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INVESTIGATION OF SURFACE ROUGHNESS IN HIGH SPEED TURNING OF EN 31 STEEL

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Abstract:

In this paper the experiment is conducted on EN 31 alloy steel with carbide insert. Number of experiments and arrangement of process parameters are determined with the help of face centred central composite design. The input parameters are spindle speed, feed and depth of cut which is varied in three different levels. Response Surface Methodology is used to generate empirical relationship between the inputs and the responses which is validated by analysis of variance. The predicted values derived from Response Surface Methodology are compared with experimental data. Effects of input parameters on responses are analysed with the help of Response Surface Methodology. MINITAB software is used for optimization of surface roughness.

Key Words: Surface Roughness, Surface Methodology, EN 31 Alloy Steel, High Speed Turning& MINITAB

1. Introduction:

All the varied modern technology depends for the satisfactory functioning of the processes on special properties of some solids, mainly, these properties are the bulk properties, but for an important group of phenomena these properties are the surface properties. This is especially true for wear resistant components, as their surface must perform many engineering functions in variety of complex environments. The behaviour of material therefore greatly depends on surface of the material, surface contact area and their influence on the performance of various components, units and machines, a branch of science called surface science has been developed.

A surface can be described in simple turn to the outermost layer of an entity. An interface can be defined to be the transition layer between two or more entities that differ either chemically or physically or in both aspects. Surface and interfaces can be examined closely by high resolution microscope, physical and chemical method.

Surface science can be defined as a branch of science dealing with any type and level of surface and interface interaction between two or more entities. These interactions can be physical, chemical, electrical, mechanical, thermal etc.

Surface roughness affects:

- ✓ The conditions of fit between mating components
- ✓ The corrosion resistance
- ✓ The flow of fluids along pipelines
- ✓ The general appearance of a product

The main definitions which are required to specify surface integrity are given below.

Surface Integrity: Surface integrity is the surface condition of a work piece after being modified by a manufacturing process. The surface integrity of a work piece or item changes the material's properties. The consequences of changes to surface integrity are a mechanical engineering design problem, but the preservation of those properties are a manufacturing consideration. There are two aspects to surface integrity

Topography Characteristics: The topography is made up of surface roughness, waviness, errors of form, and flaws.

Surface Layer Characteristics: The surface layer characteristics that can change through processing are: plastic deformation, residual stresses, cracks, hardness, over aging, phase changes, recrystallization, intergranular attack, and hydrogen embrittlement. When a traditional manufacturing process is used, such as machining, the surface layer sustains local plastic deformation [5].

Variables: Manufacturing processes have five main variables: the work piece, the tool, the machine tool, the environment, and process variables. All of these variables can affect the surface integrity of the work piece by producing

- ✓ High temperatures involved in various machining processes

- ✓ Plastic deformation in the work piece (residual stresses)
- ✓ Surface geometry (roughness, cracks, distortion)
- ✓ Chemical reactions, especially between the tool and the work piece.

Surface Quality: Surface quality is determined by the geometric, natural, chemical and crystallographic characteristics of a machines surface.

Normal Surface: We begin this visualization process with a discussion of normal surfaces only. There are the six principal projection planes: Front, Back, Top, Bottom, Left, Right. A normal surface is a surface that is perpendicular to two of the principal planes and parallel to the third. To illustrate the simplest example of normal surfaces, we will use a rectangular block.

Effective or Machined Surface: The surface obtained by one of the known cutting (milling, turning etc.) or forming (rolling, extrusion etc.) processes.

Deviations: Deviation is the difference from nominal surface.

Definition of Roughness: The irregularities in the surface texture, which are inherent in the production process but excluding waviness and errors of from. Irregularities are the peaks and valleys of a machined surface.

Parameters of Surface Roughness: The following two terms are used in the definitions of parameters:

- ✓ Sampling length is the length of profile selected for the purpose of making an individual measurement of surface roughness
- ✓ Centre or mean line is the line, which divides a sampling length of surface L, so that the sum of areas above this line to be equal with the sum of areas below fig. This may be expressed by:

Area (A+C+E+G+I) Area (B+D+F+H+J+K)

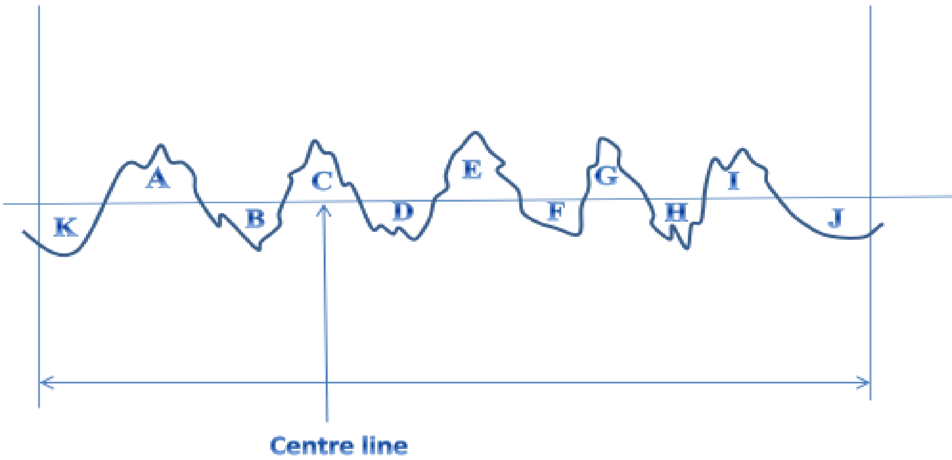


Figure 1: Definition of centre or mean line

Roughness Average (R_a): The CLA or AA roughness (R_a) is obtained by measuring the mean deviation of the peaks from centre line of a trace, the centre line being established as the line above and below of which there is an equal area values for a given surface

Maximum Depth (R_v): R_v is the maximum distance between valley and mean line in the limits of a sampling length L.

Maximum Height ($R_{p:}$): R_p is the maximum distance between peak and mean line in the limits of a sampling length L**.**

Total Height (R_t): R_t is the maximum distance between valley and peak in the limits of a sampling length L. Parameters $R_{z.}$.

Height Parameters (R_z): The R_z value is known as the ISO 10-point height parameter. It is measured over a single sampling length and is itself an average of positive and negative peak values. It is useful a parameter ‘k’ a short length of the surface is available for assessment.

2. Literature Review:

W. S. Lin et al. [6] have focused on the surface roughness variation in high speed fine turning of the austenitic stainless steel. Design/methodology/approach- A series of experimental tests have been done to evaluate the possibility of high speed fine turning of the austenitic stainless steel from the surface roughness variation and machining stability. Findings- It have been found that, the higher the cutting speed, the higher the cutting temperature of cutting tool. The cutting tool has softened and the surface roughness of the work piece has been deteriorated.

S. Hasan et al. [7] have investigated on hard turning of materials have been a process where dimensional accuracies, dimensional controls can be easily obtained. Currently hard components have been produced by hard machining in a very short time which also have saved on cost. The cutting tool used for this material is normally a super hard cutting tool like CBN and PCBN tools and less tool wear is possible. The influence of flank wear was due to abrasive action of hard martensitic carbides of the work material at low cutting speed, and low feed rate. The crater wear also formed and was due to abrasive action of the saw tooth chips and also by heat at cutting zone.

D. Singh et al. [8] have conducted due to technical and economic factors; hard turning has been competing successfully with the grinding process in the industries. Many practical applications require components to be hardened in order to improve their wear behaviour. Higher productivity and good surface quality are the requirements of the modern industries. However, tool wear has been the major problem in hard turning. The tool wear models, used to assess the performance of hard turning process, play an important role in predicting the surface quality. So, in the present work, an attempt has been made to develop an analytical tool wear model for the mixed ceramic inserts during the hard turning of bearing steel incorporating abrasion, adhesion, and diffusion wear mechanisms. The new model developed can reliably be used to assess the wear of the mixed ceramic tools within the domain of the parameters. It has been observed that tool wear has been increasing with the increase in cutting speed, feed, and effective rake angle. However, it has been found to be slightly decreasing with the increase in nose radius.

A. E. Diniz et al. [9] have carried out a high-pressure coolant (HPC) delivery has been an emerging technology that delivers a high-pressure fluid to the tool and work piece in machining processes. High fluid pressure allows for better penetration of the fluid into the cutting zone, enhancing the cooling effect, and decreasing tool wear through lubrication of the contact areas. The main objective of this work has been to understand how tool wear mechanisms are influenced by fluid pressure under different cutting speeds in the finish turning of AISI 1045 steel using coated carbide tools. The main finding has been the use of a lower cutting speed (v_c = 490 m/min) in dry cutting resulted in tool life close to that obtained with cutting fluid, but when the cutting speed was increased (vc = 570 m/min), the high-pressure coolant was effective in prolonging the life of the cutting tool. It has been also concluded that, regardless of the cutting speed and cooling/lubrication system, the wear mechanisms were the same, namely abrasion and attrition.

M. Dogra et al. [10] have showed that the turning has been a topic of great interest in today's industrial production and scientific research. The hard turning technology has the potential for improving productivity by replacing grinding in the process of manufacturing. In machining processes, it has been necessary to attain the desired surface quality in order to produce parts providing the required functioning. The surface quality has also defined some mechanical properties of the product, such as wear resistance. Being such a considerable quality, surface quality has been influenced by various parameters. Since improvement of surface quality can be hindered by tool wear, resistance of the tool against thermal and mechanical loads should be taken into consideration. Looking from this aspect, an ideal tool should possess the properties of good wear resistance, high mechanical strength and high thermal stability.

V. Bushlya et al. [11] has studied on this paper material used Inconel 718 (45 HRC), it is a super alloy. To machine this material with the help of cemented carbide at various used is done Aspects of tool life, tool wear, and generated surface quality were studied. It has been found that protective function of the coating, which increases the tool life up to 20 %, is limited only to low cutting speed range.

S. Khamel et al. [12] have determined the effects of process parameters (cutting speed, feed rate and depth of cut) on perform- acne characteristics (tool life, surface roughness and cutting forces) in finish hard turning of AISI 52100 bearing steel with CBN tool. The cutting forces and surface roughness are measured at the end of useful tool life. The combined effects of the process parameters on performance characteristics are investigated using ANOVA. The results show that feed rate and cutting speed strongly influence surface roughness and tool life. However, the depth of cut exhibits maximum influence on cutting forces. The proposed experimental and statistical approaches bring reliable methodologies to model, to optimize and to improve the hard turning process. They have extended efficiently to study other machining processes.

H. Hu et al. [13] have investigated on this paper we come to known the finite element modelling has approach with lagrangian increment method for 3D metal turning. The work material has been hardened steel H13 and the tool have been ceramic, ultrafine grained tool respectively. The results showed that predicted primary turning force and maximum temperature in common ceramic are bigger than which was caused by ultrafine-grained ceramic tool.

3. Mathematical Model of Surface Roughness:

Scope of the Present Work: From above Literature review, it is found that various parameters like depth of cut (D), feed (F), cutting speed (V) affects the high speed turning. It is clear that substantial research work have been done on optimization of parameters of different types of machining, but there are few literatures available on experimental study on feed (F), depth of cut (D) and observed parameter Surface Roughness.

The objectives of the present work are to

- ✓ Select cutting tool insert and job material as CNMG120408 EN-TMR CTC1135 Carbide insert and EN 31 alloy steel respectively.
- ✓ Machine with the help of CNC Machining Centre MAXTURN PLUS. No. of job was determined as per the design of experiment.

- ✓ Measure Surface roughness (Ra).
- ✓ Analyze the result and modeling by Response Surface Methodology and ANOVA.
- ✓ Optimize the process parameters for surface roughness with the help of Response Surface Methodology (RSM).

Mathematical Model of Surface Roughness: The components of surface roughness due to tool nose geometry may be readily calculated. Fig.2 shows a plan view of conventional turning operation with ridges left behind on the finished surface. Fig.2 shows an enlarged view of the tool tip which is defined in terms of three quantities.

- ✓ Nose radius (r = OT in Fig.4)
- ✓ End cutting edge angle (C_e)
- ✓ Side cutting edge angle (C_s)

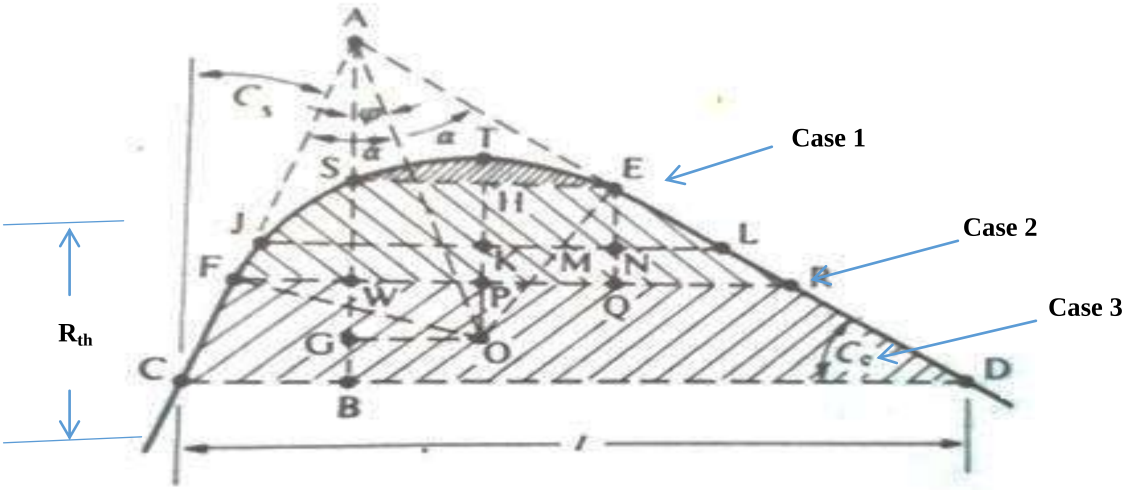


Figure 2: Plan view of cutting tool

The three cases arrive when feed is varied fixing tool nose radius. R_{th} is the theoretical surface roughness. Following three cases are analyzed from geometrical point of view.

Case 1:

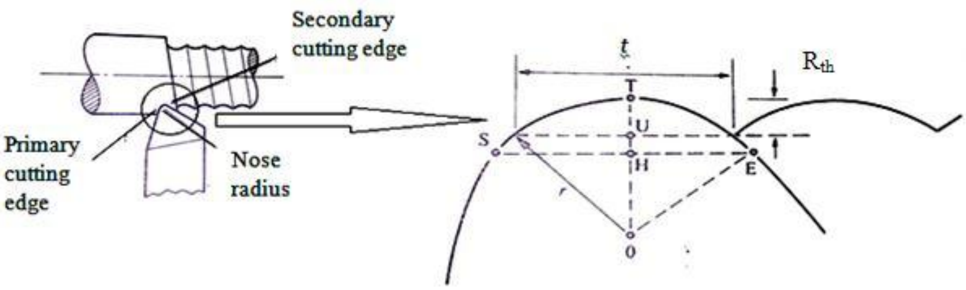


Figure 3: Enlarged view of tool job interface area

When the nose radius is large and feed is very small, the surface will be generated by the nose radius alone.

$$R_{th} = OT - OU = r\left(r^2 - t^2/4\right)^{1/2} \approx \frac{t^2}{8r}$$

Orinon-dimensional form

$$\frac{R_{th}}{r} = \frac{1}{8}\left(\frac{t}{r}\right)^2$$

Case 2: For larger values of feed

$$\frac{t}{r}\left[2\frac{R_{th}}{r} - \left(\frac{R_{th}}{r}\right)^2\right]^{\frac{1}{2}} + \sin C_e + \left(\frac{R_{th}}{r} - 1 + \cos C_e\right)\cot C_e$$

Case 3: For still larger values of feed

$$\frac{R_{th}}{r} = \frac{t/r}{\tan Cs + \cot Ce} - \frac{\cos\left(45 - \frac{Ce}{2} - \frac{Cs}{2}\right)}{\sin\left(45 - \frac{Ce}{2} + \frac{Cs}{2}\right)} + 1$$

or

$$\frac{R_{th}}{r} = \frac{t/r}{\tan Cs + \cot Ce}, \qquad \frac{t}{r} \gg 1$$

1. Experimentation:

Selection of Work Piece: EN 31 alloy steel is selected as work piece material for the present work. EN31 High carbon alloy steel which achieves a high degree of hardness with compressive strength and abrasion resistance. By its character this type of steel has high resisting nature against wear and can be used for components which are subjected to severe abrasion, wear or high surface loading. A good tool material should have all of the following characteristics

- ✓ Harder than the work it is cutting.
- ✓ High temperature stability.
- ✓ Resists wear and thermal shock.
- ✓ Impact resistant
- ✓ Chemically inert to the work material and cutting fluid

Select cutting tool insert and job material as CNMG120408 EN-TMR CTC1135 Carbide insert and EN 31 alloy steel respectively. Carbide tools are more expensive per unit than other typical tool materials, and it is more brittle, making it susceptible to chipping and breaking. To offset these problems, the carbide cutting tip itself is often in the form of a small insert for a larger tipped tool whose shank is made of another material, usually carbon tool steel. This gives the benefit of using carbide at the cutting interface without the high cost and brittleness of making the entire tool out of carbide. Its main use is in turning tool bits although it is very common in milling cutters and saw blades. Hardness up to about HRC 90. Sharp edges generally not recommended.

Figure 4: Carbide insert tool

Carbide Insert Specification:

Made- Taegu Tec (TT) Member IMC Group

Specification- CNMG 120408 EA TT5080

The EN 31 steel rod of size 120 mm and diameter 25 mm has been used for present work which is known for its high quality, High tensile strength usually supplied with machine able, giving good ductility, good shock resisting properties and good resistance to wear. The chemical composition and mechanical properties are given below in tabular form. EN 31 is usually supplied with a tensile strength of 750 N/ mm^2. EN 31 is a popular grade of through hardening alloy steel due to its excellent machinability. EN 31 can be further surface hardened to create components with enhanced wear resistance by induction or nit riding processing.

Table 1: Typical chemical composition of EN 31 steel

	C	Mn	Si	S	P	Cr
EN 31	0.90-1.20	0.3-0.75	0.10-0.35	0.040	0.040	1.0-1.060

Table 2: Mechanical properties of EN 31 steel

Element	**Objective**
Tensile Strength	750N/mm^2
Yield Stress	450N/mm^2
Reduction of Area	45%
Elongation	30%
Modulus of elasticity	215000N/mm^2
Density	7.8kg/m^3
Hardness	63HRC

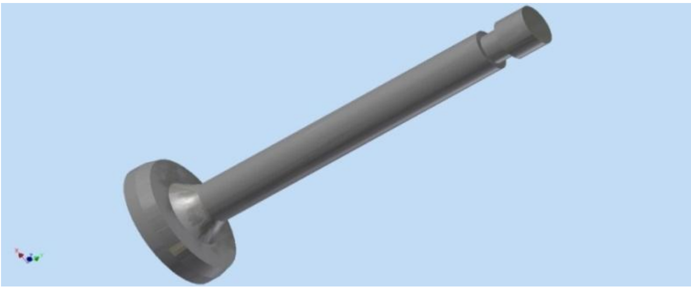


Figure 5: 3D modelling of poppet valve

Figure 6: Work pieces after experimentation

Experimental Setup: The EN 31 steel bar is held on the three jaw auto-centre pneumatic chuck on CNC turner. For machining, suitable CNC programming is used.

Figure 7: CNC maxturn plus

Table3: Machine Specification

Capacity	
L x W x H	1700x1400x2100 (mm)
Weight	2500 kg
X-axis travel	120 mm
Z-axis travel	200 mm
Chuck size	135 mm
Max. turning diameter	200 mm
Max. turning length	200 mm
Swing over cross slide	130 mm
Swing over way covers	320 mm
Feed rate	0-10000 mm/min.
Rapid travers rate (X,Z)	10 m/min.
Spindle nose taper	A2/4
Spindle bore taper	MT4
Bore through spindle	41 mm
Maximum speed	6000 rpm
Turret	BTP63
Number of stations	8
Turning tool STD	20x20 mm
Total indexing for adjacent tool	0.35 sec
Boring bar size	32 mm

Process Variables and their Limits:

The working ranges of the parameters for subsequent design of experiment, based on there

Table4: Process Variables and Their Limits

Variables/ Levels	-1	0	1
Depth of cut (mm)	0.08	0.18	0.28
Feed (mm/rev.)	0.07	0.12	0.17
Rotational speed (rpm)	900	1400	1900

Surface Roughness Measurement:

Introduction: Measurements of surface roughness are expressed in terms of R_a or R_z. These values include peak to valley profile measurement in combination with an assessment of the frequency of peaks within the sample area. Theelcometer surface roughness tester is a light weight and portable measuring solution for the range of surface roughness measurements required for compliance to International Standards. The unit is also suitable for assessing surface roughness conditions in a wide range of general industrial applications; particularly where the sample is too large to bring to the laboratory.

- ✓ Multi Lingual Display- All the required information is displayed on screen in a choice of 14 languages.
- ✓ Flexible- Can be used in virtually any position horizontally, vertically, upside down. A height adjustment accessory to accommodate various sample sizes is supplied with each gauge as standard.
- ✓ Integrated Calibration Standard- No external calibration standard is required provides greater ease of use.
- ✓ Drive Unit- Can be rotated and moved longitudinally enables the stylus pick-up to be moved to the calibrating position. The stylus pick-up is also protected for transport in this position.
- ✓ Stylus pick-up with removable protection- 2µm diamond stylus tip with a measuring force of 0.7 m N. Different stylus are available for various applications.

How to Use a Surface Roughness Tester: The Roughness tester is stylus type. The stylus moves along the machined surface with parallel to the job axis. The roughness is measured in three position of the machined surface for each job and the average value is taken for that job. The measurement technique provides a number of measurement parameters including:

Ra**-** The average surface roughness over the sampling length.

Rz- The average distance between the highest peak and the lowest valley over a number of sampling lengths.

Made- MahrGmbh Gottingen, made in Germany

Model- MarSurf PS1

Figure 8: Surface roughness tester

Collection of Data:

Table 5: Input and output of experiment

	Coded Data			Actual Data			Measured Response	
S.No	DOC (mm)	Feed Rate (mm/rev)	Speed Rate (RPM)	DOC (mm)	Feed (mm/rev)	Speed (RPM)	Surface Roughness	
							R_a	R_z
01	-1	1	-1	0.08	0.17	900	2.29521	13.4875
02	0	0	0	0.18	0.12	1400	2.33050	12.8894
03	0	0	0	0.18	0.12	1400	2.34026	12.8883
04	1	1	1	0.12	0.17	1900	2.87254	17.8543
05	0	0	0	0.18	0.12	1400	2.33105	12.8972
06	0	0	-1	0.08	0.12	1400	2.49645	16.8094
07	1	-1	1	0.12	0.07	1900	1.52790	09.5343
08	0	0	0	0.18	0.12	1400	2.32985	12.8857
09	-1	1	1	0.12	0.17	900	3.63420	21.8545
10	1	0	0	0.08	0.12	1900	1.84762	09.9521
11	-1	-1	1	0.12	0.07	900	5.88456	33.2545
12	1	-1	-1	0.08	0.07	1900	2.27479	15.9085
13	0	-1	0	0.18	0.07	1400	2.96780	15.6169
14	0	1	0	0.18	0.17	1400	2.52590	13.1721
15	-1	0	0	0.18	0.12	900	3.35465	18.9005
16	1	1	-1	0.08	0.17	1900	3.63695	21.4296
17	0	0	0	0.18	0.12	1400	2.32975	12.8885
18	-1	-1	-1	0.08	0.07	900	4.52485	28.6821

19	0	0	1	0.12	0.12	1400	2.79475	17.3049
20	0	0	0	0.18	0.12	1400	2.33026	12.8927

2. Results and Discussion:

Response Prediction for Surface Roughness:

Regression Analysis for Surface Roughness (Ra) Versus Speed, Feed and DOC: Regression analysis is done using MINITAB software. Full quadratic model was used, because it is found in literature that strong interactions between depths of cut, federate and spindle speed exists. The following results are obtained from RSM modeling using MINITAB statistical software.

Table6: Estimated regression coefficients for Ra

Term	Coef	SE	T	P
Constant	2.33170	0.001021	2283.110	0.000
Speed (A)	-0.75337	0.000939	-801.929	0.000
Feed (B)	-0.22151	0.000939	-235.788	0.000
DOC (C)	0.14857	0.000939	158.147	0.000
Speed * Speed (A*A)	0.26980	0.001791	150.605	0.000
Feed * Feed (B*B)	0.41552	0.001791	231.944	0.000
DOC * DOC (C*C)	0.31427	0.001791	175.425	0.000
Speed * Feed (A*B)	0.89835	0.001050	855.303	0.000
Speed * DOC (A*C)	-0.52625	0.001050	-501.033	0.000
Feed * DOC (B*C)	-0.00478	0.001050	-4.551	0.001
S = 0.0297078			PRESS = 0.0156217	
R^2 = 98.95%		R^2(pred) = 96.82%	R^2(adj) = 98.52%	

R^2 the coefficient of determination, gives the greatest indication of the strength of relationship. The result shows that 98.95% of the variation in response variable can be explained in a linear relationship with the predictor. Press (predicted sum of squares) can be used as a data validation procedure by leaving out one observation, fitting a given model to their to the data and then predicting the one left out and obtaining the square of discrepancy, then repeating this for all single data point omissions. Thus we get PRESS. The PRESS value show's that the model is significant.

The estimated regression equation for surface roughness in encoded unit is as follows:

R_a =2.33170 + 0.14857 * doc - 0.22151* f+ 0.75337 * RPM - 0.31427 * doc * doc+ 0.41552 * f * f+0.26980 * RPM* RPM- 0.00478* doc * f- 0.52625* doc * RPM

To check the adequacy f the regression analysis, analysis of variance (ANOVA) has been done. ANOVA results are shown in Table 7

Table 7: Analysis of variance for Ra

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	9	18.7449	18.7449	2.08276	235992.81	0.000
Linear	3	6.3870	6.3870	2.12901	241232.19	0.000
A	1	5.6756	5.67562	5.67562	643089.94	0.000
B	1	0.4907	0.4907	0.49067	55596.21	0.000
C	1	0.2207	0.2207	0.22073	25010.41	0.000
Square	3	3.6859	3.6859	1.22864	139213.76	0.000
A*A	1	2.5040	0.2002	0.20018	22681.80	0.000
B*B	1	0.9103	0.4748	0.47480	53798.01	0.000
C*C	1	0.2716	0.2716	0.27160	30774.10	0.000
Interaction	3	8.6720	8.6720	2.89065	327532.50	0.000
A*B	1	6.4563	6.4563	6.45626	731542.67	0.000
A*C	1	2.2155	2.2155	2.21551	251034.11	0.000
B*C	1	0.0002	0.0002	0.00018	20.71	0.001
Residual Error	10	0.0001	0.0001	0.00001		
Lack-of-Fit	5	0.0000	0.0000	0.00000	0.05	0.997
Pure Error	5	0.0001	0.0001	0.00002		
Total	19	18.7450				

The experimental results were analyzed using analysis of variance (ANOVA) for identifying the significant factors affecting the performance measures that is surface roughness (R_a). The results of ANOVA for the surface roughness are shown in Table. This analysis was carried out for a significance level of α=0.5 (confidence level of 95%).

The principle of the F test is that the larger the F values for a particular parameter, the greater the effect on the performance characteristic due to change in it. From the analysis of table, it is apparent that the F calculated value is greater than the F-table value ($F_{0.05,\ 8,\ 11}$). In the table, ANOVA results show that rotational speeds (RPM) have highest and most hence most significant effect on surface roughness, and then feed rate has effect on roughness. In fact depth of cut has very little effect on surface roughness.

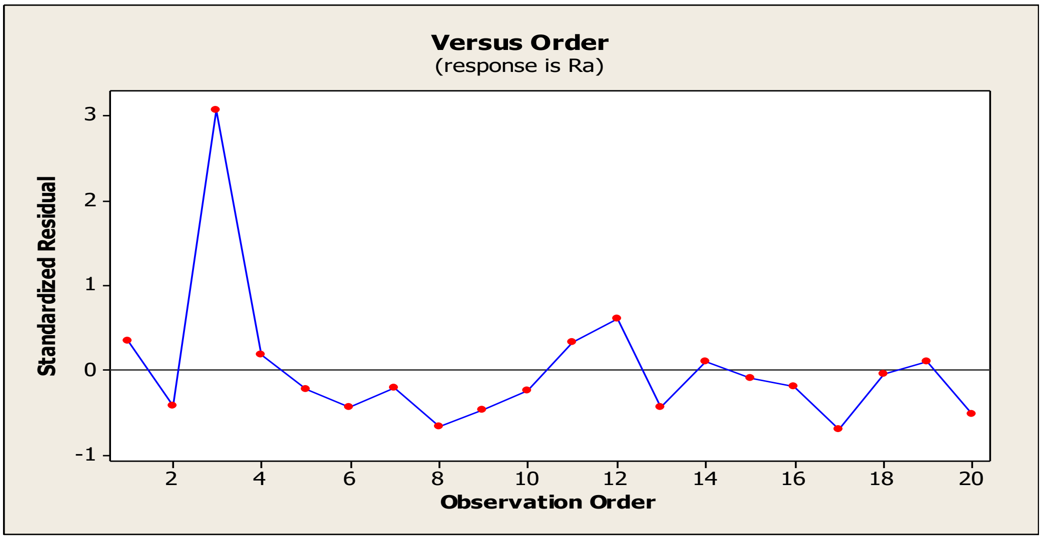


Figure 9: Residual plot for surface roughness

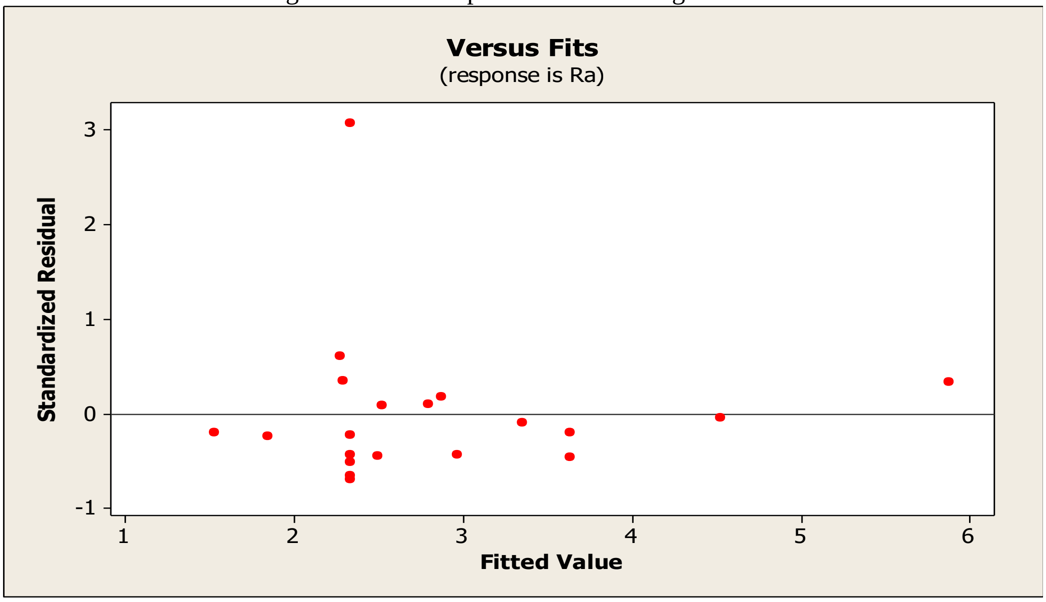


Figure 10: Residual plot for fitted values

The difference between the observed values and predicted or fitted values are called residuals. The residuals are calculated and ranked in the ascending order. The normal probabilities of residuals are shown in Figure 9. The normal probability plot is used to verify the normality assumption. As shown in Figure 9, the data are spread roughly along the straight line. Hence it is concluded that residuals are normally distributed.

Regression Analysis for Surface Roughness (R_z) Versus Speed, Feed and DOC: Now regression analysis results are done with software. For that, full quadratic model is used; because it is thought that strong inter actions between depths of cut, feed rate and spindle speed exists. The analysis was done using coded units.

Table 8: Estimated regression coefficients for R_z

Term	Coef	SE Coef	T	P
Constant	12.8680	0.08721	147.554	0.000
Speed (A)	-4.1500	0.08022	-51.733	0.000
Feed (B)	-1.5198	0.08022	-18.946	0.000
DOC (C)	0.3485	0.08022	4.345	0.001
Speed * Speed (A*A)	1.5917	0.15297	10.405	0.000
Feed * Feed (B*B)	1.5599	0.15297	10.197	0.000
DOC * DOC(C*C)	4.2226	0.15297	27.603	0.000

Speed * Feed (A*B)	5.0545	0.08969	56.355	0.000
Speed * DOC (A*C)	-2.8611	0.08969	-31.900	0.000
Feed * DOC (B*C)	0.8242	0.08969	9.189	0.000
S = 0.253680 R^2 = 99.91%		R^2(pred) = 98.99%	PRESS = 6.89338 R^2(adj) = 99.82%	

R^2 the coefficient of determination, gives the greatest indication of the strength of relationship. The result shows that 99.91% of the variation in response variable can be explained in a linear relationship with the predictor. PRESS (predicted sum of squares) can be used as a data validation procedure by leaving out one observation, fitting a given model to the rest of the data and then predicting the one left out and obtaining the square of discrepancy, then repeating this for all single data point omissions. Thus we get PRESS. The PRESS value shows that the model is significant. The estimated regression equation for cutting temperature in uncoded units is as follows.

R_Z =12.8680 + 0.3485 * doc - 1.5198 *f+ 4.1500 *RPM - 4.2226 * doc * doc+ 1.5599* f* f+1.5917 * RPM * RPM +0.8242* doc * f- 2.8611* doc * RPM

To check the adequacy of their regression analysis, analysis of variance (ANOVA) has been done. ANOVA results are shown in Table 9.

Table 9: Analysis of variance for R_z

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	9	680.579	680.579	2.08276	235992.81	0.000
Linear	3	196.541	196.541	2.12901	241232.19	0.000
A	1	172.227	172.227	5.67562	643089.94	0.000
B	1	23.099	23.099	0.49067	55596.21	0.000
C	1	1.215	1.215	0.22073	25010.41	0.000
Square	3	208.736	208.736	6.968	139213.76	0.000
A*A	1	128.083	6.968	6.968	22681.80	0.000
B*B	1	31.620	6.968	0.47480	53798.01	0.000
C*C	1	49.033	49.033	0.27160	30774.10	0.000
Interaction	3	275.303	275.303	2.89065	327532.50	0.000
A*B	1	6.4563	6.4563	6.45626	731542.67	0.000
A*C	1	2.2155	2.2155	2.21551	251034.11	0.000
B*C	1	0.0002	0.0002	0.00018	20.71	0.001
Residual Error	10	0.0001	0.0001	0.00001		
Lack-of-Fit	5	0.0000	0.0000	0.00000	0.05	0.00
Pure Error	5	0.0001	0.0001	0.00002		
Total	19	18.7450				

Analysis of Surface Roughness (Ra) by Minitab: Surface plots are obtained after Minitab run. Plots with varying parameters are described in this section.

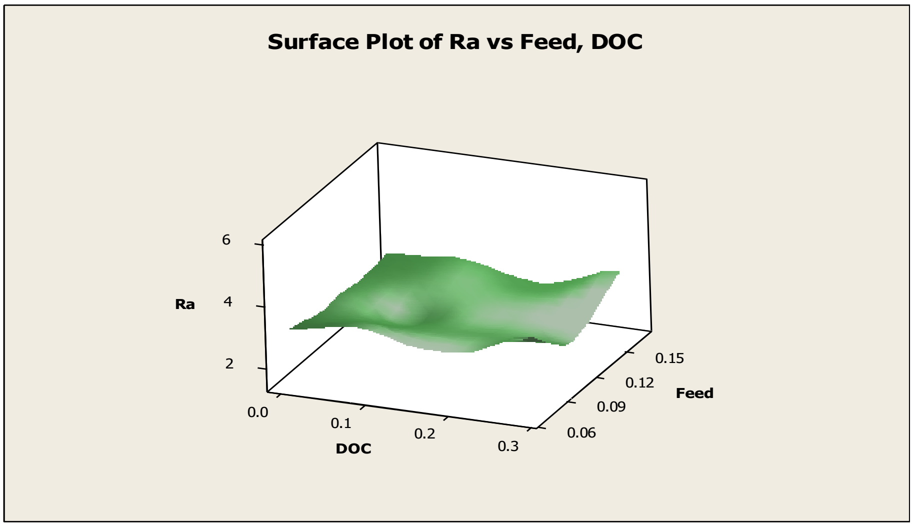


Figure 11: Surface roughness plot for Ra Vs feed and DOC

From Figure 11 it is observed that R_a increases with increase in DOC rate. Effect of feed is varying with change in DOC. So interaction between them is important. Lower surface roughness is found in higher feed.

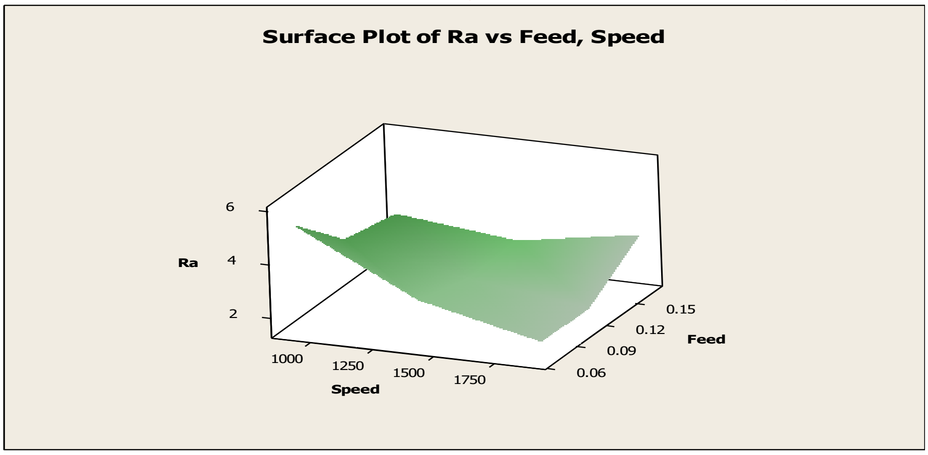


Figure 12: Surface roughness plot for Ra Vs feed and speed

From Figure 12 it is observed that highest speed and smallest feed has produced lowest roughness. Ra increases with increase in feed rate and decrease in spindle speed.

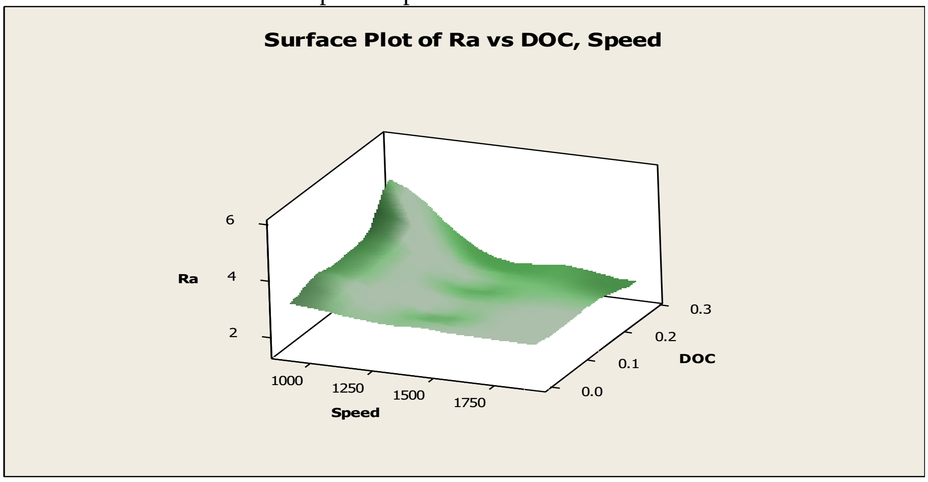


Figure 13: Surface roughness plot for Ra Vs DOC and speed

From Figure 13 it is observed that roughness increases with increase in spindle speed. Depth of cut has little effect on roughness.

Analysis of Surface Roughness (Rz) by Minitab:

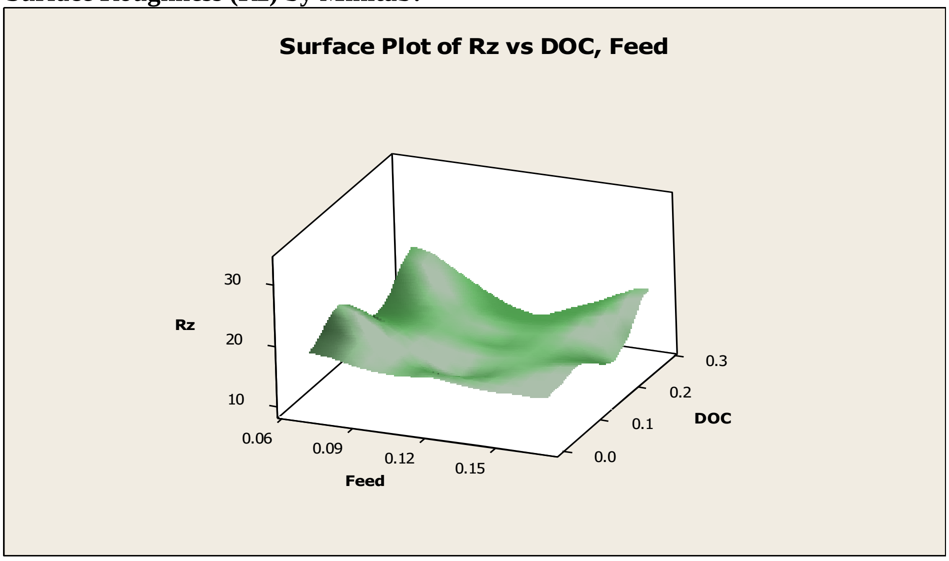


Figure 14: Surface roughness plot for Rz Vs feed and DOC

From Figure 14 it is observed that R_a increases with increase in DOC rate. Effect of feed is varying with change in DOC. So interaction between them is important. Lower surface roughness is found in higher feed.

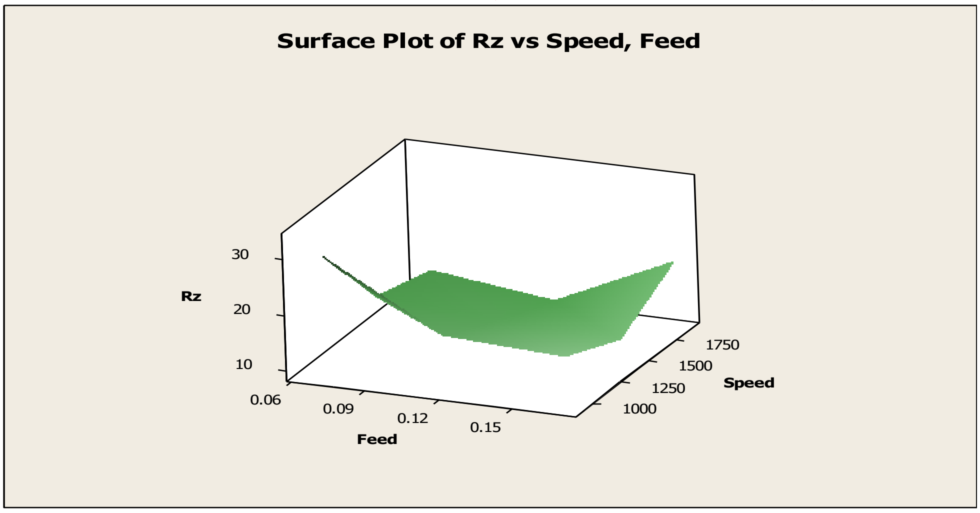
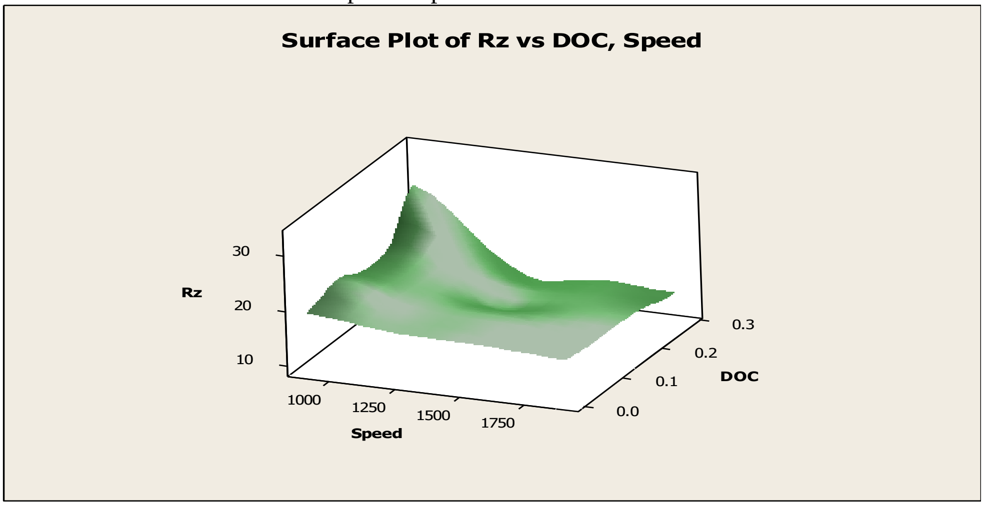


Figure 15: Surface roughness plot for Rz Vs feed and speed

From Figure 15 it is observed that highest speed and smallest feed has produced lowest roughness. Rz increases with increase in feed rate and decrease in spindle speed.



Figurer 16: Surface roughness plot for Rz Vs DOC and speed

From Figure 16 it is observed that roughness increases with increase in spindle speed. Depth of cut has little effect on roughness.

Optimization of Surface Roughness (Ra):

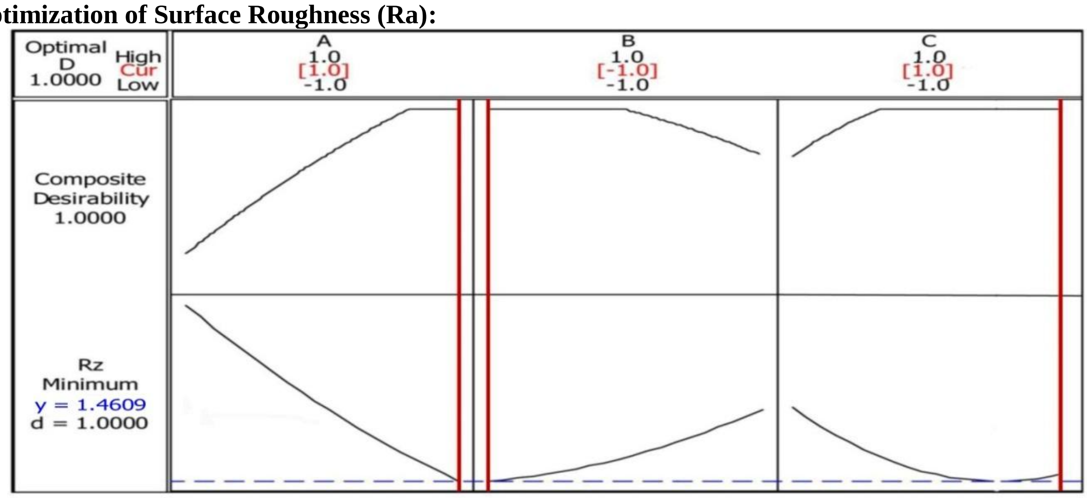


Figure 17: Optimization of surface roughness (Ra)

Response Optimization:

Parameters:

	Goal	Lower	Target	Upper	Weight	Import
Ra	Minimum	1.5279	1.5279	5.88459	1	1

Starting Point
A = 1
B = -1
C = 1
Local Solution
A = 1
B = -0.818182
C = 0.595960
Predicted Responses
Ra = 1.46089, desirability = 1.000000
Composite Desirability = 1.000000
Global Solution
A = 1
B = -0.818182
C = 0.595960
Predicted Responses
Ra = 1.46089, desirability = 1.000000
Composite Desirability = 1.000000

Optimization of Surface Roughness (Rz):

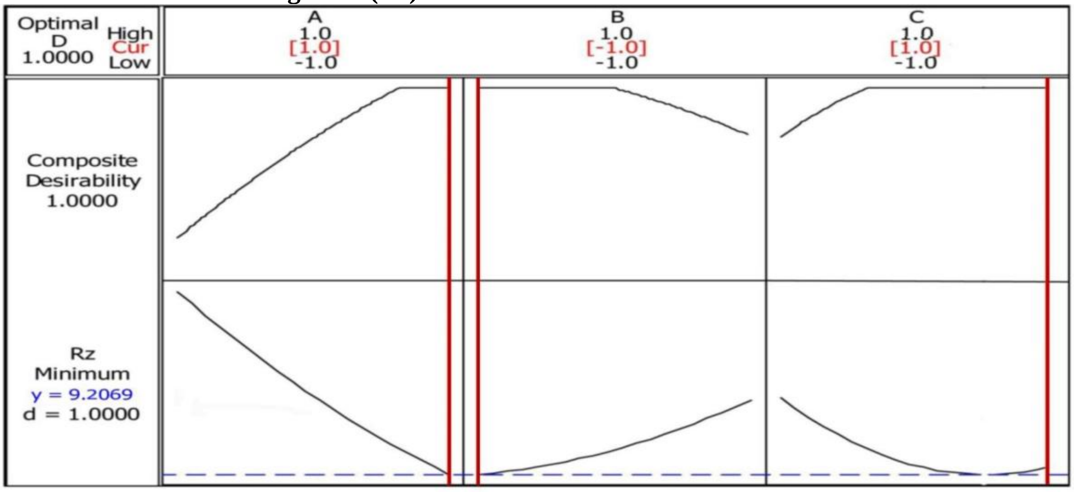


Figure 18: Optimization of surface roughness (Rz)

Response Optimization:

Parameters

	Goal	Lower	Target	Upper	Weight	Import
Rz	Minimum	9.5343	9.5343	33.2545	1	1

Starting Point
A = 1
B = -1
C = 1
Local Solution
A = 1
B = -1
C = 0.494949
Predicted Responses
Rz = 9.20690, desirability = 1.000000
Composite Desirability = 1.000000
Global Solution
A = 1
B = -1
C = 0.494949
Predicted Responses
Rz = 9.20690, desirability = 1.000000
Composite Desirability = 1.000000

Confirmation Test:

Table 10: Result of conformation test

S.No	Response	Unit	Response Value	
			Predicted	Experimental
1	Tool Wear	gm/min.	0.0000600	0.0000619
2	Surface Roughness (Ra)	Mm	1.46090	1.527900
3	Surface Roughness (Ra)	Mm	9.20690	9.53430

Confirmation test is done to check the adequacy of the developed RSM model and the experimental results thus found on the basis of optimized process parameters are given in table. It could be noticed that the predicted results are in acceptable zone with respect to the experimental results and thus it is concluded that the developed model seems to be satisfactory.

2. Conclusion:

Manufacturing processes like CNC high speed turning are heavily practised in almost all type of industry specifically in automotive industry, aeronautical industry etc. Thus it is very important to know the machining performance for a particular machining condition. In this investigation, responses were predicted for a set of machining parameters and also optimum machining conditions are evaluated considering each of the responses.

- ✓ During the present investigation, twenty no. of experiments are carried out. From the analysis of responses. it has been revealed that all the responses vary in the same nature with respect to the change in speed, feed rate and depth of cut.
- ✓ The measured results are satisfactory. Measurements are close to manual measurements which are done with a microscope for tool wear and stylus for surface roughness. However, the measurement system has problems when the wear on the tool has not yet formed properly. At current state, the measurement system, depending on cutting conditions, may require a few cuts, before the system can give reliable results.
- ✓ Experimental results show that the tool wear of the work materials are correlated with each other and influences of cutting parameters on surface roughness are given. These figures show that both responses are affected as same manner.
- ✓ The result of optimization considering the responses showed the optimum conditions for the responses with the optimum value. According to the optimization, developed model seems to be satisfactory because the predicted results are in acceptable range with respect to the experimental result.

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