Prediction of Al and Cu Surface Roughness Based Regression Analyses Model

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The advancement in automation and accuracy of machine tool made it possible to produce high quality industrial products. One of the main perceptions of quality in mechanical products is its physical appearance. One of the most important factors in physical appearance is the surface roughness. Number of research publications addressed this issue of surface roughness measurement and analyses. This research focuses on study and analyses of surface quality improvement in turning operation of Aluminium and Copper. These metals are selected as they are most widely used in education as well as in industry. This research paper develops an empirical model for surface roughness (Ra) prediction in turning using Al (6061T) and Cu (ASME B152 annealed). The impact of cutting speed, feed, depth of cut, tool geometry and work piece material are studied on surface roughness. The result produced using Regression Analyses (RA) give a good prediction of surface roughness when compare with actual surface roughness.

The computer (IT) generated predicted model produced through this research can be used in production setup to enhance the surface quality of final products. It may also be used to demonstrate to the students, in an education environment, the application of IT in production industry

Keywords: surface roughness (SR), regression analyses (RA), speed, feed, depth of cut, tool geometry, material (Al, Cu)

1 Introduction

The recent advancements in the CNC machine tool technology and the wide availability in manufacturing of mechanical components made it possible to produce high quality products. The factors defining "quality of a component" are generally its geometrical and dimensional tolerance, material specification, optimal design efficiency and good surface finish. The surface operations during manufacturing are affected by these factors directly or indirectly. They not only affect the surface quality but also influence the tool wear, fracture and work piece rejection, which leads to economic losses. [Groover 2000]

2 Measurement of Surface Roughness

Number of surface roughness studies is conducted and results are available in literature. One of the first studies conducted on surface roughness was in Germany in 1930's [Bayrak, 2002]. The DIN 140 standard was formulated. In this standard the classification of surface roughness was done as coarse, rough, medium and fine. The hand feel and visional inspection were used for theses classifications.

There are many ways to define surface roughness depending on its applications like R_a, R_y, R_q, R_k, R_{pk}, but roughness average R_a is widely used in industry for the mechanical components for indication of surface roughness, also known as arithmetic average (AA) or centre line average (CLA) [ISO-4287, 1997]. R_a is the area between surface profile and centre line, by [Boothroyd 89], hence in this study R_a is used for indication of surface roughness.

$$R_a = \frac{1}{L}\int_0^L |Y(x)|\,dx$$

Where as L is the sample length, Y(x) is the profile along the direction x. Also

$$R_a = \frac{1}{n}\sum_{i=1}^{n} |Y_i|$$

Where n is the total number of samples and Y_i is the height of profile at ith position. If geometry of tool and feed is considered as the major factors in determining the surface roughness then in terms of geometry of tool, nose radius r and feed f , the ideal arithmetic average (AA) is [Boothroyd 1989, Groover 1996]

$$R_i = \frac{f^2}{32r}$$

Where R_i is the ideal arithmetic average (AA)

If the tool is sharp i.e. radius r = 0 then tool angles are important so;

$$R_i = \frac{f^2}{4(\cot\alpha + \cot\beta)}$$

Where
α = Major cutting edge angle (MCEA)
β = End cutting edge angle (ECEA)

The above approach uses geometric modelling and is also extended by [Sata 1963, Dicinson 1968, and Fischer1971]. The geometric models are based on motion and geometry of the cutting process [Feng 2002].

The other approach for modelling cutting process is using regression analyses. The draw back of geometric modelling is the cutting dynamics like speed, depth of cut and work piece material. Where as in regression analyses these factors are also considered in modelling the process.

3 Effect of Parameters on Surface Roughness (SR)

Number of studies investigated the effect of different manufacturing parameters on surface roughness. In most of the studies the effect of feed and cutting speed are studies as they are most important and influencing factors on surface roughness [Petropoulos 2003]. Kopac [Kopac 1999] investigated the surface roughness for the tempered AISI 1060 and 4140 steel found that the speed is the most dominant factor affecting the SR. Yuan [Yuan 1996] and Eriksin [Eriksin 1998] reported the similar results. Gokkaya [Gokkaya 2004, 2006] investigated the affect of cutting tool coating materials. Lin [Lin 2001] studied the effect of cutting forces on SR by using regression analyses using S5C steel. Similar investigations were conducted by Risbood [Risbood 2003], Ghani [Ghani 2002], Petropoulos [Petropoulos 2003], Feng [Feng 2002], Sekulic [Sekulic 2002] and Gadelmavla [Gadelmavla 2002]. In this research factors Speed, Feed, Depth of Cut (DoC), Tool angles and work piece material are used to study their effect on surface roughness.

4 Experimental Procedure

In this investigation Aluminium and Copper are used. The test sample dimensions were 130 m long x 10 mm dia. In total 32 work pieces (16 for Al and 16 for Cu) are prepared. The machining is done on EMCO CNC turning machine Concept 155. Depth of cut of 0.25 mm and 0.75 mm are used with fee of 25 and 100 mm/min. Machining is done between centres (face plate on one side and tail stock on the other). The tool used are carbide left hand insert coated with Ti (C, N), Al_2O_3 and TiN grade TP200 CCGT09T304FN-27 commonly used as roughing tool and DCGT070204FN-27 commonly used as finishing turning tool. CNC programs for the experiment were generated on WinCAM v4.2 software. Surface roughness was measured by using Mitutoyo SJ-120P surface roughness tester. The sampling size on the tester is set at 2.5 mm cutoff length and (2.5 mm x 3 samples) 7.5 mm sampling length. These reading are done at 120o apart on the work piece, the surface tester has a repeatability of 5 % (from Mitutoyo literature and also verified by actual reading). The measuring head of the tester moved along (parallel to) the rotational axis of work piece

Following steps are used in design and analyses in this study

1. Design of experiment
2. Estimate factor effects
3. Form initial model
4. Perform statistical testing
5. Refine the model
6. Analyse the residual
7. Interpret results and discussion.

5 Design of Experiment (DoE)

In this research, factorial design is used, which is widely used in experimentation involving several factors, where it is necessary to study the joint effects of the factors on a response. In this work, 5 factors at two levels are used (2^5 factorial design) as shown in the Table 1. The factor levels are chosen on the extreme ends of the values used in the practical levels in machining (chosen from the recommended values for EMCO lathe), so the likely values used in production will be in these ranges. The approach is also useful as it removes the need of replicating the experiment [Montgomery 2005]. The effect of these factor and effect of their interaction on the surface roughness (response) is studied by using Regression Analyses (RA).

Total number of $2^5 = 32$ experiments are conducted. Experiments are randomised to remove the effect of system variation like tool wear, machine tool vibration and noise effect. The 32 surfaces are produced on CNC machine and surface roughness (R_a) is measured along the work piece rotational axis. The results are presented in Table 2.

Level	Factors				
	Speed (A) rpm	Feed (B) mm/min	Depth of Cut (C) (DoC) mm	Tool (D)	Material (E)
Low (-1)	500	25	0.25	Rough	A1 (6061T) (44 HRB)
High (+1)	1500	100	0.75	Finish	Cu (ASME B152) (34 HRB)

Table 1: Factors and their Levels

6 Regression Analyses

The data given in the Table 2 is analysed by using a software package MiniTab ver 15 [MiniTab 2007]. The regression analysis and ANOVA are presented in Table 3. Model in Table 3 is the initial model and includes all the main and two way interactions.

Table 3 indicates that value of $p < 0.05$ (at the end of table) for both main effects and 2 way interaction i.e. that both of theses effects are significant on the surface roughness (response). The initial model also indicates that the tool shape does not affect the response and the DoC influence is also limited but more then tool shape. Significant main factors and their interaction are shown in bold in Table 3.

In the light of above initial model, the insignificant factors and interaction can be removed to generate a more precise model. Table 4 shows a more precise model in which only significant terms ($p < 0.05$) from Table 3 are considered.

Std Order	Factors						
	Run Order	Speed (A)	Feed (B)	DoC (C)	Tool (D)	Material (E)	R_a
20	1	1	1	-1	1	-1	0.52
17	2	-1	-1	-1	1	-1	0.32
32	3	1	1	1	-1	-1	0.61
21	4	1	-1	1	1	-1	1.26
30	5	1	-1	1	-1	-1	0.58
28	6	1	1	-1	-1	-1	0.65
31	7	-1	1	1	-1	-1	3.46
24	8	1	1	1	1	-1	0.65
29	9	-1	-1	1	-1	-1	0.59
18	10	1	-1	-1	1	-1	0.58
22	11	1	-1	1	1	-1	0.63
19	12	-1	1	-1	1	-1	2.47
23	13	-1	1	1	1	-1	3.02
26	14	1	-1	-1	-1	-1	0.26
25	15	-1	-1	-1	-1	-1	0.5
27	16	-1	1	-1	-1	-1	3.42
6	17	1	-1	1	1	1	2.37
7	18	-1	1	1	1	1	4.62
9	19	-1	-1	-1	-1	1	1.26
2	20	1	-1	-1	1	1	2.28
8	21	1	1	1	1	1	0.6
13	22	-1	-1	1	-1	1	2.05
14	23	1	-1	1	-1	1	0.81
10	24	1	-1	-1	-1	1	0.54
3	25	-1	1	-1	1	1	4.05
15	26	-1	1	1	-1	1	4.38
16	27	1	1	1	-1	1	2.83
12	28	1	1	-1	-1	1	2.15
11	29	-1	1	-1	-1	1	4.4
5	30	-1	-1	1	1	1	3.7
1	31	-1	-1	-1	1	1	1.2
4	32	1	1	-1	1	1	0.94

Table 2: Design of Experiment and Result

7 Analyses of Results

Table 4 takes into account only major factors and factor interactions that are influencing the surface roughness. Based on 5 % confidence interval i.e. the value of $p < 0.05$, Speed, feed, DoC, material, speed-feed and feed-tool interaction plays an important role in affecting R_a. Seq SS for each of these factor and interactions are also given at the end of table which indicate the relative influence of each of these factors. R-Sq(adj) is high indicating that our model can predict within 86.7 % accuracy.

The empirical equation for predicting the surface roughness R_a is given by regression analysis is

$$R_a = 1.80 - 0.741\,\text{Speed} + 0.620\,\text{Feed} + 0.207\,\text{DoC} - 0.583\,\text{Material} - 0.564\,\text{Speed*Feed} + 0.337\,\text{Feed*Tool}$$

Further analyses can be done by looking at the main factors and interaction plots.

The Normal probability plot given in figure 1 show a clear pattern (as the points are almost in a straight line) indicating that all the factors and their interaction given in table 4 are affecting the surface roughness.

Figure 2 shows the significant effect of all the main factors, two and three way interactions. The significant factors are shown as squires. More a factor or interaction is away from normal plot line, more significant that factor or interaction is. Note that same conclusion was reached when table 1 was inter operated.

Note that factor D (Tool angle) has no significant effects, it may be due to the fact that only tool angle geometry is considered for this study and nose radius is kept constant at 0.4 mm. Factor C (DoC) is also very close to the line but as it is one of the main factors so it is included in the calculation although its effect will not be very significant. Figure 2 indicates that from the main factors speed, feed DoC

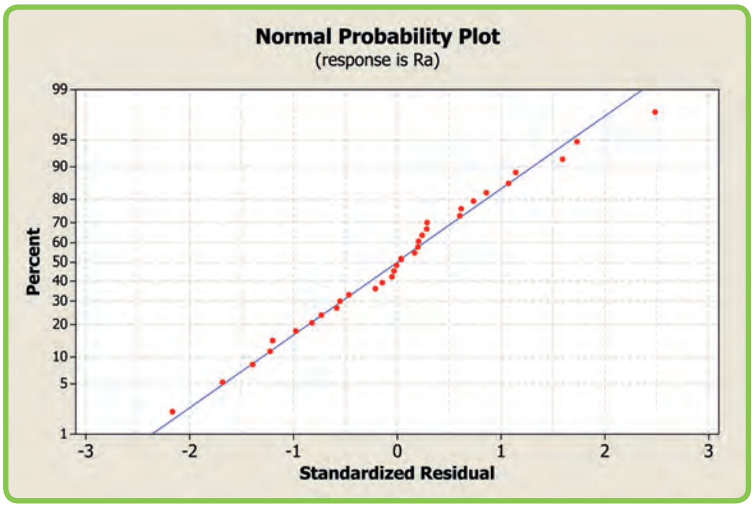

Figure 1: Normal Probability Plot

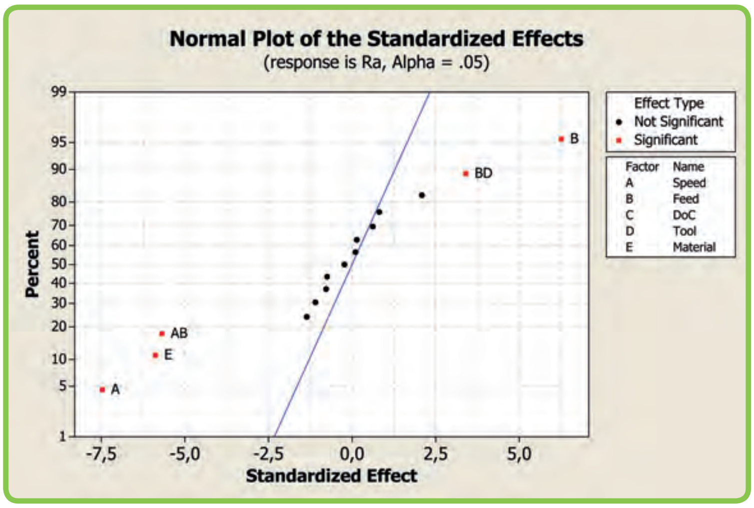

Figure 2: Normal Plot of all Level Effects

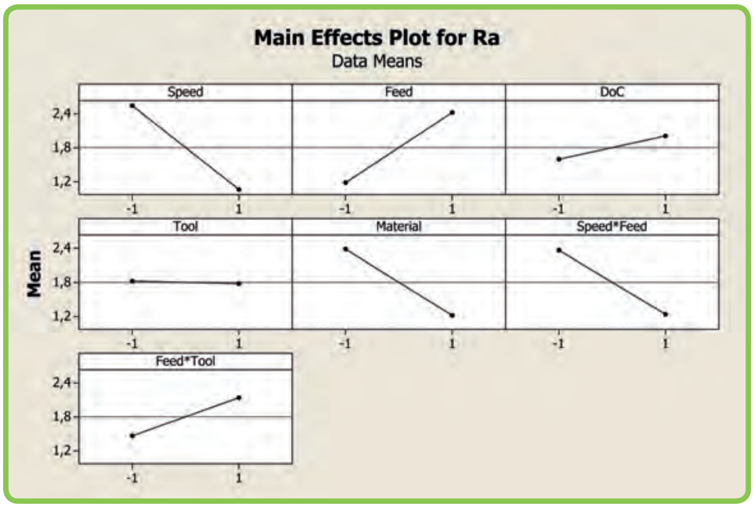

Figure 3: Main factors Plot for Ra

and material and from two way factor interaction, speed-feed and feed-tool are significant. Similar conclusion can also be reach by studying the graph between main factors and interactions against the surface roughness as shown in figure 3.

Following conclusions can be deduced from figure 3.

1. Speed: An increase in speed will significantly reduce the surface roughness. This conclusion is also supported by experience.
2. Feed: An increase in feed will increase surface roughness. This conclusion is also supported by observation.
3. DoC: Increasing the depth of cut would slightly increase

the R_a i.e. reducing the surface finish.

4. Tool: As the tool angle effect is almost flat, it has no effect on surface roughness.
5. Material: Harder material (Al) has better surface finish then the softer (Cu) material.
6. Speed-Feed: From experience we know that speed and feed interaction effects the surface roughness. The above graph shows that increasing the Speed-Feed first increase the surface roughness but further increase will improve the surface finish. This conclusion may be very useful as for mass production, optimal values for speed-feed can be set hence reduce the manufacturing time without losing surface finish.
7. Feed-Tool: This is a very interesting outcome. Although tool angles on their own does not have any effect on surface roughness but with the feed it has significant effect. Using high angle tool (finishing tool) with low feed will improve the surface finish.

8 Conclusion and Further Research

In this research the effect of manufacturing parameters speed, feed, depth of cut, tool angles are studied on surface roughness for aluminium and copper. Factorial design for experiment approach is used to design the experiments. The above five parameters at two levels (5^2 design) is used. Regression Analyses (RA) technique is used to study the effect of these parameters and their interaction on surface roughness. An empirical equation is formed by using RA in MiniTab software to predict the surface roughness. The predicted value of surface roughness is within 86 % of the actual measured values. The study also concluded that the effect of tool angles and depth of cut on surface roughness is negligible based on 95 % confidence level ($p > 0.05$). In the order of their influence, Speed, Feed, Material, Feed-Speed interaction and Feed-Tool interaction has most influence on surface roughness.

The surface roughness model produced during this research work may be used in enhancing the surface quality of a product as cutting parameters are optimised and can give better surface finish. The work may also be used to demonstrate the students in an educational environment the application of Information Technology (IT) in production.

The research also highlights the role of IT as an enabler for efficient and high quality parts in mass production environment. The knowledge gain about the controlling of surface quality by using different cutting parameter also enables us to produce good quality products.

There are many application and hence ways to define surface roughness. The surface topology can also be represented using surface features defined in ISO 13565 like R_y, R_q, R_k, R_{pk}, etc. Further research work may be done in predicting these surface parameters by using similar approach as given in this paper.

In this study, a Regression Analysis is used to predict the surface roughness. The identification of a pattern is objected here. It may be possible in future to used Artificial Neural Network

Estimated Effects and Coefficients for Ra (Coded Units)			
Term	Effect	Coef	p
Constant		1.8031	0.000
Speed	-1.4812	-0.7406	0.000
Feed	1.2400	0.6200	0.000
DoC	0.4138	0.2069	0.053
Tool	-0.0450	-0.0225	0.823
Material	-1.1662	-0.5831	0.000
Speed*Feed	-1.1275	-0.5637	0.000
Speed*DoC	-0.2688	-0.1344	0.194
Speed*Tool	0.0275	0.0138	0.891
Speed*Material	0.1613	0.0806	0.428
Feed*DoC	-0.2175	-0.1087	0.289
Feed*Tool	0.6737	0.3369	0.004
Feed*Material	0.0200	0.0100	0.921
DoC*Tool	-0.1475	-0.0738	0.468
DoC*Material	-0.1537	-0.0769	0.449
Tool*Material	0.1225	0.0612	0.545
R-Sq = 91.96 %; R-Sq(pred) = 67.85 %; R-Sq(adj) = 84.43 %			
Analysis of Variance for Ra (Coded Units)			
Source	DF	p	
Main Effects	5	0.000	
2-Way Interactions	10	0.002	
Residual Error	16	0.3145	
Total	31		

Table 3: Statistical Analyses Using Main Factors and Two Level Interactions

to identify the pattern between the surface turning parameters and surface roughness.

Table 4: Refined Statistical Analyses Using Main Factors and Two Level Interactions

Estimated Effects and Coefficients for Ra (Coded Units)		
The regression equation is Ra = 1.80 - 0.741 Speed + 0.620 Feed + 0.207 DoC - 0.583 Material - 0.564 Speed*Feed + 0.337 Feed*Tool		
Predictor	**Coef**	**p**
Constant	1.80313	0.000
Speed	-0.74062	0.000
Feed	0.62000	0.000
DoC	0.20688	0.033
Material	-0.58312	0.000
Speed*Feed	-0.56375	0.000
Feed*Tool	0.33688	0.001
S = 0.517899 R-Sq = 89.3% R-Sq(adj) = 86.7%		
Analysis of Variance		
Source	**DF**	**p**
Regression	6	0.000
Residual Error	25	0.2682
Total	31	
No replicates		

9 References

Bayrak, M.: The Effect of Machining Parameters on Surface Roughness and Their Comparison With Expert System. MSc Gazi University Institute of Science and Technology, Ankara, Turkey, 2002

Boothroyd, G.; Knight, W. A.: Fundamentals of Machining and Machine Tool. Marcel Dekker, New York, 1989

Dikinson, G.R.: Survey of factors affecting surface finish. Proceedings of Conference on Properties and Metrology of Surfaces, the Institution of Mechanical Engineers (Great Britain), Vol. 182, Part 3K, pp. 135–147, 1967/1968

Eriksen, E.: Influence from Production Parameters on the Surface Roughness of a Machined Short Fibre Reinforced Thermoplastic. International Journal of Machine Tools & Manufacture, 39, 1611–1618, 1998

Feng, C.; Wang X.: Development of Empirical Models for Surface Roughness Prediction in Finish Turning. International Journal of Advanced Manufacturing Technology, 20, 1–8, 2002

Fischer, H. L.; Elrod, J. T.: Surface finish as a function of tool geometry and feed – a theoretical approach. Microtecnic, 25(3): 175–178, 1971

Gadelmavla, E.S.; Koura, M.M.: Roughness Parameter. Journal of Material Processing Technology, 123, pp. 133–145, 2002

Ghani, A.K.; Choudhury, I.A.: Study of Tool Life Surface Roughness and Vibration in Machining Nodular Cast Iron With Ceramic Tool. Journal of Material Processing Technology, 127, pp. 17–22, 2002

Gokkaya, H.; Sur, G.; Dilipak H.,: Experimental Investigating of the Effect of Cemented Carbide Cutting Tools Coated by PVD and CVD on Surface Roughness According to Machining Parameters. Journal of Zonguldak Karaelmas University, Technical Education Faculty, 3–4, pp. 473–478, 2004

Groover, M. P.: Fundamentals of Modern Manufacturing. Prentice Hall, Upper, ISO 4287, Geometrical Product Specifications (GPS) - Surface texture: Profile method - Terms, definitions and surface texture parameters, 2000

Petropoulos, G.; Mata, F.; Paula Davim, J.: Statistcal Study of Surface Roughness in Turning of Peek Composites, Journal Materials and Design, 10, 1016, 2006

Kopac, J.; Bahor, M.: Interaction of the Technological History of a Work piece Material and the Machining Parameters on the Desired Quality of the Surface Roughness of a Product. Journal of Materials Processing Technology, pp. 92–93, pp. 381–387, 1999

Lin, W.S.; Lee, B.Y.: Modelling the Surface Roughness and Cutting Forces During Turning. Journal of Material Processing Technology, p. 108, pp. 286–293, 2001

Montgomery, Douglas: Design and Analysis of Experiments, 6th Edition, Wiley, New York, 2005.

MiniTab: MiniTab version 15 documentation, 2007. www.minitab.com

Petropoulos, G.A.; Torrance, A.; Pandazaras, C.N.: Abbott Curves Characteristics of Turned Surfaces. International Journal of Machine Tool & Manufacture, 43, pp. 237–243, 2003

Risbood, K.A.; Dixit, U.S.: Prediction of Surface Roughness and Dimensional Deviation by Measuring Cutting Forces and Vibration in Turning Process. Journal of Material Processing Technology, 132, pp. 203–214, 2003

Sata, T.: Surface finish in metal cutting. C.I.R.P. Annalen, Saddle River, NJ (now published by John Wiley & Sons, New York), 12(4): 190–197, 1963/1964

Sekulic, S.: Correlation between the Maximal Roughness Height and Mean Arithmetic aviation of the Profile from the Mean Line of Machined Surface in Finish Turning. International Conference on Tribology, pp 29–34, Kayseri, 2002

Yuan, Z.J.; Zhou, M.; Dong, S.: Effect of Diamond Tool Sharpness on Minimum Cutting Thickness and Cutting Surface Integrity in Ultra precision Machining. Journal of Material Processing Technology 62, pp. 327–330, 1996

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