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Experimental Investigation and Parametric Analysis of Surface Roughness in CNC Turning Using Design of Experiments

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Abstract:*The manufacturing industries are very much concerned about the quality of their products. They are focused on producing high quality products in time at minimum cost. Surface finish is one of the crucial performance parameters that have to be controlled within suitable limits for a particular process. Surface roughness of machined components has received serious attention of Researchers for many years. It has been an important design feature and quality measure in machining process. There are a large number of parameters which affect the surface roughness. These include cutting tool variables, work piece material variables, cutting conditions etc. Therefore, prediction or monitoring of the surface roughness of machined components has been challenging and unexplored area of research*

The present work is therefore in a direction to integrate effect of various parameters which effect the surface roughness. Experiments were carried out with the help of factorial method of design of experiment (DOE) approach to study the impact of turning parameters on the roughness of turned surfaces. A mathematical model was formulated to predict the effect of machining parameters on surface roughness of a machined work piece. Model was validated with the experimental data and the reported data of other researchers. Further parametric investigations were carried out to predict the effect of various parameters on the surface research

Keywords: *Surface Roughness, Design of Experiments, CNC Turning, Surface Roughness, factorial method,*

I. Introduction

The manufacturing industries are very much concerned about the quality of their products. They are focused on producing high quality products in time at minimum cost. Surface roughness is one of the crucial parameters that have to be controlled within suitable limits for a particular process. Therefore, prediction or monitoring of the surface roughness of machined components has been an important area ofresearch.

In the present research, modelling the distribution of the resulting surface roughness values, in fine turning of Aluminium 6061, using wiper insert tools has been undertaken. This study will enable the assessment of the process variability with respect to surface roughness in fine turning. Though some studies on this particular aspect have been done, a different approach has been used in the current study. The important parameters discussed here are cutting speed, feed depth of cut, nose radius and rake angle.In the second part of this study, predictive equations for use in predicting the surface roughness values have been developed in terms of five important variables cutting speed, feed, depth of cut, nose radius and rake angle. Use of such predictive equations has been demonstrated with the application of regression techniques. In the third part of the present study, the performance of wiper insert tools is given. Several statistical techniques were used in this study to analyze the data instead of drawing conclusions based on the trends of the graphs as was done in earlier studies. A theoretical approach for predicting the surface roughness values has been discussed in terms of cutting speed, feed, depth of cut, nose radius and rake angle of the tool. Many researchers have indicated different methods of predicting the surface roughness values from various combinations of machining variables using the Design of experiments, ANN and GA.In establishing the predictive equations in the present study, emphasis has been placed on the experimental design. To develop the first order models (log transformed) for predicting the surface roughness values a regression modelling has been done. For establishing the second-order predictive models a full factorial design has been used.

II. Experimental Setup

Experimental Setup includes the following:1. CNC Turning Machine2.The geometry of tools selected are with the combinations of Nose radius: 0.4mm, 0.8mm, 1.2 mm and Rake angles $16^{0,}$ 18^{0} , 20^{0}3. Work material-Aluminum 6061,Heat Treatable Alloy manufactured in the form of bars by HINDALCO4. Surface Roughness Measuring Instrument Talysurf Surtronic 3+ 5. Software

The CNC turning machine consists of the machine unit with a three jaw independent chuck, a computer numerically controlled tool slide. CNC System used was Fanuc 0i mate - TD/Siemens 828D Basic T. with turret tooling BTP 80.The cutting tool which provided with the CNC turning lathe was a 25 x 25 mm square tool holder with 60 mm length having the positive tool angles.The tool used was cemented carbide insert type. The geometry of tools selected are with the combinations of three nose radius:0.4, 0.8, 1.2 and positive Rake angles 16^0,18^0, $20^{0.}$ Plate 3.7 shows the inserts and tool holder.

Figure 1: Inserts and Tool Holder

The Surtronic 3+ is a portable, self-contained instrument for the measurement of surface texture and is suitable for use in both the workshop and laboratory. Parameters available for surface texture evaluation are: Ra, Rq, Rz (DIN), Ry and Sm.The parameters evaluations and other functions of the instrument are microprocessor based. The measurements results are displaced on an LCD screen and can be output to an optional printer or another computer for further results. Minitab 13 was used for analyzing the results.

III. Design Of Experiments

The Design of Experiments were carried according to full factorial design methods.

Table 1: Process Parameters and Levels

Process Parameters Design	Process Parameters	Level (1)	Level (2)	Level (3)
A	Tool Rake angle (Degree)	16	18	20
B	Tool nose Radius (mm)	0.4	0.8	1.2
C	Cutting Speed (m/min)	175	225	275
D	Feed rate (mm/rev.)	0.05	0.1	0.15
E	Depth of cut (mm)	0.1	0.2	0.3

Factorial Design

- Factors: 5
- Factor Levels: 3, 3, 3, 3, 3
- Runs: 243
- Replicates: 1
- General Linear Model: Ra versus A, B, C, D, E
- Factor Type Levels Values
- A (Rake angle) fixed 3 1 2 3
- B (Nose Radius) fixed 3 1 2 3
- C (Speed) fixed 3 1 2 3
- D (Feed) fixed 3 1 2 3
- E (Depth of Cut) fixed 3 1 2 3

IV. Data Analysis

The purpose of developing the mathematical model relating the machining responses and their machining factors was to facilitate the optimization of the machining process. Using the mathematical model, the objective function and process constraints were formulated, and the optimization problem was then solved by using regression analysis.

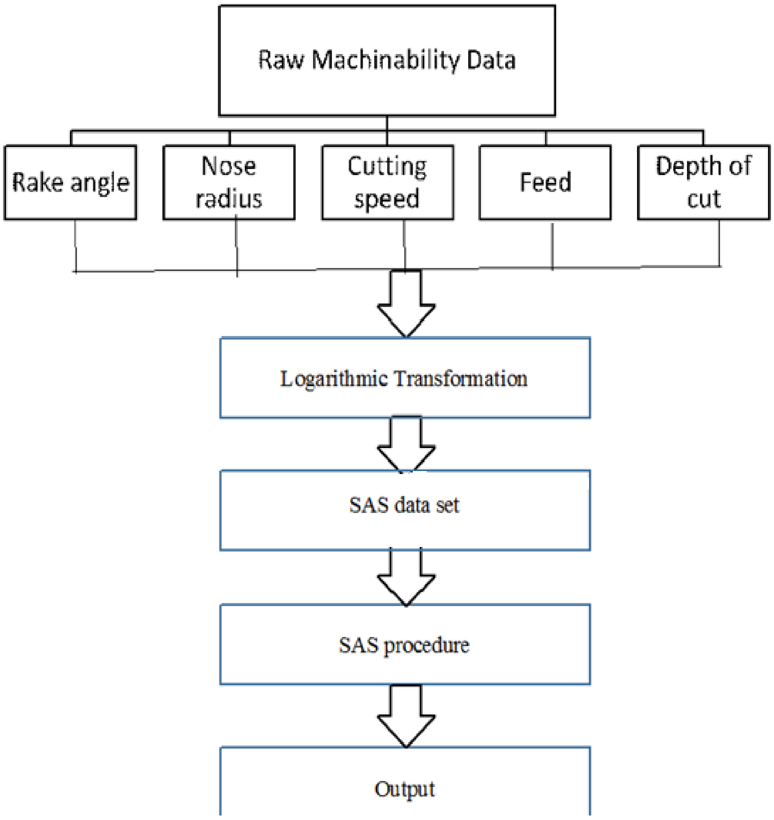

Figure 2: Program data vector for processing in regression analysis [Vipin and Kumar, 2009]

Regression Analysis has been made for Surface Roughness (Ra) versus Rake angle (Rk), Nose radius (Nr), Cutting Speed (V), Feed (f), and Depth of Cut (d).The regression equation obtained is

$$Ra = 478.63\ Rk^{-0.653} Nr^{-0.271} V^{-0.539} f^{\ 0.707} d^{0.184}$$

The R-square value of 0.908 indicated that 90.8% of the variability in the surface roughness was explained by the model with factors Rk, Nr, V, f and d. based on the mathematical model, it can be concluded that the feed is a dominant factor in the roughness model of finish turning of Al 6061.
The developed regression model is reasonably accurate and can be used for prediction within limits.

Figure 3: (a) shows the main effect plots for Ra. Figure 3: (b) shows the Interaction plots for Ra.
The interactions considered between the selected factors are:
Rake angle and Nose Radius (*A & B*)
Rake angle and Cutting speed (*A&C*)
Rake angle and Feed (*A&D*)
Rake angle and Depth of Cut (*A&E*)
Nose Radius and Cutting speed (*B&C*)
Nose Radius and Feed (*B&D*)
Nose Radius and Depth of Cut (B*&E*)
Cutting speed and Feed (*C&D*)
Cutting speed and Depth of Cut (*C&E*)
Feed and Depth of Cut (*D&E*)
Three-factor interactions *ABC*, *ABD*, *ABE*, *ACD*, *ACE*, *BCD*, *BCE*, *CDE*,
Four-factor interaction *ABCD*, *ABCE*, *ACDE*,
Five-factor interaction *ABCDE*

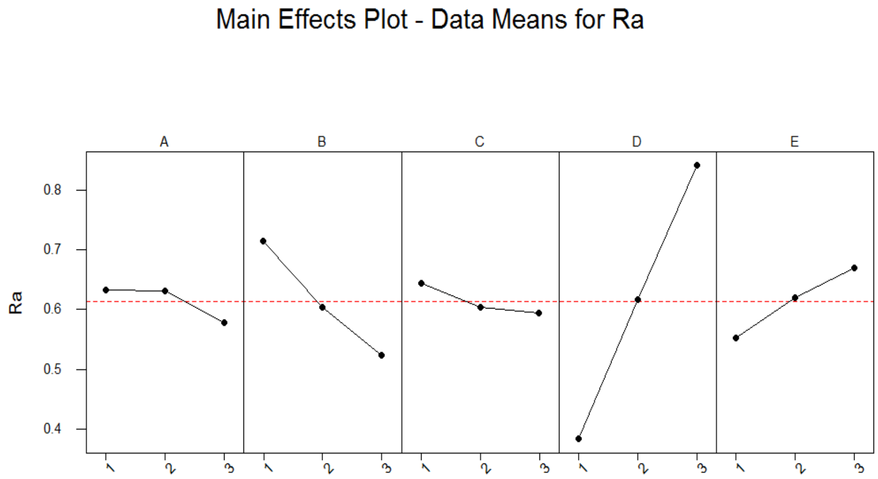

Figure 3: (a) main effect plots for Ra.

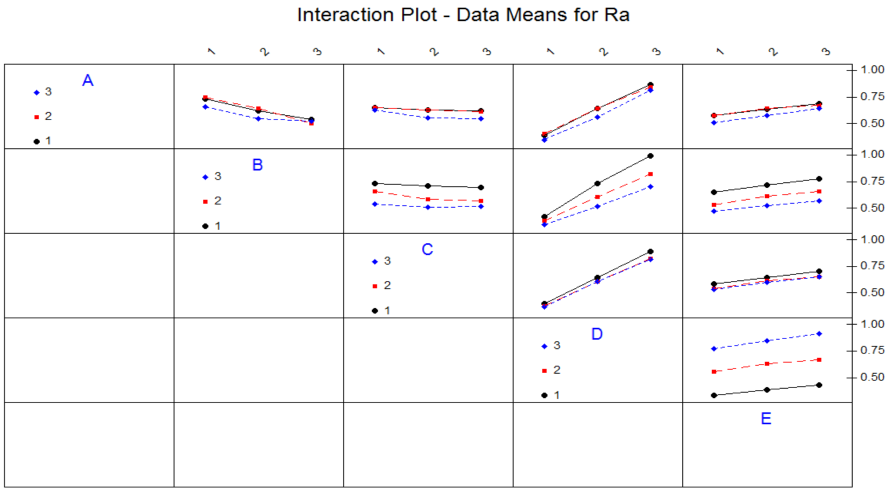

Figure 3: (b) Interaction plots for Ra.

V. RESULTS AND DISCUSSIONS

In this section the effect of cutting speed, feed,depth of cut, nose radius and rake angle have been discussed through graphs in detail with varying the parameters. Nearly 226 graphs have been produced with different combinations. The following sample graphs have been shown with variations.

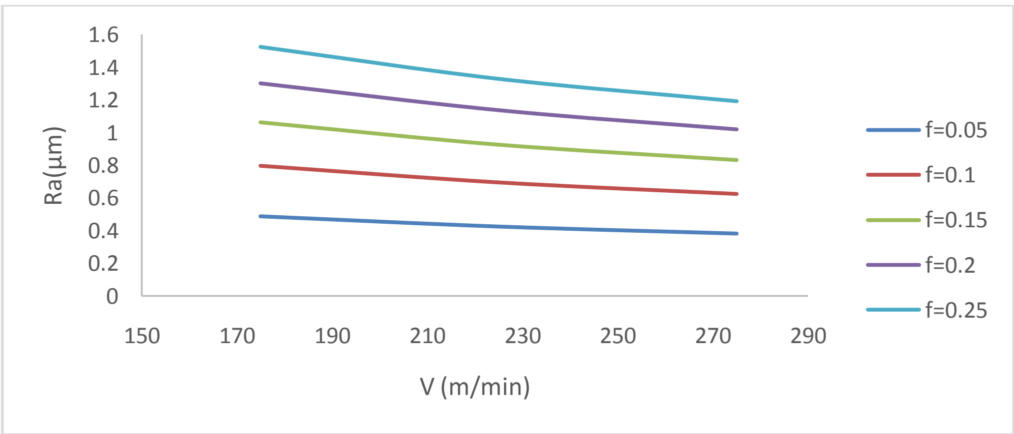

Figure 4: Graph between Surface Roughness and Cutting Speed for different feed values (mm/rev) at constant Rk=16 deg, Nr=0.4mm and d=0.1mm

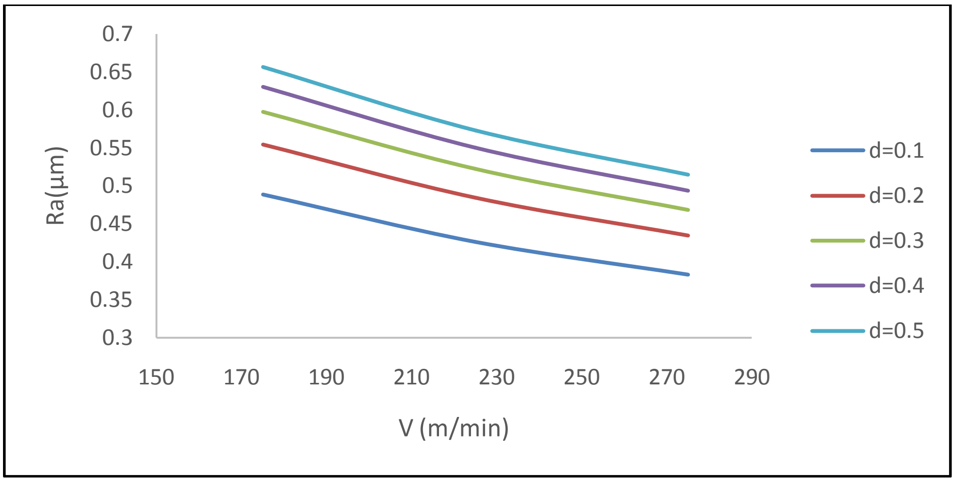

Figure 5: Graph between Surface Roughness and Cutting Speed for different depth of cut values (mm) at constant Rk=16 deg, Nr=0.4mm and f=0.05 mm/rev

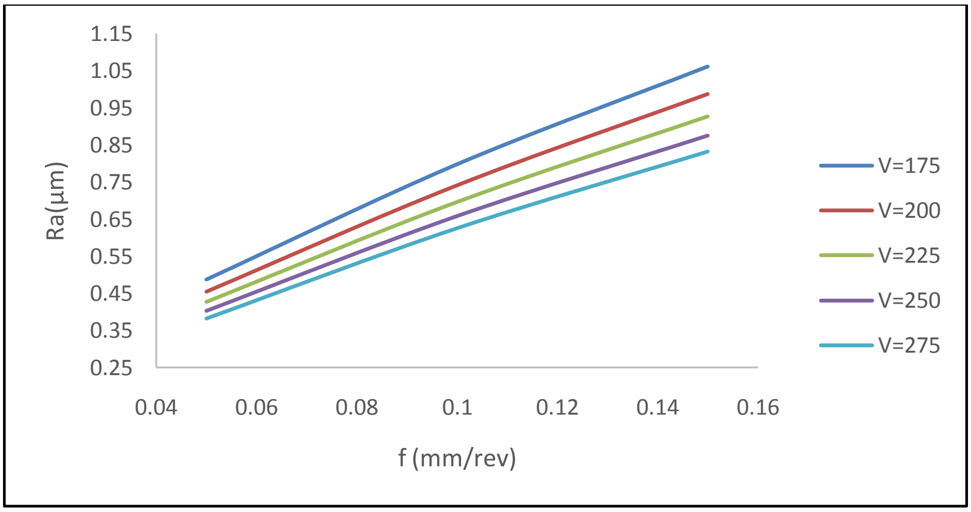

Figure 6: Graph between Surface Roughness and Feed for different cutting speed values (m/min) at constant Rk=16 deg, Nr=0.4mm and d=0.1mm

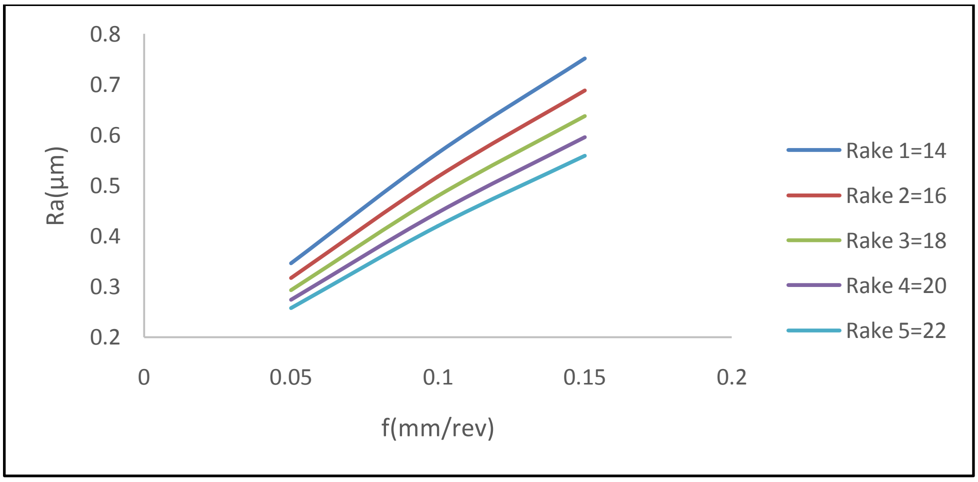

Figure 7: Graph between Surface Roughness and Feed for different rake angle values in (degrees) at constant Nr=1.2mm, V=225m/min and d=0.1

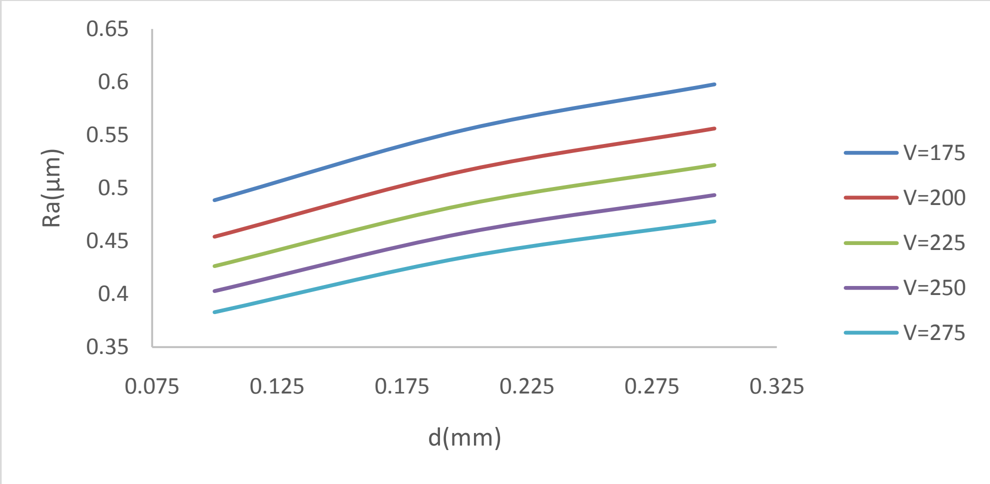

Figure 8: Graph between surface Roughness and Depth of Cut for different cutting speed values (m/min) at constant Rk=16 deg, Nr=0.4mm and f=0.05mm/rev

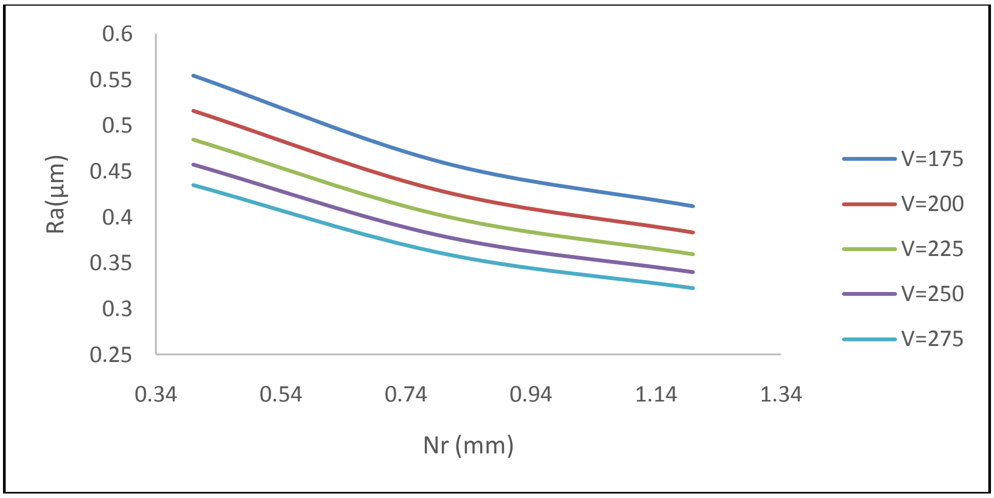

Figure 9: Graph between surface Roughness and Nose Radius for different cutting speed values (m/min) at constant Rk=16 deg, f=0.05mm/rev and d=0.1mm

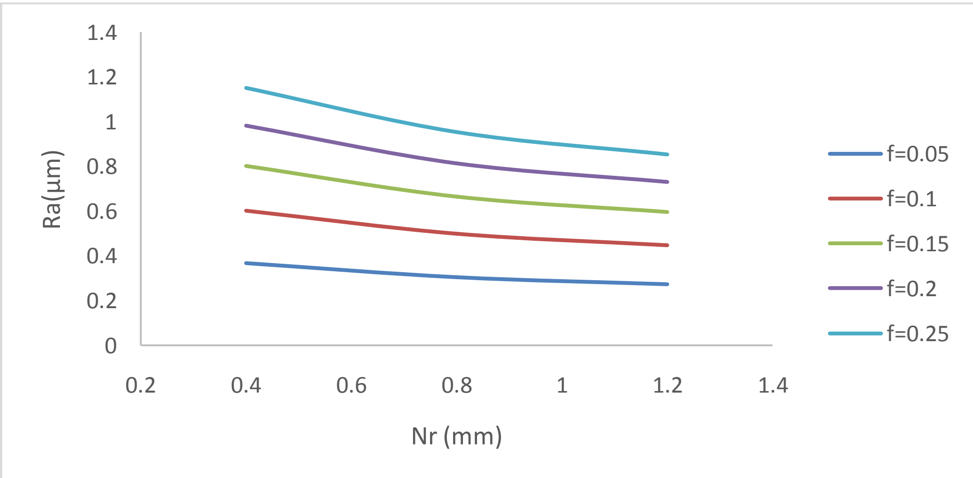

Figure 10: Graph between Surface Roughness and Nose Radius for different feed values (mm/rev) at constant Rk=20 deg, V=225m/min and d=0.1mm

Results Obtained From Graphs

1. Variation of Roughness values

- As speed increases from 175m/min to 275 m/min the surface roughness values varies from 0.263µm to 1.865µm.
- As depth of cut increases from 0.1mm to 0.3mm the surface roughness values varies from 0.257µm to 1.865µm.
- As feed increases from 0.05mm/rev to 0.15 mm/rev the surface roughness values varies from 0.257µm to 1.427µm
- As nose radius increases from 0.4mm to 1.2mm the surface roughness values varies from 0.263µm to 1.865µm
- As rake angle increases from 16 degrees to 20 degrees the surface roughness values varies from 0.274µm to 1.427µm

2. Minimum and Maximum Ra values

- The minimum Roughness value 0.257 is at Rk 22, Nr 1.2, V 225,f 0.05 and d 0.1
- The maximum Roughness value 1.865 is at Rk 16,Nr 0.4 V 175 f 0.25 and d 0.3

3. The optimal combination process parameters for minimum surface roughness is obtained at 20^0, 0.4mm, 275 m/min, 0.05 mm/rev and 0.1mm.

VI. CONCLUSIONS

The following conclusions have been made on the basis of results obtained and analysis performed:

- Increase in cutting speed improves the surface finish, thus the average surface roughness value decreases.
- Impact of Increase in depth of cuteffects the surface finish adversely to a small extent, but as depth of cut increases beyond a certain limit surface finish deteriorates to a large extent.
- Small increase in feed rate deteriorates surface finish to a large extentas compared to same amount of increase of depth of cut.
- Surface roughness also decreases as the nose radius increases hence surface finish increases.
- Increase in back rake angle the surface roughness decreases and improves the surface finish.
- The ANOVA and F-test revealed that the feed is dominant parameter followed by depth of cut, speed, nose radius and rake angle for surface roughness.
- The optimal combination process parameters for the work piece under consideration with regards to minimum surface roughness or maximum surface finish is obtained at rake angle of 20^0, nose radius 0.4mm, cutting speed 275 m/min, feed rate0.05 mm/rev and depth of cut 0.1mm.

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