Prediction of machining parameters for optimum Surface Roughness in turning SS 304

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B. Tech.

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By

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CERTIFICATE

This is to certify that the work in this thesis entitled **Prediction of machining parameters for optimum Surface Roughness in turning SS 304** by **Smrutiranjan Sahoo** has been carried out under my supervision in partial fulfillment of the requirements for the degree of **Bachelor of Technology** in *Mechanical Engineering* during session 2010- 2011 in the Department of Mechanical Engineering, National Institute of Technology, Rourkela.

To the best of my knowledge, this work has not been submitted to any other University/Institute for the award of any degree or diploma.

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Abstract

In any machining process, apart from obtaining the accurate dimensions, achieving a good surface quality is also of utmost importance. A machining process involves many process parameters which directly or indirectly influence the surface quality of the product. Surface roughness and waviness in turning process are caused due to various parameters of which feed, speed, depth of cut are important ones. A precise knowledge of these optimum parameters would facilitate reduce the machining costs and improve product quality. Extensive study has been conducted in the past to optimize the process parameters in any machining process to have the best product. Current investigation on turning process is a Taguchi optimization technique applied on the most effective process parameters i.e. feed, cutting speed and depth of cut while machining SS 304 as the work piece with brazed cutting tool. Main effect plots are generated and analyzed to find out the relationship between them. The details of experimentation and analysis are given in the following context.

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Chapter 1

1. INTRODUCTION

Technology is advancing, demand of the hour is increasing and to face that engineers are also ready. Maintaining the economic production with optimal use of resources is of prime concern for the engineers. Metal machining is one of them. In machining process, there are various parameters involved. Some challenges that the engineers come across are to find out the optimal parameters for the desired product quality and to maximize the performance of manufacturing using the available resources. In today's manufacturing industry, special attention is given to dimensional accuracy and surface finish. The surface quality is an important parameter to evaluate the productivity of machine tools as well as machined components. Surface roughness is used as the critical quality indicator for the machined surface. Formation of a rough surface is a complicated mechanism involving many parameters. The quality of the work piece (either roughness or dimension) are greatly influenced by the cutting conditions, tool geometry, tool material, machining process, chip formation, work piece material, tool wear and vibration during cutting [1]. Extensive effort has been done to observe the critical parameters which affect the surface roughness. This work aims at one such Taguchi optimization study of process parameters for surface roughness as the response.

On surfaces produced by machining and abrasive operations, the irregularities produced by the cutting action of tool edges and abrasive grains and by the feed of the machine tools are called surface roughness. It is the irregularity of primary texture. Roughness may be considered as being superposed on a wavy surface.

The maximum height or the roughness form produced by a single point cutting tool is given by

$$H_{max}=f^2/8R \qquad \text{(f=feed rate, R= nose radius) --------------------- (1)}$$

The CLA or centre line average value of surface roughness (R_a) (as per the BS-1134) is the arithmetical average of the departure of the whole of the profile both above and below its centerline throughout the prescribed meter cut-off in a plane substantially normal to the surface.

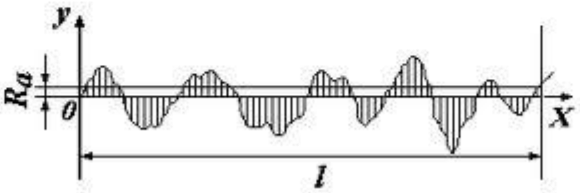


Fig. 1.1. Average surface roughness

R_z –the ten point averaged height of irregularities is the difference between the average height of five highest peaks and five lowest peaks within the sampling length *l* measured with respect to datum parallel to mean line.

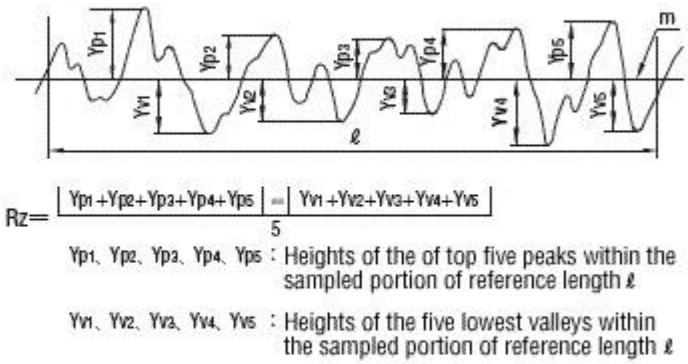


Fig. 1.2. Ten point averaged height of irregularities

Chapter 2

2. Literature review

As categorized in [2] the current study is a experimental approach that examines the effect of various parameters through the experiment and results. The experimental approach may be thought of as the most ‘obvious’ method: experiments with the factors that are considered to be the most important are conducted and the obtained results are used to investigate the effect of each factor as well as the influencing mechanism on the observed quality characteristic. Regression analysis is often employed in order to build models based on the experimental data. The researcher’s intuition and insight play a great role in this approach but a high understanding of the examined phenomenon is also necessary for the experiment to yield any meaningful results. The experimental approach is mainly adopted in cases where there can be no analytical formulation of the cause and effect relationships between the various factors.

J.P.Davim & V.N.Gaitonde in [3] presented the effect of feed rate, cutting speed & depth of cut on surface roughness by developing ANN models during turning of free machining steel using cemented carbide tools. The objective of ANN development is to imitate human brain so as to implement the functions such as association, self-organization and generalization.

The relationship between tool life, surface roughness and vibration was examined in Ref. [4]. The variables that were considered included the cutting speed, feed rate, depth of cut, tool nose radius, tool overhang, approach angle, work piece length and work piece diameter and the accelerations in both radial and feed directions. The acceleration signals were fed to an FFT analyzer that produced ASCII files. The experimental data were analyzed to produce regression analysis models.

Ghani and Choudhury [5] followed a similar approach in which the vibration signals were used to monitor tool wear and to verify the correlation between tool wear progression and surface roughness during turning. The experiments were conducted on nodular cast iron with ceramic tool, something that lead to very short tool life (approximately 1.5 min).

A series of experiments that aimed at determining the cutting speed for built-up-edge formation in turning was conducted in Ref. [6] and based on the experimental data two mathematical models which correlate surface roughness with cutting parameters were established. The first one included the effects of the cutting tool's nose radius, feed rate, cutting speed and depth of cut while the second added the effect of the material's hardness on surface finish. The most important terms were found to be the feed rate, tool's nose radius and cutting speed, in that order.

The relation between vibrations and surface generation was investigated in Ref. [7] for slab milling operations. Since the periodical microgroove structure that is generated by sequential engagement of the cutter teeth is the primary parameter of surface roughness, it was suggested that in a dynamic process, the different surface profiles would depend on the amplitude, frequency and phase of the relative motion between the workpiece and the cutting tool. The separate contribution of each of the cutter's teeth to the resulting surface profile was verified by conducting experiments with known vibrational characteristics.

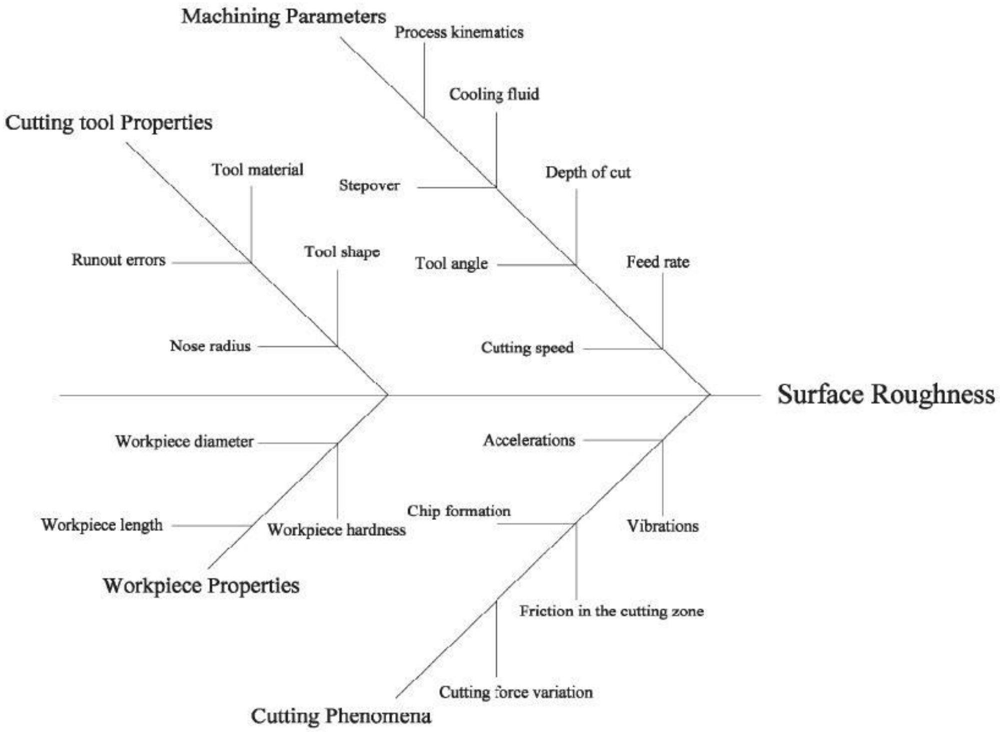


Fig. 2.1: fishbone diagram showing the parameters that affect the surface roughness

Chapter 3

3. Experimental Procedure

3.1 Taguchi method

The Taguchi method is a commonly adopted approach for optimizing design parameters. The method was originally proposed as a means of improving the quality of products through the application of statistical and engineering concepts. Since experimental procedures are generally expensive and time consuming, the need to satisfy the design objectives with the least number of tests is clearly an important requirement. The Taguchi method involves laying out the experimental conditions using specially constructed tables known as ‘‘orthogonal arrays’’. The use of these tables ensures that the experimental design is both straightforward and consistent [10]. Adopting the Taguchi approach, the number of analytical explorations required to develop a robust design is significantly reduced, with the result that both the overall testing time and the experimental costs are minimized. Taguchi’s philosophy [8], developed by Dr. Genichi Taguchi, is an efficient tool for the design of high quality manufacturing system. It is a method based on Orthogonal Array (OA) experiments, which provides much-reduced variance for the experiment resulting optimum setting of process control parameters. Orthogonal Array (OA) provides a set of well-balanced experiments (with less number of experimental runs), and Taguchi’s signal-to-noise ratios (S/N), which are logarithmic functions of desired output; serve as objective functions in the optimization process.

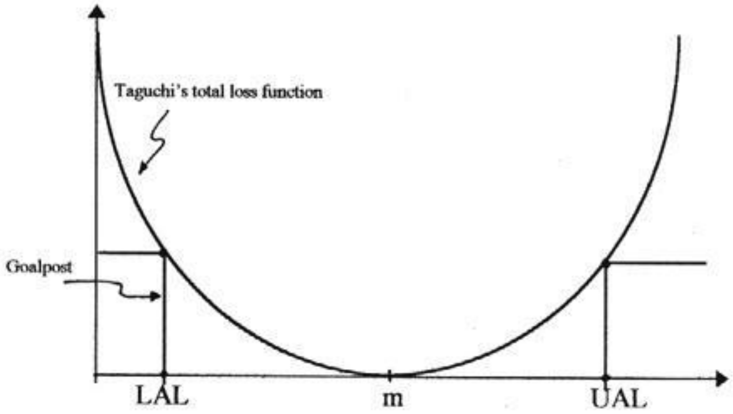


Fig. 3.1: Quality characteristic curve

This technique helps in data analysis and prediction of optimum results. In order to evaluate optimal parameter settings, Taguchi method uses a statistical measure of performance called signal-to-noise ratio. The S/N ratio takes both the mean and the variability into account. The S/N ratio is the ratio of the mean (Signal) to the standard deviation (Noise). The ratio depends on the quality characteristics of the product/process to be optimized. The standard S/N ratios generally used are as follows: - Nominal-is-Best (NB), lower-the-better (LB) and Higher-the-Better (HB). The optimal setting is the parameter combination, which has the highest S/N ratio.

The S/N ratio for minimum surface roughness coming under *smaller-is-better* characteristic, which can be calculated as logarithmic transformation of the loss function as shown below.

Smaller is the better characteristic: $\frac{S}{N} = -10 \log \frac{1}{n} \left(\sum y^2 \right)$ -------------------------------------- (3)

Where n is the number of observations, and y is the observed data. *Smaller-is-better* characteristic, with the above S/N ratio transformation, is suitable for minimization of surface roughness.

3.2 Present Problem

Design of experiment is a powerful analysis tool for modeling and analyzing the influence of control factors on performance output. The initial step in the Taguchi model development is to build up an input- output database required for the optimization through the turning experiments. In order to have a complete knowledge of turning process over the range of parameters selected, a proper planning of experimentation is essential to reduce the cost and time. Hence an experimental plan based on Taguchi orthogonal array (L_9) was chosen. The machining tests were conducted on a conventional lathe with a 6KW power. Stainless steel 304 (32mm dia) as the work piece and ISO 6R 1212 brazed cutting tool. Taking the stainless steel 304 rod, an initial roughing pass was given. Markings were done over the SS rod for machining. Taking the different set of cutting parameters as mentioned below, 27 observations were taken for analysis which was a full factorial design of experiments. From these 27 data points, the suitable L_9 array data points were chosen. With the finished product, the surface roughness values were measured. Proper precautions were taken while machining for the steady state process. For surface roughness measurement Handysurf: E- 35A/B was used.

Table 3.1: Machining parameters and their levels

Parameter	Unit	Level		
		1	2	3
Feed rate (f)	mm/rev	0.10	0.16	0.25
Cutting speed (v)	m/min	13.63	21.42	35.0642
Depth of cut (d)	mm	0.5	0.6	0.7

Table 3.2: Experimental layout plan of L_9 Taguchi orthogonal array

d	f	v
0.5	0.10	13.60
0.5	0.16	21.40
0.5	0.25	35.06
0.6	0.10	21.40
0.6	0.16	35.06
0.6	0.25	13.60
0.7	0.10	35.06
0.7	0.16	13.60
0.7	0.25	21.40

Cutting tool specifications:

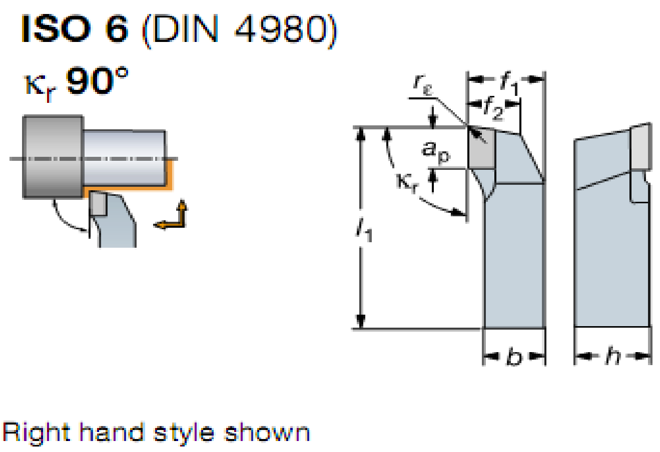
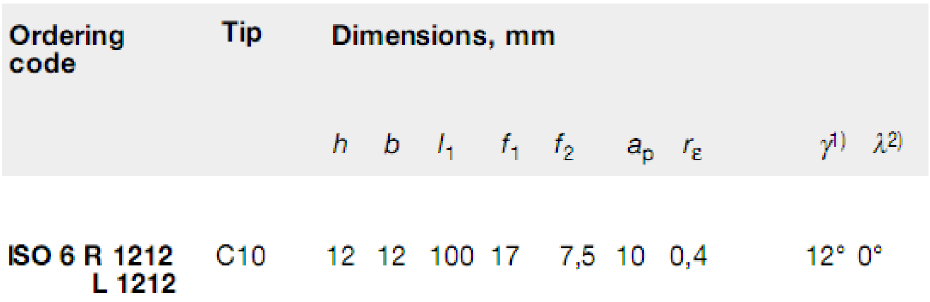


Fig. 3.2. cutting tool specifications



Ordering code	Tip	Dimensions, mm								
		h	b	l_1	f_1	f_2	a_p	r_ε	$\gamma^{1)}$	$\lambda^{2)}$
ISO 6 R 1212 **L 1212**	C10	12	12	100	17	7,5	10	0,4	12°	0°

Work piece: Stainless Steel 304, diameter 31mm

Table 3.3. Chemical Composition

%	SS 304
C	0.08 max
Mn	2.0
Si	0.75
P	0.045
S	0.03
Cr	18-20
Ni	10.5
N	0.1

Table 3.4. Mechanical Properties

Grade	SS 304
Tensile Strength (MPa)	520
Compression Strength (MPa)	210
Proof Stress 0.2% (MPa)	210
Elongation A5 (%)	45
Hardness Rockwell B	92

Table 3.5.Physical Properties

Property	Value
Density	8.00 g/cm^3
Melting Point	1400-1450°C
Modulus of Elasticity	193 GPa
Electrical Resistivity	0.072x10^{-6} Ω.m
Thermal Conductivity	16.2 W/m.K at 100°C
Thermal Expansion	17.2x10^{-6} /K at 100°C

-

Fig. 3.3. Experimental setup

Fig. 3.4. Finished product

Chapter 4

4. Results and Discussion

4.1 Observations

Table 4.1. Experimental layout plan of full factorial L_{27} Taguchi orthogonal array

Sl No	**Depth (mm)**	**Feed (mm/rev)**	**Speed (m/min)**	**R_a (μm)**	**R_z (μm)**
1	0.5	.1	13.6	1.89	9.22
2	0.5	.1	21.4	2.25	10.0
3	0.5	.1	35.06	1.62	8.09
4	0.5	.16	13.6	2.04	9.74
5	0.5	.16	21.4	2.08	8.61
6	0.5	.16	35.06	2.10	10.31
7	0.5	.25	13.6	1.68	8.67
8	0.5	.25	21.4	3.57	16.73
9	0.5	.25	35.06	5.3	24.0
10	0.6	.1	13.6	3.0	16.7
11	0.6	.1	21.4	2.8	14.7
12	0.6	.1	35.06	2.52	13.93
13	0.6	.16	13.6	5.5	29.7
14	0.6	.16	21.4	2.81	16.66
15	0.6	.16	35.06	3.2	16.4
16	0.6	.25	13.6	4.74	19.49
17	0.6	.25	21.4	5.15	21.32
18	0.6	.25	35.06	5.3	22.4
19	0.7	.1	13.6	5.9	28.2
20	0.7	.1	21.4	3.49	19.96
21	0.7	.1	35.06	3.8	17.32
22	0.7	.16	13.6	4.56	18.9
23	0.7	.16	21.4	2.1	16.5
24	0.7	.16	35.06	3.64	10.3
25	0.7	.25	13.6	3.50	17.32
26	0.7	.25	21.4	3.11	17.1
27	0.7	.25	35.06	3.10	12.53

Table 4.2. Design of experiment and response data (L_9 array) extracted from table 5.1

d	f	v	Ra	Rz
0.5	0.10	13.60	1.89	9.22
0.5	0.16	21.40	2.08	8.61
0.5	0.25	35.06	5.30	24.00
0.6	0.10	21.40	2.80	14.70
0.6	0.16	35.06	3.20	16.40
0.6	0.25	13.60	4.74	19.49
0.7	0.10	35.06	3.80	17.32
0.7	0.16	13.60	4.56	18.90
0.7	0.25	21.40	3.11	17.10

The Taguchi experiment which was conducted can be used to analyze the effects of the selected process parameters on surface roughness. In order to analyze the main effects, main effect plots were drawn manually from the full factorial design data & the same was again obtained from the optimization using MINITAB 14. From the S/N ratio calculation, it is clear that the feed has a significant effect on the surface roughness value as is given by the formula also i.e. $H_{max}=f^2/8R$. then comes the speed and then the feed.

Table 4.1. Roughness at different values of depth of cut from full factorial design data

	0.5	0.6	0.7
R @0.1f, 13.6v	1.89	3	5.9
R @0.16f, 21.4v	2.08	2.81	2.1
R @0.25f, 35.06v	5.3	5.3	3.1

Table 4.2. Roughness at different values of speed from full factorial design data

	13.6	**21.4**	**35.06**
R @0.5d, 0.1f	1.89	2.25	1.62
R @0.6d, 0.16f	5.5	2.81	3.2
R @0.7d, 0.25f	3.5	3.11	3.1

Table 4.3. Roughness at different values of feed from full factorial design data

	0.1	**0.16**	**0.25**
R @0.5d, 13.6v	1.89	2.04	1.68
R @0.6d, 21.4v	2.8	2.81	5.15
R @0.7d, 35.06v	3.8	3.64	3.1

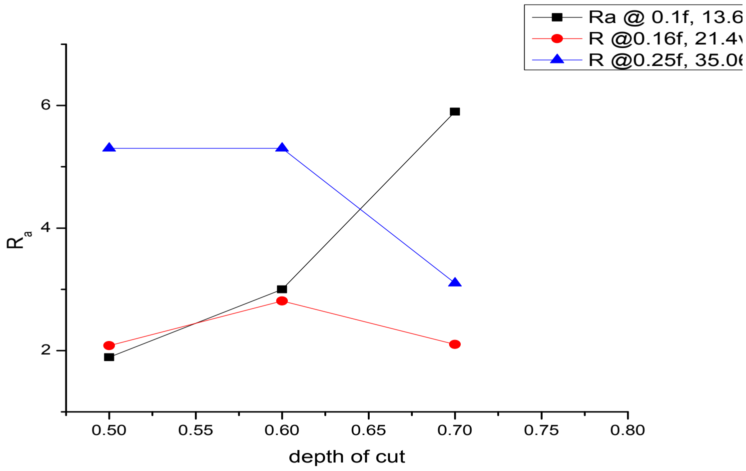


Fig. 4.1. Main effect plots from full factorial design R_a Vs depth of cut

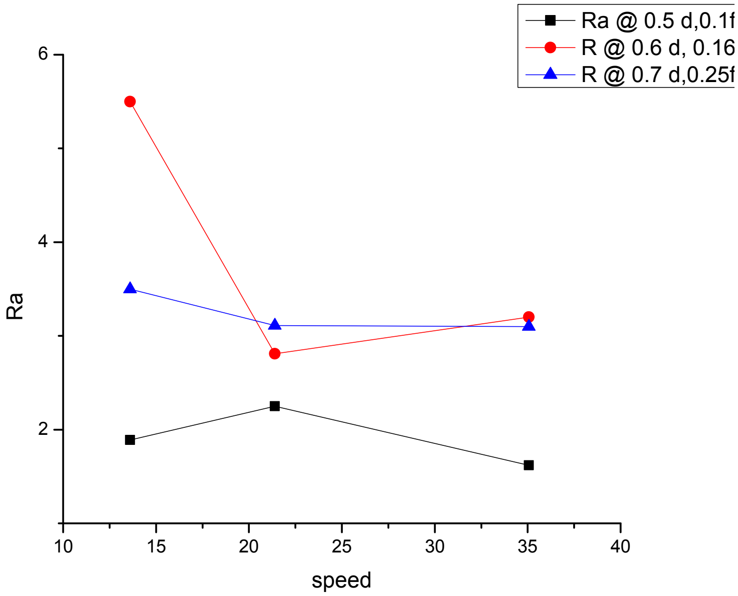


Fig. 4.2. Main effect plots from full factorial design R_a Vs speed

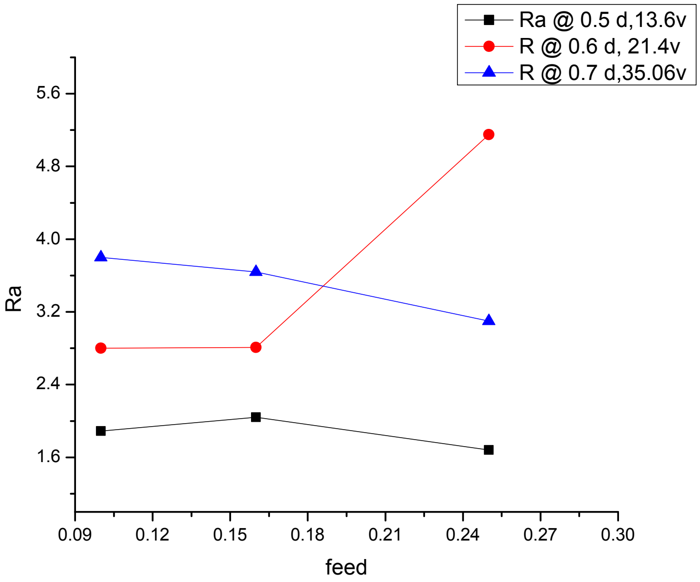


Fig. 4.3. Main effect plots from full factorial design R_a Vs feed

From the main effects plot, it is clear that, the minimal surface roughness results with combination of low feed rate & high cutting speed. When depth of cut is low, surface roughness is highly sensitive to cutting speed however this reduction becomes smaller and smaller with the higher values of depth of cut. It is also observed that at higher values of cutting speed, roughness varies negligibly with the variation of depth of cut.

Table 4.4. Response Table for Signal to Noise Ratios of Ra

Smaller is better

Level	d	f	v
1	-8.7920	-8.6894	-10.7414
2	-10.8539	-9.8812	-8.3865
3	-11.5434	-12.6188	-12.0614
Delta	2.7514	3.9294	3.6749
Rank	3	1	2

S/N ratio (Ra)
-5.5292
-6.3613
-14.4855
-8.9432
-10.1030
-13.5156
-11.5957
-13.1793
-9.8552

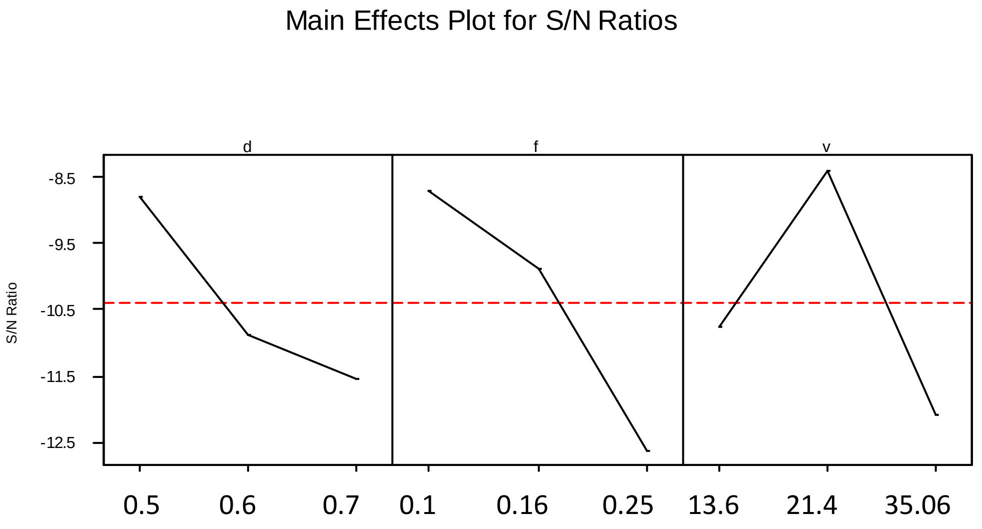


Fig. 4.4. main effect plots for S/N ratios of speed, feed & depth of cut of R_a

Table 4.5.Response Table for Signal to Noise Ratios (Rz)

Smaller is better

Level	d	f	v
1	-21.8663	-22.4706	-23.5400
2	-24.4798	-22.8421	-22.2354
3	-24.9867	-26.0201	-25.5574
Delta	3.1204	3.5495	3.3219
Rank	3	1	2

S/N ratio (Rz)
-19.2946
-18.7001
-27.6042
-23.3463
-24.2969
-25.7962
-24.7710
-25.5292
-24.6599

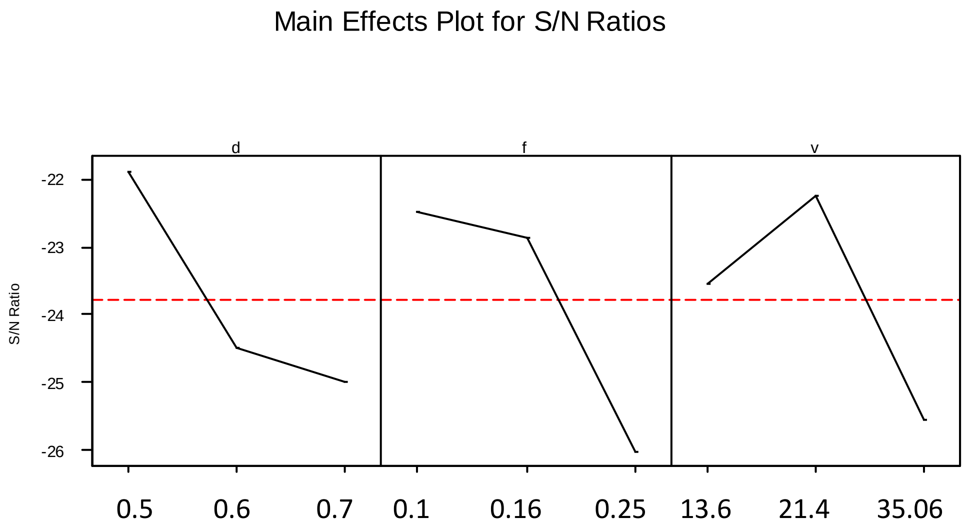


Fig. 4.5. main effect plots for S/N ratios of speed, feed & depth of cut of R_z

Above discussion shows that the surface roughness varies very quickly as feed rate varies and with cutting speed. On the other hand, depth of cut has very less effect on surface roughness. Roughness remains low as we increase cutting speed &decrease feed rate. Presence of coolant would enhance the surface quality.

Chapter 5

5. Conclusion

The present investigation aimed at optimization of surface roughness during turning of SS 304 work piece with a brazed tool. This analysis was carried out by developing surface roughness models of R_a & R_z based on L_9 orthogonal array in Taguchi optimization technique. Main effect plots were drawn manually & also using Taguchi design & compared with each other. It draws the following conclusions.

Surface roughness & the cutting parameters have highly non-linier relationships among them. The surface roughness is very sensitive to feed rate & speed. Depth of cut has least effect on roughness. The optimized main effect plots and the manually drawn plots show a close similarity between them. The minimal surface roughness is obtained at a combination of d_1(0.5 mm), f_1 (0.1 mm/ rev), & V_2 (21.4 m/min).

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