manufacturing engineering. It is characteristic that could influence the performance of mechanical parts and the production cost. Various failures, sometime catastrophic, leading to high cost, have been attributed to the surface finish of the components in question. For these reasons there have been research developments with the objective of optimizing the cutting condition to obtain a surface finish.

During a turning operation, the cutting tool subjected to a prescribed deformation as a result of the relative motion between the tool and work-piece both in the cutting speed direction and feed direction. As a response to the prescribed

Deformation, the tool is subjected to traction and thermal loads on those faces that have interfacial contact with the work-piece or chip. In the metal-cutting process, during which chips are formed, the work-piece material is compressed and subjected to plastic deformation.

Previous studies proved the significant impact of depth of cut, machining speed, and rake angles on surface roughness. The combination of both of these factors suggests a significant in effect the relationship.

1.2 Problem Statement

The determination of optimal cutting condition for specified surface roughness and accuracy of product are the key factors in the selection of machining process. To reduce the problem of vibration and ensure that the desired shape and tolerance are achieved, extra care must be taken with production planning and in the preparations for the machining of a work-piece.

Researchers have been done to improve cutting tool material, tool geometry and cutting parameter to optimize the machining process. The cutting parameter such as cutting speed, feed rate and depth of cut are the most important factor has to be considering in turning operation. The wrong selection of combination cutting parameter will lead to the bad cutting condition e.g. vibration that effect the poor surface finish. Different work piece material with different property and microstructure give different effect to the cutting tool performance.

In turning operation, the performances of cutting tools are depending on a few cutting conditions and parameters. The proper selection of feed rate has direct effect to the product surface roughness. Turning process by maximizing cutting speed and depth of cut will optimize the cutting process and minimize the production cost. The tool life, machined surface integrity and cutting forces are directly dependent on cutting parameters and will determine the cutting tool performances. The study of surface roughness form will resolve the characteristic and phenomena happening during the machining process.

1.3 Objective of the Study

The study was carried out to evaluate the effects of different cutting parameters on work piece for surface profile with turning operation, where the surface roughness values were statistically

comparable and to find out the optimum cutting condition by analyzing the different cutting parameter's value to get the lowest surface roughness in turning a Mild Steel solid bar.

Objective of this study are following:

• To evaluate the effects of different process parameter on surface roughness.

• To develop a mathematical model for predicting surface roughness for turning operation using design of experiment approach.

1.4 Significance of the Study

Machining operations tend to leave characteristic evidence on the machined surface. They usually leave finely spaced micro-irregularities that form a pattern known as surface finish or surface roughness. The quality of the finished product, on the other hand, relies on the process parameters; surface roughness is, therefore, a critical quality measure in many mechanical products.

Severe acoustic noise in the working environment frequently occurs as a result of dynamic motion between the cutting tool and the work piece. In order to achieve sufficient process stability, the metal removal rate is often reduced or the cutting tool changed. But as productivity is normally a priority in manufacturing, this is the wrong route to go.

Instead the method of being able to machine at high rates should be examined. For these reason there have been research development with the objective of optimizing cutting condition to obtain a surface finish with making the process more stable. To study the optimum cutting condition used during cutting process will reduce the machining cost by reducing of changing the cutting tool and to increase the metal removal rate.

1.5 Scope of the Study

The study has been conducted on the following scopes:

a) Experiments on CNC Turning machine will be carried out on the basis of two level full factorial design.
b) Mild Steel solid bar will be used as work-piece material.
c) Two different nose radius cutting tool will be used.
d) Cutting speed, feed and depth of cut are the other main factors investigated along with nose radius.
e) Design of Experiment technique will be used for the analysis.

1.6 Overview of the Methodology

The following methodology has been used as a guide in the study to achieve the study objectives.

a) Selecting the proper cutting parameters based on literature reviews.
b) Plan and design the experiments on the basis of 2 level full factorial design.
c) Measurement of surface roughness.
d) Analysis using design Expert software for:
e) To evaluate the effect of various parameters on the surface roughness
f) To evaluate the effect of interaction of cutting parameters on the surface roughness.

been carried out for the prediction of surface roughness in metal machining.

In machining operation, the quality of surface finish is an important requirement in manufacturing engineering. It is characteristic that could influence the performance of mechanical parts and the production cost. Various failures, sometime catastrophic, leading to high cost, have been attributed to the surface finish of the components in question. For these reasons there have been research developments with the objective of optimizing the cutting condition to obtain a surface finish.

During a turning operation, the cutting tool subjected to a prescribed deformation as a result of the relative motion between the tool and work-piece both in the cutting speed direction and feed direction. As a response to the prescribed deformation, the tool is subjected to traction and thermal loads on those faces that have interfacial contact with the work-piece or chip. In the metal-cutting process, during which chips are formed, the work-piece material is compressed and subjected to plastic deformation.

2.DESIGN OF EXPERIMENTS

2.1 Introduction

Based on the literature review and assessment of experimental studies, a methodology was developed to investigate the effect of process parameter on surface roughness produced by turning operation. In this study, two different sizes of tools having different nose radius are used as a categorical parameter to be considered. The cutting variables as cutting speed, feed rate and depth of cut are independent variables that includes in machining parameter. The output that has to be study is surface roughness produced by turning operation.

In this study, dry turning condition was applied to cut the work-piece. This chapter describes the steps that were under taken to achieve the objective of this study from work-piece preparation, measuring data and data analysis. With using the appropriate machining parameter so that the experiment would simulate the conditions according to the standard operation and requirements

Design of Experiment (DOE) is a useful method in identifying the significant parameters and in studying the possible effect of the variables during the machining trials. This method also can developed experiment between a ranges from uncontrollable factors, which will be introduced randomly to carefully controlled parameters. The factors must be either quantitative or qualitative. The range of values for quantitative factors must be decided on how they are going to be measured and the level at which they will be controlled during the trials. Meanwhile, the qualitative factors are parameters that will be determined discretely.

For this experiment one-half fractional factorial is used as a tool for the overall research design and analysis. Design of experiment includes determining controllable factors and the levels to be investigate. While, analysis of results is to determine the best possible factor combination from individual factor influences. Lastly, confirmation tests would be carried out as a proof to the optimum results studied.

In this study, four factor experiment design will be employed with two levels of full factorial design experiment. The total number of experiments (combinations) required is 16 experiments. The total six center points are adding in this experiment for each nose radius to make all 28 experiments.

This experiment design will include all the possible combinations factors at two levels which are called low and high value for each parameter. The notation used to denoted this levels is "plus" for high value and "minus" for low value. The arrangements of the factors for this project will be based on Design Expert software.

This program will randomly choose the combination of factors to run the experiment. This software also will automatically analyze all the experimental results in order to investigate the influence of machining parameters on the surface integrity of the work piece material. The results of the experiments were presented as the combination of four factors with one response surface roughness.

2.2Factorial design

The same software was also used to analyze the data collected by following the steps as follows:-

1. Choose a transformation if desired. Otherwise, leave the option at "None".
2. Select the appropriate model to be used. The Fit Summary button displays the sequential *F*-tests, lack-of-fit tests and other adequacy measures that could be used to assist in selecting the appropriate model.
3. Perform the analysis of variance (ANOVA), post-ANOVA analysis of individual model coefficients and case statistics for analysis of residuals and outlier detection.
4. Inspect various diagnostic plots to statistically validate the model
5. If the model looks good, generate model graphs, i.e. the contour and 3D graphs, for interpretation. The analysis and inspection performed in steps (3) and (4) above will show whether the model is good or otherwise. Very briefly, a good model must be significant and the lack-of-fit must be insignificant.The various coefficient of determination, *R*2 values should be close to 1. The diagnostic plots should also exhibit trends associated with a good model and these will be elaborated subsequently.

3. EXPERIMENTAL STUDY

In the present work, two level full factorial design is applied to determine the optimal turning parameters to achieve minimum surface roughness value for AISI 1019 steel under varying machining conditions.

1. The relationships between the turning parameters i.e. cutting speed, feed rate, depth of cut, nose radius and the response factors (surface roughness).
2. The optimal conditions of the turning parameters for minimum surface roughness.

3.1 Experimental details Experimental details contain about the study of CNC turning center, cutting insert, and
Turning operations were carried out on Pushkar 200, Make HMT Pvt. Ltd. The CNC machining center equipped with continuously variable spindle speed up to 5000 rpm, and 15 kW motor drive was used for machining center
Coated carbide tool performs better than uncoated carbide tools. Because of this reason, commercially used carbide coated carbide Inserts for turning steel was used in this research for turning. The cutting inserts used for experimentation was WNMG 089404 MF-2 with grade TP2500 manufactured by seco tools.

3.2 Work piece

The machining experiments were performed on AISI 1019steel. All the pieces used in experimentation were 40 mm in diameter and 60 mm in length as shown in
Composition of the work piece material:-

C	Mn	Si	P	S
0.19	**0.5**	**0.11**	**0.027**	**0.013**

Table 3.1. 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 liter of water and 1 liter of cutting oil in it. Physical properties of cutting oil are summarized in
Table 3.3 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**

VARIABLE	SETUP
Work piece	Mild Steel (Diameter-32mm, Length:- 40mm)
Tool used (Material)	Cemented Carbide
Tool (Nose Radius)	Max:-0.8mm, Min:-0.4mm
Cutting Speed (m/min)	90.54m/min, 209.46m/min
Feed Rate (mm/rev)	0.10-0.32
Depth of Cut (mm)	0.28-0.82
Cutting Condition	Wet Condition

Table 3.4 Factors and levels of independent variables

Table no 3.5 complete design layouts

Run	Speed (m/min)	Feed (mm/rev)	Depth of cut (mm)	Nose Radius (mm)
1	209.46	0.1	0.28	0.4
2	150	0.21	0.55	0.8
3	90.54	0.1	0.82	0.4
4	90.54	0.1	0.28	0.8
5	150	0.21	0.55	0.4
6	209.46	0.32	0.82	0.8
7	150	0.21	0.55	0.4
8	90.54	0.32	0.28	0.8
9	90.54	0.1	0.28	0.4
10	209.46	0.32	0.28	0.4
11	150	0.21	0.55	0.4
12	209.46	0.32	0.28	0.8
13	209.46	0.1	0.82	0.8
14	150	0.21	0.55	0.8
15	150	0.21	0.55	0.4
16	209.46	0.1	0.82	0.4
17	150	0.21	0.55	0.8
18	150	0.21	0.55	0.8
19	209.46	0.1	0.28	0.8
20	90.54	0.1	0.82	0.8
21	90.54	0.32	0.82	0.8
22	150	0.21	0.55	0.4
23	90.54	0.32	0.82	0.4
24	90.54	0.32	0.28	0.4
25	150	0.21	0.55	0.4
26	150	0.21	0.55	0.8
27	209.46	0.32	0.82	0.4
28	150	0.21	0.55	0.8

Table3.6 Surface roughness measurement

Run	Speed (m/min)	Feed (mm/rev)	Depth of cut (mm)	Nose Radius (mm)	Roughness (microns)
1	209.46	0.1	0.28	0.4	0.566
2	150	0.21	0.55	0.8	2.296
3	90.54	0.1	0.82	0.4	2.821
4	90.54	0.1	0.28	0.8	2.5
5	150	0.21	0.55	0.4	3.78
6	209.46	0.32	0.82	0.8	4.525
7	150	0.21	0.55	0.4	3.35
8	90.54	0.32	0.28	0.8	8.369
9	90.54	0.1	0.28	0.4	2.745
10	209.46	0.32	0.28	0.4	10.13
11	150	0.21	0.55	0.4	2.513
12	209.46	0.32	0.28	0.8	4.185
13	209.46	0.1	0.82	0.8	0.696
14	150	0.21	0.55	0.8	2.812
15	150	0.21	0.55	0.4	2.34
16	209.46	0.1	0.82	0.4	0.823
17	150	0.21	0.55	0.8	3.022
18	150	0.21	0.55	0.8	2.327
19	209.46	0.1	0.28	0.8	0.544
20	90.54	0.1	0.82	0.8	2.376
21	90.54	0.32	0.82	0.8	6.838
22	150	0.21	0.55	0.4	3.59
23	90.54	0.32	0.82	0.4	7.812
24	90.54	0.32	0.28	0.4	10.492
25	150	0.21	0.55	0.4	2.546
26	150	0.21	0.55	0.8	2.125
27	209.46	0.32	0.82	0.4	8.439
28	150	0.21	0.55	0.8	2.519

4. RESULTS AND ANALYSIS

ANOVA Analysis

Source	Sum of squares	df	Mean Square	F Value	P value	
Model	16.58424159	9	1.842693511	60.46849	< 0.0001	significant
A-Cutting Speed	2.745291035	1	2.745291035	90.08747	< 0.0001	
B-Feed Rate	11.81534662	1	11.81534662	387.7238	< 0.0001	
C-Depth of Cut	1.1649-06	1	1.1649E-06	3.82E-05	0.9951	
D-Nose Radius	0.405288592	1	0.405288592	13.29966	0.0018	
AB	1.265590811	1	1.265590811	41.53071	< 0.0001	
AC	0.06718322	1	0.06718322	2.204636	0.1549	
AD	0.07426776	1	0.07426776	2.437117	0.0359	
BC	0.089807855	1	0.089807855	2.947069	0.1032	
BD	0.121464533	1	0.121464533	3.985892	0.0412	
Residual	0.548525073	18	0.030473615			
Lack of Fit	0.242808112	8	0.030351014	0.992781	0.4941	not significant
Pure Error	0.305716961	10	0.030571696			
Cor Total	17.13276667	27				

Std. Dev.	0.17	**R-Squared**	0.9680
Mean	1.07	**Adj R- Squared**	0.9520
C.V. %	16.32	**Pred R-Squared**	0.9197
PRESS	1.37	**Adeq Precision**	29.401

Table no 4.1 ANOVA for selected factorial model

Analysis of variance (ANOVA) was conducted on the collected data to investigate the main effect of cutting speed, feed rate, depth of cut, nose radius.

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 Surface Roughness (Ra) in turning operation after transformation by Box-Cox plot using natural log (generated by the Design Expert software).. The P value of Lack of fit is also not significant with a value of 0.4941. It implies that the chances that the model doesn't fit are insignificant. Also the predicted R value 0.9197 is also in agreement with the adjusted R value which is 0.9520. Also the adequate precision value is 29.401, which is greater than the desirable value of 4, which

The final empirical models in terms of coded factors were presented

Ln (Roughness) = 1.07 – (0.41*A) + (0.86*B) –(2.698E – 004 * C) – (0.12 * D) + (0.28 * A * B) + (0.065 *A * C) – (0.068 *A * D) – (0.075 *B *C) – (0.087 * B* D) (5.1)

The value at the right extreme has the strongest effect on the roughness and keeps on decreasing as it comes nearer and nearer to the line. It can also be understood in the Fig4.1, which shows the of effectiveness rank wise. The graph is between t-value and rank of factors

The t-value here denotes the effectiveness of the factor. As it can be seen from the fig above, that the most effective factor is B alone (Feed rate), followed by A (Cutting speed) then the effectiveness is of the combination of A & B (interaction of Cutting speed and Feed rate) which is followed by the D (Nose radius) again then it is combination of B & D (interaction of Feed rate and Nose radius) then B & C then A & D.

Fig 4.2 is describing the mechanism of error. It can be seen that the points are following evenly on the straight line that shows the errors are evenly distributed.

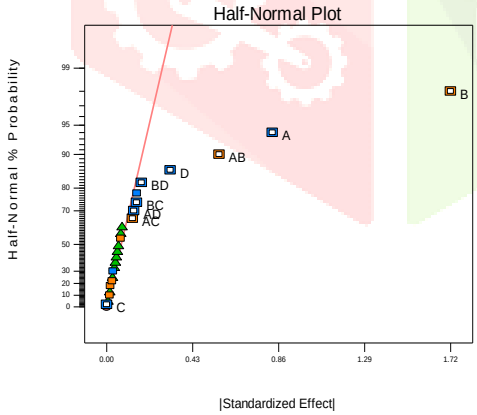


Fig4.1 normal plot shows the effectiveness

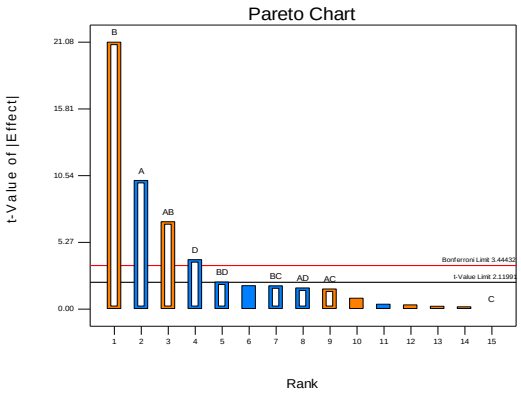


Fig.-4.2: Graph between t-value and rank

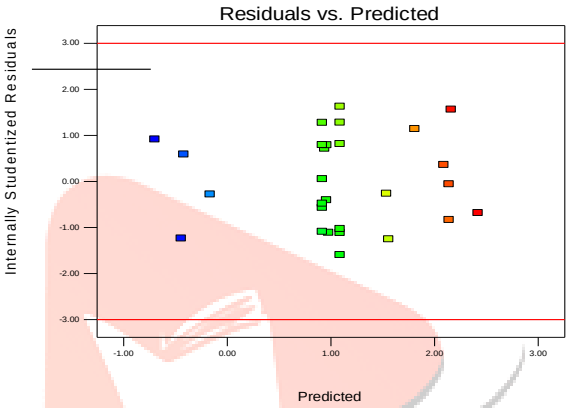


Fig.-4:.3 Plots of Residual vs. Predicted response for the surface roughness in turning operation

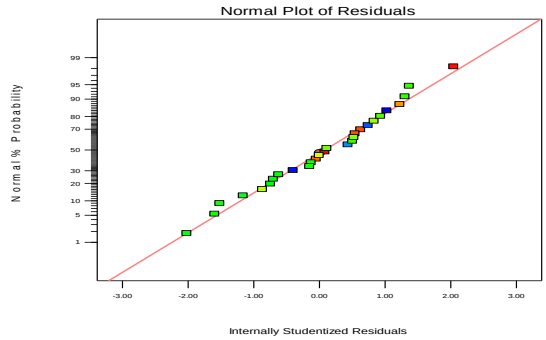


Fig 4.4surface roughness

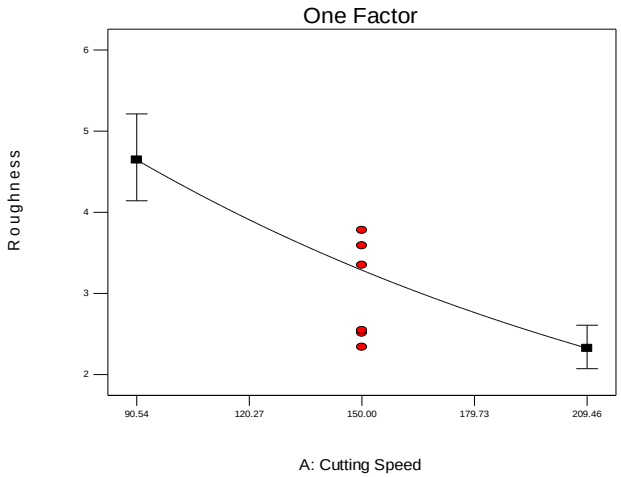


Fig 4.5,Plot surface roughness with cutting speed

Fig.-4.3 and 4.4 shows the behavior pattern of surface roughness with increase and decrease in the Cutting speed, in minimum nose radius and maximum nose radius (0.4mm & 0.8). These figures are showing the sole effect of these factors on the roughness. The dotted points are showing the design points. It is seen that the surface roughness decreases with the cutting speed in turning operation

Fig.-4.5 and 4.6 shows the behavior pattern of surface roughness with increase and decrease in the Cutting speed, in minimum nose radius and maximum nose radius (0.4mm & 0.8). These figures are showing the sole effect of these factors on the roughness. The dotted points are showing the design points.

- It is seen that the surface roughness decreases with the cutting speed in turning operation.

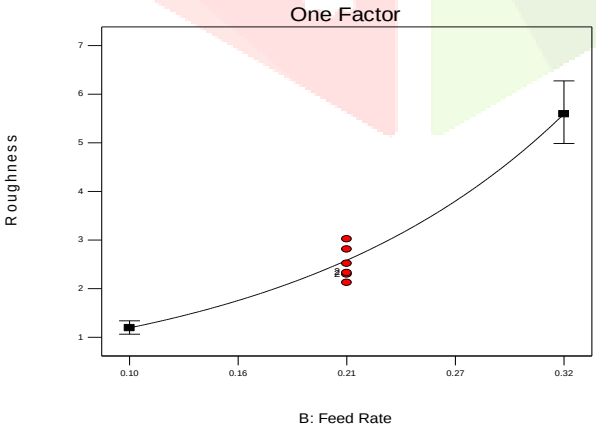


Fig.4.8: Plot of Feed rate vs Roughness at nose radius maximum (0.8mm)

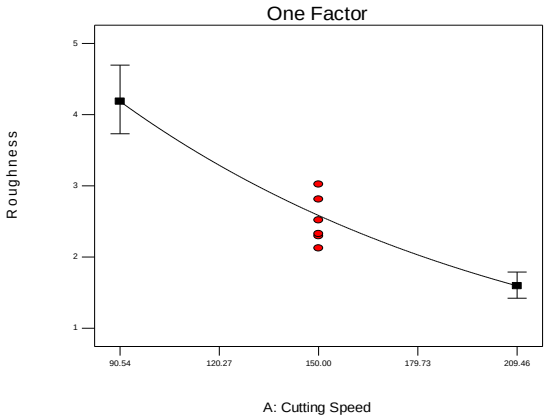


Fig.-4.6. Plot of Roughness vs Cutting Speed at nose radius 0.8

The Fig.4.7 and 4.8 shows the relation between surface roughness and feed rate at nose radius minimum and maximum This effect is solely due to the feed rate on roughness in the turning operation. It is seen that there is no significant effect on the roughness pattern in either of the nose radius.

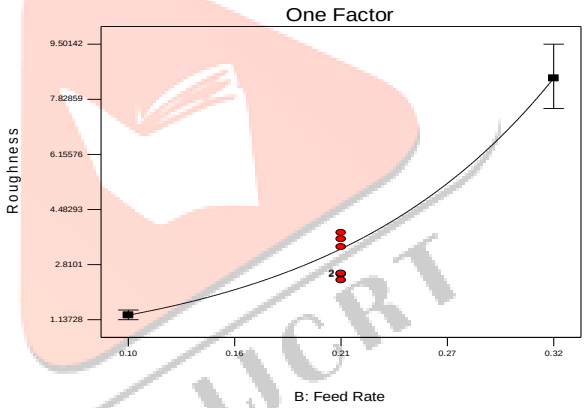


Fig 4.7 Plot of Feed rate Vs. Roughness at min nose radius (0.4mm)

The next fig.4.9 shows the relation between nose radius and the surface roughness. It can be seen that with increase in the nose radius of tool used for the turning operation, the surface roughness decreases.

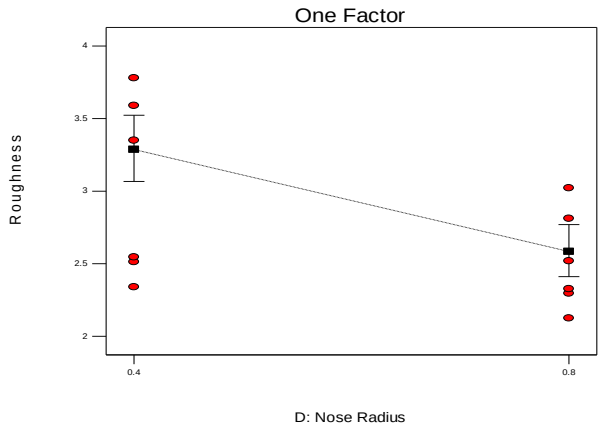


Fig.4.9 Plot of Nose radius of tool Vs. Roughness

Fig.5.10 shows the variation of roughness when there is an interaction between the two factors i.e A & B which are cutting speed and feed rate. When these two interact with each other what effect they have on the roughness can be seen here. Here two curves can be seen. One is when the feed rate is at low level (-1) with ▲mark and the other is at higher level (+1) with ■ mark of the feed rate. The roughness shows decrement with the increase in AB. The nose radius taken is average.

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

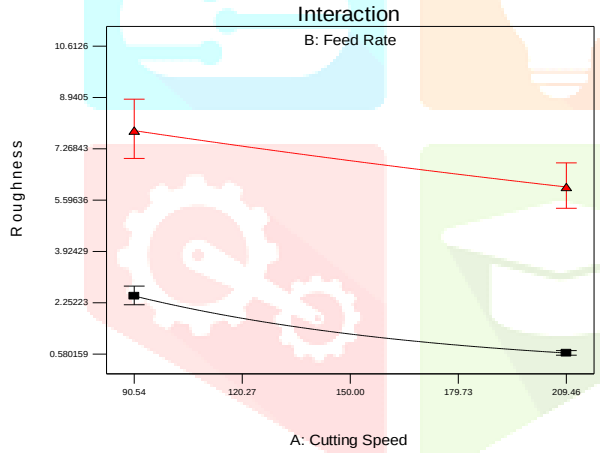


Fig.4.10. Plot of roughness vs. interaction of AB

(Upper line is showing feed rate of +1 level while the lower one is of -1 level)

Fig.4.11 shows the interaction curve of A & D i.e. cutting speed and nose radius with the roughness. The line with ■mark shows plot for higher nose radius and the line with ▲ mark shows the plot at low nose radius. It is seen that at both high level and low level nose radius the roughness still decrease with the cutting speed. It is noteworthy that even when there was no interaction with these two factors the roughness was decreasing with cutting speed as well as nose radius. There combination is also producing the same effect.

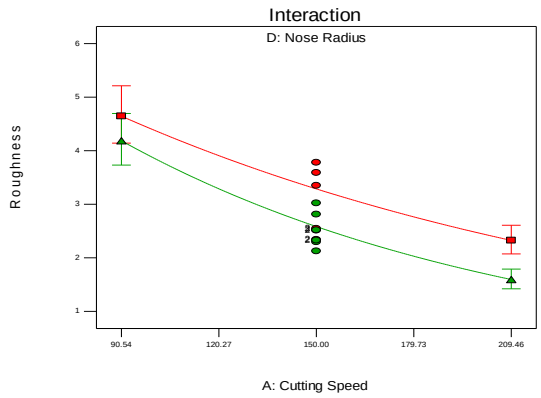


Fig.4.11 Plot of roughness vs. interaction of AD.

Fig.4.13 shows the interaction curve of B & D i.e. feed rate and nose radius with roughness. The line with ■ mark shows plot for higher nose radius and the line with ▲ mark shows the plot at low nose radius. It can be seen that at both the nose radius i.e. minimum and maximum the roughness is increasing. It is clear that the dominating effect is of the feed rate as with feed rate only the roughness increase. However, only with nose radius the roughness decreases. So, in the interaction of these two factors the dominating effect is of the feed rate.

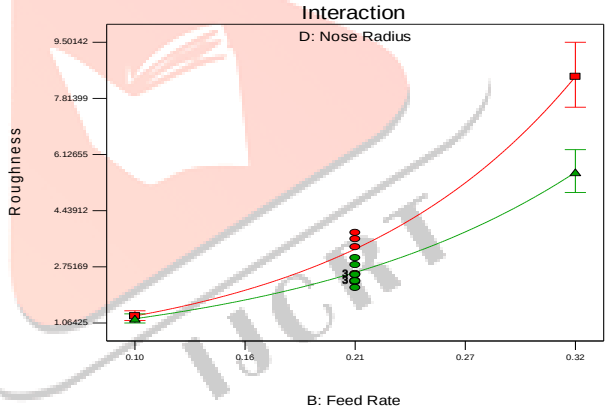


Fig.4.12. Plot of Roughness vs interaction of B&D.

(Upper line is showing nose radius of +1 level while the lower one is of -1 level)

Fig.4.13 shows the cubical graph that shows the effect on roughness at a simultaneous time due to three major factors, which are:

a) Cutting speed (on the horizontal axis)

b) Feed rate (on the vertical axis)

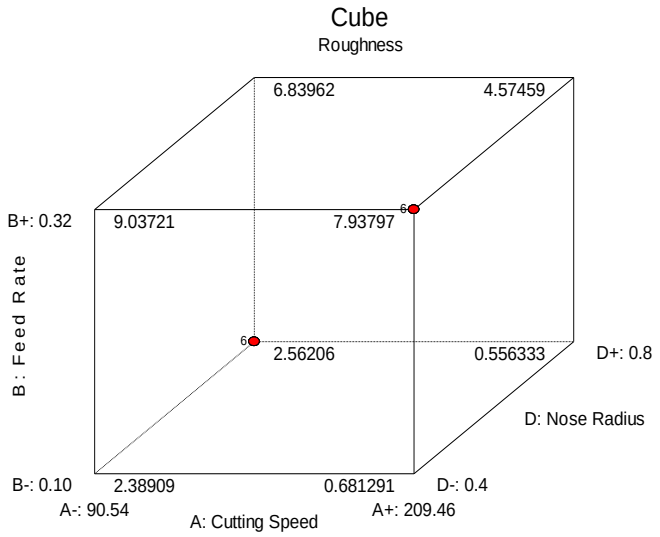


Fig.4.13: Cubical graph to show the value of roughness with A,B,D

- As the cutting speed increase the roughness decrease when the nose radius is 0.4mm as well as when the nose radius is 0.8 mm. Also at low feed rate and high feed rate. Which is the genuinely we have seen earlier in the interaction curve.
- Roughness is decreasing with increasing nose radius at both the speed (min. and max.) but the roughness is showing a little increase when the feed rate is very low.
- Roughness shows a mark increase with increase in the feed rate at every value of the cutting speed and nose radius.
- Fig.4.14 shows the 3-D curve of roughness vs. Cutting speed and Feed rate. It can be clear from the diagram how the roughness is changing with the change in both the cutting speed as well as feed rate at the same time.

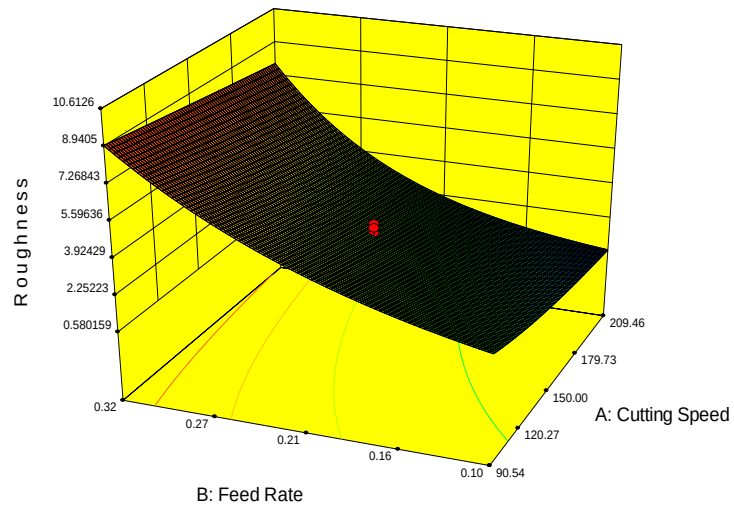


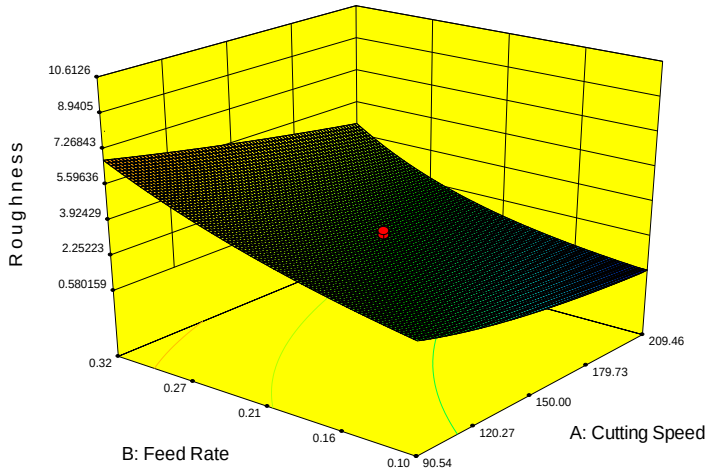
Fig.4.14. Roughness Vs A and B.

It can be seen that as the feed rate increasing, from left to right the roughness is also increasing. Whereas, the cutting speed increase the roughness is decreasing. The slope is high, that is the increase in the roughness is steeper in this case when nose radius is 0.4 mm.

Fig. 4.15 shows the same graph pattern but the condition there is that nose radius has been increased to 0.8 mm. In this case the increase in the roughness is not at much high rate in comparison to lower nose radius. However, the roughness still shows the same behavior of increment with feed rate and decrement with the increase in the cutting speed but the rate is low.

Fig.4.15 Plot of roughness vs. feed rate and cutting speed.

This behavior of the roughness gives the idea about the effect of various factors on the roughness. By keeping these behavioral patterns, the roughness can be optimized with the best possible combination value of the factors.



4.15 Plot of roughness vs. feed rate and cutting speed

CONCLUSION

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

a) If the cutting speed is high roughness decreases at all the feed rate what we have taken in the model range and at all the nose radius in our range.

b) If the nose radius is increased the roughness is decreased within all the permissible range of values of all the factors but at too little feed rate the roughness has shown increase, although it was too little but it has increased.

c) When we increase the feed rate the roughness also increases at all the values of factors within the permissible range of model.

d) In the interaction curve, it has been seen that roughness decrease even when there is an interaction between the cutting speed and feed rate. It shows the dominance of speed factor.

- When cutting speed and nose radius interact together, the roughness also decreases. It may be due to combined effect of the speed as well as nose radius as both alone also cause the roughness to decrease.
- When feed rate and nose radius interact together the roughness tend to increase. However, at too low feed rate at 0.10 mm/rev the roughness is almost increasing with the nose radius.

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