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Experimental Study of the Effects of Machining Parameters on the Surface Roughness in the Turning Process

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Abstract: - In this work, experiments are carried out to study the effect of cutting parameters cutting speed, feed rate, and depth of cut on surface roughness during dry turning of 40C8. The objective of this study is to build multiple regression models for a better understanding of the effects of spindle speed, feed and depth of cut on the surface roughness. Full factorial design of experiments corresponding to trials was followed for the experimental design. Analysis of variance determines the contribution of each factor on the output. It is found that feed rate is the most influencing parameter affecting the surface roughness (44.13%) and is followed by cutting speed and depth of cut. The developed predicted model, which includes the effect of spindle speed, feed rate an extent h decrease t and any two-variable interactions, gives an accuracy of about 91.91 %. This study is helpful for understanding and controlling effect of cutting parameters on the surface finish of machined surfaces in dry turning operation.

Keywords: Surface Finish; ANOVA; Regression, Surface Roughness; Turning, SN ratio.

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1. Introduction

Nowadays, due to the increasing demand for higher precision components for its functional applications, the surface roughness of a machined part plays a vital role in the modern manufacturing process. Turning is a machining operation, which is carried out on the lathe. The quality of the surface decides the performance of turning. Fatigue strength, corrosion resistance and creep life significantly improve by a good quality turned surface. Surface roughness also affects several functional attributes of parts, such as contact causing surface friction, wearing, light reflection, heat transmission, the ability to distribute and holding a lubricant, load-bearing capacity, coating or resisting fatigue. Therefore, it is necessary to select the appropriate processes to reach the required quality and is usually specified by desired finish surface. A good predictive model is required to achieve the desired surface finish, for stable machining. Generally, these models have a complicated relationship between surface roughness and cutting parameters [1].

Effects of cutting speed, feed rate and depth of cut on surface roughness were investigated by applying the statistical methods of the signal to noise ratio and the analysis of variance (ANOVA). Hence a systematic study to understand the effect of different cutting parameters like speed, feed and depth of cut need to be undertaken. The optimum cutting parameters for minimum surface roughness in the metal machining industries is obtained by developed model [2].

Prediction models were created using second-order multiple regression methods. The model provided good prediction accuracy with a mean absolute error of 3.47% for surface roughness and 6.8 % for the cutting forces. The proposed model is capable of predicting the surface roughness and cutting troops with reasonable accuracy. The statistical analysis and multiple regression modelling predictions were performed on MINITAB 16 [3].

Among the four turning parameters of nose radius, cutting speed, feed rate and depth of cut, changes to the feed rate have the most significant impact on workpiece surface roughness, followed by nose radius, cutting speed and the bottom of cut [4].

Regression Analyses technique is used to study the effect of these parameters and their interaction on surface roughness. An empirical equation is formed by using Regression Analyses in MINITAB software to predict the surface roughness. On surface roughness, the effect of feed rate is more considerable than cutting speed [5].

The quadratic mathematical models allow prediction of surface roughness parameter with a 96% confident interval was obtained by the result of ANOVA [6].

A model is generating to predict surface roughness using regression technique. Also, an attempt has been made to optimise the process parameters using Taguchi technique, S/N ratio and ANOVA. Speed has a more significant influence on the surface roughness followed by feed. The depth of cut had the least impact on Surface Roughness [7]

An experimental investigation of the end milling of M.S material up to 30 HRC with carbide tool by varying feed, speed and depth of cut and the surface roughness was measured using Mitutoyo surface roughness tester. Surface roughness increase as feed rate increase [8].

A full factorial design is executed for the carried out experiment. Analysis of variances shows that the most significant parameter is feed rate followed by spindle speed and lastly depth of cut. Average percentage error is calculated after the predicted surface roughness has been obtained by using both methods. The multiple regression methods used for developing mathematical model shows the accuracy of 86.7%. It is found that this method is reliable to be used in surface roughness prediction [9].

The Taguchi method is used to find the optimal cutting parameters for surface roughness in turning. The performance characteristics in turning operations were studied by the orthogonal array, the signal-to-noise ratio, and analysis of variance [10].

The quality of design can be improved by improving quality and productivity in company-wide activities. A simple and systematic approach to optimise a design for performance, quality and cost are obtained by Taguchi's parameter design for robust design. The productive performance output and machining conditions were found out by effectively by the Taguchi method [11-12].

A technique is required to predict the surface roughness of a product before turning. The robustness of machining parameters such as feed rate, spindle speed and depth of cut evaluated for keeping the desired surface roughness and increasing product quality. It is also essential that the prediction technique should be accurate and reliable.

The models are developed by researchers in this area which can predict the surface finish of metal for a variety of machining conditions such as speed, feed, depth of cut, etc. Reliable model simplifies a manufacturing process planning and control. The model also assists in optimising machinability of materials. Therefore, the purpose of this study is (1) To study the effect of cutting parameters on the surface finish of the machined surfaces, (2) To develop one surface prediction model which is termed the regression prediction model and (3) To evaluate prediction accuracy of the model.

2. Methodology

2.1. Experiment Design

The effects of several cutting parameters of the process parameters (spindle speed, feed rate and depth of cut) and their interactions on the surface finish of the machined surface have been investigated by carrying out the experiments. An experiment involving two or more factors can affect the response individually or interactively. At a time of experimentation, the experimental design does not give an idea about the interaction effects of the elements as in the case of one item. All possible factor level combinations experiments conducted in entirely randomised designs are especially useful for testing the interaction effect of the factors. Completely randomised designs are appropriate when there are no restrictions on the order of the testing to avoid systematic biases error due to the wear of the cutting tool. The procedure to define a model of the process includes the following steps:

1. Selecting the cutting parameters to be involved in the process and choosing the levels of settings.
2. Experiments are conducting at all possible factor level combinations randomly.
3. The collected data is analysed using parametric analyses of variance (ANOVA).
4. Constructing the regression model.
5. Validation of the model.

2.2. Experimental Procedure

Experiments were carried out on a Panther 1350 Lathe under different cutting conditions are shown in Fig. 1. Machining tests were performed on a 40C8 bar having diameter Φ15 mm. High-speed steel (HSS) tool was used. The experiment has been done under dry machining environment. The cutting parameters were set as four levels of spindle speed (192, 256, 384, 512 rpm), three levels of feed rate (0.065, 0.13, 0.26 mm/rev), and three levels of depth of cut (0.5, 1.0, 1.5 mm). The surface roughness Ra measured was the response variable.

Figure 1: Turning operation

A close control on several variables including the machine on which turning operation was performed (the same tool was used for all experimental work), and the operator (the same operator machined all specimens). 36 machining conditions defined by the levels of independent variables (4 spindle speeds ×3 cutting feeds × 3 depths of cut) and the surface roughness data were collected for each of the experiment. Surface roughness is measured by Mitutoyo SJ-210 Series 178 portable surface roughness tester as shown in Fig. 2. It combines high accuracy and measurement speed. Transverse tracing type of drive unit is provided to the examiner.

Figure 2: Surface roughness measurement

2.3. Building the Regression model

The proposed regression model is a two-way interaction equation:

Y = C + B1 X1 + B2 X 2 + B3 X 3 + B12 X1 X 2 + B13 X1 X 2 + B23 X 2 X 3 (1)

where

Y: Surface roughness in µm

X1: spindle speed in rpm

X2: Cutting feed in mm/rev

X3: depth of cut in mm

Surface Roughness (Ra) =
0.00073 Cutting speed + 41.21 Feed + 3.36 Depth of cut
- 0.0451 Cutting speed*Feed
- 0.00266 Cutting speed*Depth of cut
- 4.11 Feed* Depth of cut

The surface roughness (Ra) is the response variable, and the predictor variables are spindle speed, feed rate and depth of cut in this model. These variables control machining parameters; they can be used to predict the surface roughness in turning which will the enhance product quality.

A commercial statistical package MINITAB 17 was used to do the regression analysis. Percentage deviation φi and average percentage deviation φ and the multiple regression prediction models were used to predict the accuracy and defined as

$$\emptyset_i = \frac{|R_{aim}-R_{aip}|}{R_{aim}} \times 100\ \% \qquad (2)$$

Where φ_i: Percentage deviation of single sample data.

R_{aim}: Measured surface roughness.

R_{aip}: Predicted surface roughness generated by a regression model.

$$\bar{\emptyset} = \frac{\sum_{i=1}^{n} \emptyset_i}{n} \quad (3)$$

where $\bar{\varphi}$: average percentage deviation of all sample data

n: the size of sample data

This approach would enable to compare the average percentage deviation of actual R_a (measured by a surface roughness tester) and predicted R_a (produced by the regression model).

3. Results and Discussion

Total 36 experiments were carried out, and surface roughness was measured by using surface roughness tester to obtain the roughness average value Ra. All 36 experiments are cutting parameter details which were used to test the accuracy and the validity of the regression model as shown in Tables 1.

Table 1: Cutting parameter and its effect on the surface finish

Exp. No.	Cutting speed (rpm)	Feed (mm/rev)	Depth of cut (mm)	Surface Roughness (µm)
1	192	0.065	0.5	3.9
2	192	0.065	1	4.34
3	192	0.065	1.5	4.87
4	192	0.13	0.5	7.71
5	192	0.13	1	7.86
6	192	0.13	1.5	9.71
7	192	0.26	0.5	11.52
8	192	0.26	1	11.96
9	192	0.26	1.5	12.98
10	256	0.065	0.5	4.01
11	256	0.065	1	4.86
12	256	0.065	1.5	6.27
13	256	0.13	0.5	4.71
14	256	0.13	1	6.03
15	256	0.13	1.5	7.73
16	256	0.26	0.5	5.42
17	256	0.26	1	6.53
18	256	0.26	1.5	8.59
19	384	0.065	0.5	2.74
20	384	0.065	1	3.55
21	384	0.065	1.5	3.78
22	384	0.13	0.5	1.78
23	384	0.13	1	1.92
24	384	0.13	1.5	4.25
25	384	0.26	0.5	7.72
26	384	0.26	1	7.93
27	384	0.26	1.5	8.19
28	512	0.065	0.5	2.76
29	512	0.065	1	4.03
30	512	0.065	1.5	5.62
31	512	0.13	0.5	3.85
32	512	0.13	1	4.67
33	512	0.13	1.5	5.48
34	512	0.26	0.5	6.68
35	512	0.26	1	6.83
36	512	0.26	1.5	6.89

The data collected were analyzed using analyses of variance (ANOVA) and SN ratio with surface finish as the response variable and spindle speed N, cutting feed F and depth of cut D as cutting parameters. The ANOVA model was developed to study the main effects of the independent variables and interactions of two variables and given in Table 2. The significance level was based on the P-value from ANOVA as

Insignificant if $P > 0.10$

Mildly significant if $0.05 < P < 0.10$

And

Significant if $P < 0.05$ (4)

Table 2: Analysis of variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
N	3	70.347	23.4490	92.01	0.000
F	2	112.179	56.0896	220.08	0.000
D	2	19.892	9.9458	39.02	0.000
N*F	6	45.241	7.5402	29.59	0.000
N*D	6	2.268	0.3779	1.48	0.264
F*D	4	1.239	0.3098	1.22	0.355
Error	12	3.058	0.2549		
Total	35	254.224			

A statistical model was created from the data. The R Square showed that the independent variables could explain 79.62 % of the observed variability in surface roughness R_a. The correlation between the perceived value of the dependent variable and the predicted values based on the regression model and was high. The amount of multiple R was 0.9597.

The multiple regression equation could be expressed as:

$$R_a = 0.00073N + 41.21F - 3.36D - 0.0451N \times F - 0.00266N \times D - 4.11F \times D \quad (5)$$

The graph of a relation between the observed Ra and the predicted R_a of all 36 samples as shown in Fig. Three indicated that the relationship between the actual R_a and the anticipated R_a was linear.

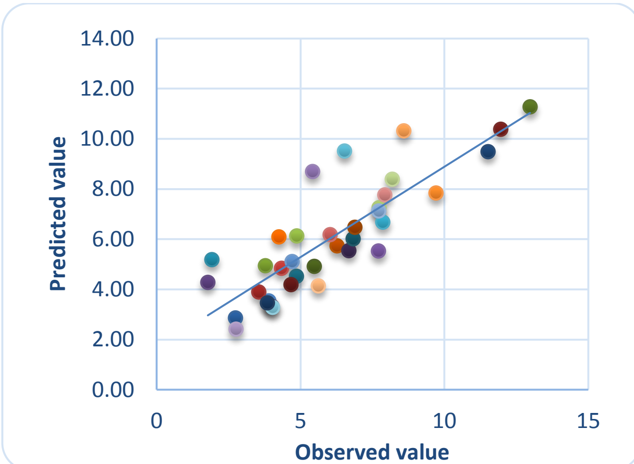

Figure 3: Observed Ra and the predicted R_a

The result of average percentage deviation (φ) of 36 experiments was 8.09 %. This indicates that the statistical model of the experimental data could predict the surface roughness (R_a) with about 91.91 % accuracy. The study showed that All main factors and their interactions were highly significant (P<0.05).

The main effect plot for means and SN ratio is given in Fig. 4 and Fig. 5 respectively. The SN ratio is calculated for lower the better. Fig. 4 and Fig. 5 shows that maximum surface roughness obtained at cutting speed 384 rpm, feed 0.065 and depth of cut 0.5.

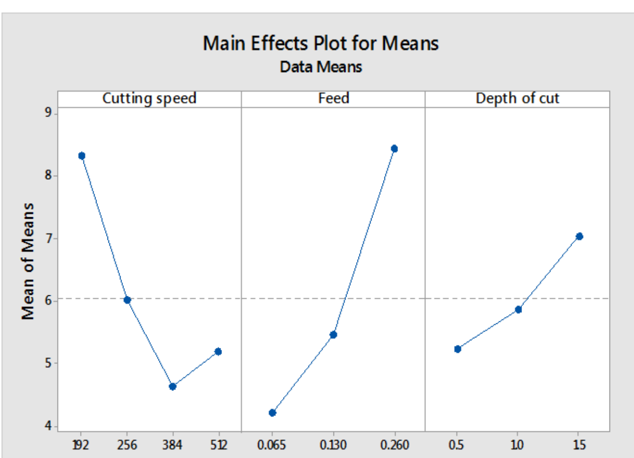

Figure 4: Main effect plot for means

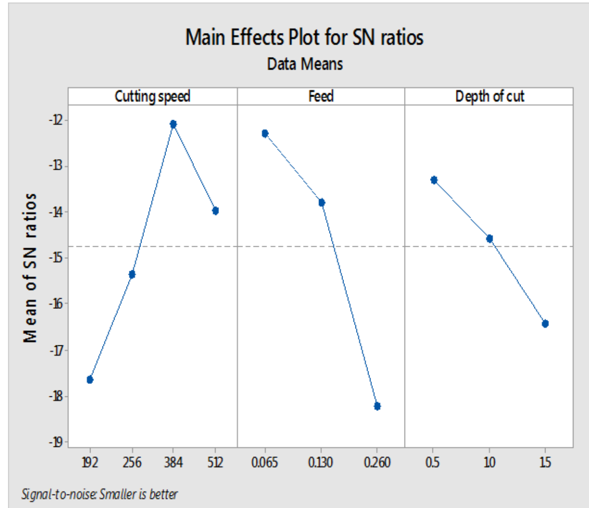

Figure 5: Main effect plot for SN ratios

The individual effects and their interactions of various factors as can be discussed from the Pareto chart shown in Fig. 6. The contribution of the single parameter and their interaction is shown in the chart. The effects of all parameters and interactions terms are calculated (its standard error divides each effect). The order of result displayed corresponds to the order of the contribution of the impact on surface roughness.

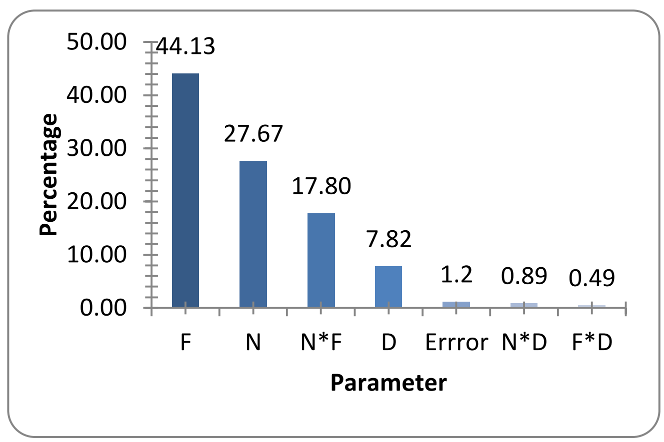

Figure 6: Contribution of parameters on surface roughness

The numerical estimates of the effects indicate that the impact of feed is the largest (44.13%) and the surface finish deteriorated with increasing the cutting feed. As the cutting feed increases the distance between the successive grooves made by the tool during the cutting action increases, which results in the deterioration of surface finish with expanding the cutting feed which is shown in Fig 4.

The effect of spindle speed 27.67% and is shown in Fig. 6. Increasing the spindle speed improves the surface finish. It is generally well known that an increase in cutting speed enhances surface roughness. The surface roughness decreases from 192 rpm to 384 rpm and then increases up to 512 rpm. This may be due to the built-up edge formation decreases as the cutting speed increases.

The interaction between the cutting speed and feed significantly affects the surface roughness, and its contribution is 17.80 %. The communication also suggests that to get a particular surface finish it is preferable to use a high cutting speed associated with the low feed.

The depth of cut has also effect on surface roughness, and it is 7.82 %. Surface roughness increases with increase in thickness of cut. The effect of the depth of cut is less significant on the surface finish as shown in Fig. 6.
The interaction between the depth of cut and spindle speed and depth of cut and feed is less significant as shown in Fig. 6.

4. Conclusion

A series of experiments have been conducted to begin to characterise the factors affecting surface roughness for the turning process. The effect of spindle speed, feed rate, depth of cut on the surface roughness of 40C8 was studied. The model generated, which includes the impact of spindle speed, feed rate, depth of cut, and any two-variable interactions, predicts surface roughness reasonably well. The machining parameters investigated influenced the surface finish of the machined workpiece significantly.

- In general, the study shows that feed is the most dominant factor of those studied and is followed by cutting speed and depth of cut.
- The most critical interactions that affect surface roughness of machined surfaces were between the cutting speed and feed.
- Optimum surface roughness obtained at cutting speed 384 rpm, feed 0.065 and depth of cut 0.5.
- The predictive model could predict the surface roughness (Ra) with about 91.91 % accuracy

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