ASSESSMENT OF SURFACE ROUGHNESS MODEL FOR TURNING PROCESS

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Abstract: The quality surface of an engineering component plays an important role in its performance. This research focuses on developing an empirical model for prediction of surface roughness in finish turning. The model considers the following working parameters: feed, depth of cut, and spindle speed. Nonlinear regression analysis, with logarithmic data transformation is applied in developing the empirical model. Metal cutting experiments and statistical tests demonstrate that the model developed in this research produces smaller errors and has a satisfactory result.

Key words: surface roughness model, finish turning, prediction

1. INTRODUCTION

Surface roughness has received serious attentions for many years. It has formulated an important design feature in many situations such as parts subject to fatigue loads, precision fits, fastener holes and esthetic requirements. In addition to tolerances, surface roughness imposes one of the most critical constraints for selection of machines and cutting parameters in process planning. A considerable number of studies have investigated the general effects of the speed, feed, depth of cut, nose radius and others on the surface roughness.

A popularly used model for estimating the surface roughness value is as follows (Groover 1996) and (Boothroyd and Knight 1989):

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$$R_i = \frac{f^2}{32r} \quad (1)$$

Where,

R_i: ideal arithmetic average (AA) surface roughness (mm)

f: feed (mm/rev)

r: cutter nose radius (mm)

This model assumed a none zero nose radius. The surface roughness models developed by Dickinson (1968), Fischer and Elrod (1971) considered the effect of feed rate and nose radius based on the motion geometry in a turning process, which provided the base for Equation (1). These models concluded that the effect of cutting speed is insignificant. However, different conclusions were presented in Shaw (1966), Hasegawa et al. (1976), Sundaram and Lambert (1979), Boothroyd and Knight (1989), Feng (2001), and Feng and Hu (2001). They demonstrated that cutting speed had a significant impact on surface roughness. The depth of cut was considered by Karmakar (1970), and Sundaram and Lambert (1981). Miller et al. (1983) considered the effect of cutting fluid on surface roughness. Although a qualitative analysis of machining variables of speed, feed and depth of cut on the surface roughness has been widely available in the literature, very few comprehensive predictive models have been developed. In this paper, an empirical surface roughness model, for high carbon steel, HRC40, will be developed based on metal cutting results from factorial experiments. The model will include the feed, depth of cut, and spindle speed. Regression analysis will be used to develop the models, and hypothesis testing will be conducted to validate the models.

2. SURFACE ROUGHNESS MODELS

L. Huang and J. Chen, 2001, applied a multiple regression modeling to express the surface roughness in the following form:

$$\begin{aligned} R = \beta_0 + \beta_S S + \beta_F F + \beta_D D + \beta_V V + \beta_{SF} SF + \beta_{SD} SD \\ + \beta_{SV} SV + \beta_{DF} DF + \beta_{DV} DV + \beta_{FV} FV + \beta_{SDF} SDF \\ + \beta_{SDV} SDV + \beta_{SFV} SFV + \beta_{DFV} DFV + \beta_{SDFV} SDFV \end{aligned} \quad (2)$$

This formula is very complicated and cumbersome. In this work a simpler model is proposed in the form:

$$SR = \lambda S^{\alpha} F^{\beta} D^{\gamma} \tag{3}$$

Where: SR, surface roughness (micron).
λ , α, β, γ: constants.
S: spindle speed (rpm).
F: feed rate (mm/rpm).
D: depth of cut (mm).

3. EXPERIMENTAL DESIGN

A factorial experiment was carried out to estimate the values of the regression coefficients. A 3 factors full factorial experiment design was utilized to investigate the significant of the turning parameter and estimation of mathematical model coefficients. A carbide tool was used to machine a high carbon steel workpiece (HCR40) on a Colchester lathe (Master 2500) without any coolant. Table 1 shows the factorial design of the experimentation.

Table 1. Experimental Factors and levels

Run	Speed (rpm)	Feed (mm/rpm)	Depth of cut (mm)	Actual surface roughness (µm)	Predicted surface roughness (µm)
1	570	0.03	0.25	1.75	2.09
2	1030	0.05	0.50	2.41	1.74
3	770	0.03	1.00	2.16	2.11
4	770	0.05	0.25	2.25	1.94
5	770	0.04	0.50	2.51	2.05
6	1030	0.05	0.25	2.08	1.54
7	1030	0.04	0.25	2.08	1.44
8	1030	0.03	0.25	1.34	1.32
9	770	0.05	1.00	3.13	2.47
10	570	0.04	0.25	2.89	2.29
11	570	0.04	0.50	2.56	2.58
12	570	0.05	0.50	2.08	2.77
13	1030	0.04	0.50	2.14	1.63
14	770	0.05	0.50	2.20	2.19
15	570	0.03	1.00	2.80	2.67
16	770	0.03	0.25	2.41	1.66

17	770	0.04	1.00	2.44	2.31
18	570	0.05	1.00	4.57	3.12
19	770	0.03	0.50	2.23	1.87
20	570	0.03	0.50	2.20	2.36
21	1030	0.04	1.00	1.63	1.83
22	570	0.05	0.25	3.19	2.45
23	770	0.04	0.25	1.86	1.81
24	1030	0.03	0.50	1.67	1.49
25	1030	0.03	1.00	2.66	1.68
26	570	0.04	1.00	3.06	2.92
27	1030	0.05	1.00	3.49	1.96

After completing the experiments an analysis of variance (ANOVA) was conducted to discern whether differences in surface roughness between various runs were statistically significant.

Table 2 presents ANOVA results for experimental data generating during turning the high carbon steel workpiece. The Model F-value of 20.15 implies the model is significant. There is only a 0.01% chance that a "Model F-Value" this large could occur due to noise.

Values of "Prob > F" less than 0.0500 indicate model terms are significant. In this case A (speed), B (feed), and C (Depth of cut) are significant model terms. Values greater than 0.1000 indicate the model terms are not significant.

Table 2. Analysis of variance [Partial sum of squares]

Source	Sum of Squares	DF	Mean Square	F Value	Prob > F	
Model	1.33	3	0.44	20.15	< 0.0001	significant
A	0.95	1	0.95	43.29	< 0.0001	
B	0.11	1	0.11	5.10	0.0338	
C	0.27	1	0.27	12.05	0.0021	
Residual	0.51	23	0.022			
Cor Total	1.84	26				

Accordingly, the exponential model coefficients for surface roughness were given and the mathematical model will be as follows:

$$SR = 1113.5S^{-0.78}F^{0.3}D^{0.18} \tag{4}$$

Fig. 1 below shows how the prediction model match up to the actual experiments data.

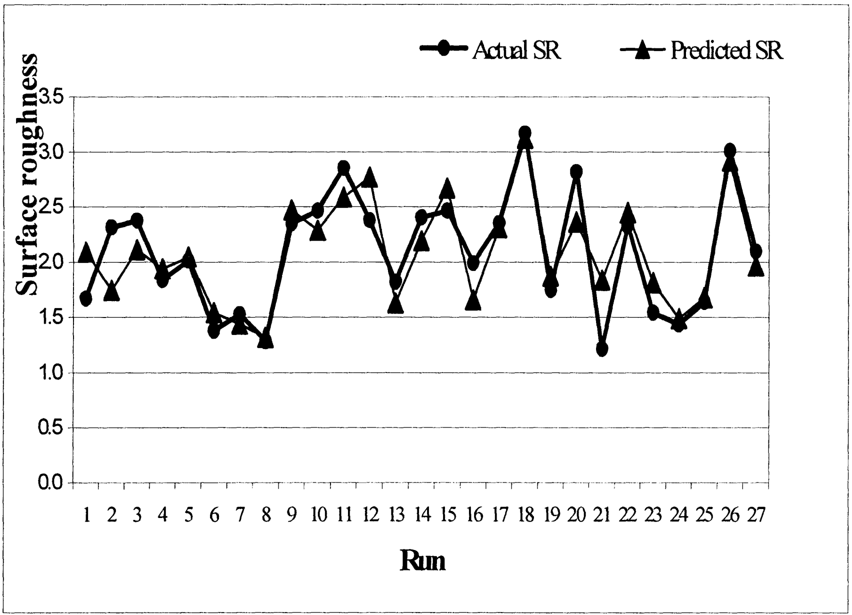

Figure (1) : Predicted versus actual surface roughness

4. CONCLUSION

1. The smallest values of surface roughness were produced when the material was machined with a smaller feed.
2. All cases showed that a higher speed would smooth the surface within the range of experiments.
3. A logarithmic transformation can be applied to convert the nonlinear form of Equation (3) into the additive (linear) form. This is one of the most popularly used data transformation methods in empirical model building (Box and Draper 1987).
4. The mathematical model, equation (4), can reasonably predicted the surface roughness within the range of machining parameters used in the experimentations

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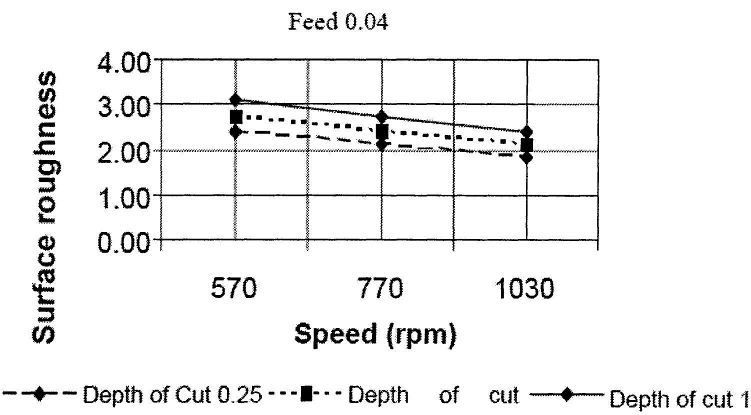
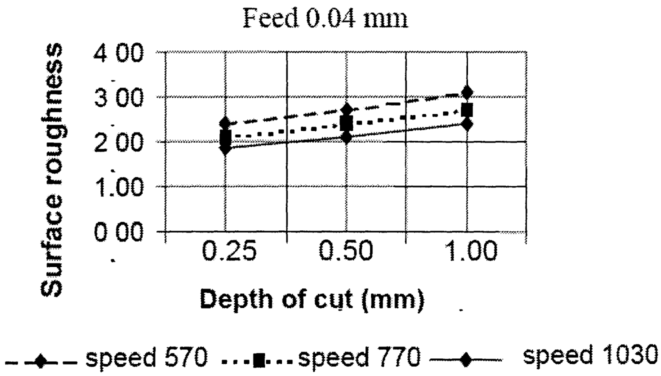
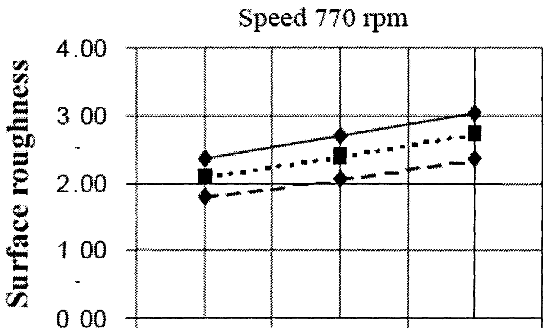
6. APPENDIX




Feed 0.04 mm
Surface roughness
4 00
3 00
2 00
1.00
0 00
0.25
0.50
1.00
Depth of cut (mm)
speed 570
speed 770
speed 1030


Speed 770 rpm
Surface roughness
4.00
3 00
2.00
1 00
0 00