EFFECT AND OPTIMIZATION OF MACHINING PARAMETERS ON CUTTING FORCE AND SURFACE FINISH IN TURNING OF MILD STEEL AND ALUMINUM

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Abstract

Productivity and the quality of the machined parts are the main challenges of metal cutting industry during turning process. Therefore cutting parameters must be chosen and optimize in such a way that the required surface quality can be controlled. Hence statistical design of experiments (DOE) and statistical/mathematical model are used extensively for optimize. The present investigation was carried out for effect of cutting parameters (cutting speed, depth of cut and feed) In turning off mild steel and aluminum to achieve better surface finish and to reduce power requirement by reducing the cutting forces involved in machining. The experimental layout was designed based on the 2^k factorial techniques and analysis of variance (ANOVA) was performed to identify the effect of cutting parameters on surface finish and cutting forces are developed by using multiple regression analysis. The coefficients were calculated by using regression analysis and the model is constructed. The model is tested for its adequacy by using 95% confidence level. By using the mathematical model the main and interaction effects of various process parameters on turning was studied.

***Keywords:** Universal Lathe, Surface Finish, Cutting Force, High Speed Steel Tool, Factorial Technique.*

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1. INTRODUCTION

Cutting forces are to be reduced in order to minimize the vibrations of the machine and to increase the life of the tool. The single point cutting tools being used for turning, shaping, planning, slotting, boring etc. usually HSS material is preferred for single point cutting tool is characterized by having only one cutting force during machining.

Surface finish produced on machined surface plays an important role in production. The surface finish has a vital influence on most important functional properties such as wear resistance, fatigue strength, corrosion resistance and power losses due to friction. Poor surface finish will lead to the rupture of oil films on the peaks of the micro irregularities which lead to a state approaching dry friction and results in decisive wear of rubbing surface. Therefore finishing processes is employed in machining to obtain a very high surface finish.

Rodrigues L.L.R [1] has done a significant research over Effect of Cutting Parameters on Surface Roughness and Cutting Force in Turning of Mild Steel.Hamdi Aouici , Mohamed Athmane Yallese , Kamel Chaou [2] have carried research over Analysis of surface roughness and cutting force components in hard turning with CBN tool: Prediction model and cutting conditions optimization. Ilhan Asiltürk , Süleyman Nes eli [3] has studied the Multi response optimization of CNC turning parameters via Taguchi method-based response surface analysis. The method of Determining the effect of cutting parameters on surface roughness in hard turning using the Taguchi method was given by, Ilhan Asiltürk , Harun Akkus [4] and Mustafa Günay , Emre Yücel [5] were used of Taguchi method for determining optimum surface roughness in turning of high-alloy white cast iron.

Factorial technique is a combination of Mathematical and statistical technique. It is useful for the modeling and analysis of problems in which a response of interest is influenced by several variables and the objective is to optimize the response. For example, a person wishes to find levels of temperature (x1) and pressure (x2) that maximize the yield (Y) of a process. Equation (1) yields a function with the levels of temperature and pressure.

$$Y = f(x_1, x_2) + K \quad (1)$$

Where K represents the error or noise observed in the response Y.

In most of the problems, the relationship between the response and the independent variable is unknown. The first step in factorial technique is to find suitable approximation for the true function of relationship between Y and the set of independent variables. Usually, a lower order polynomial in some region of the independent variables is employed. If the response is well modeled by a linear function of the independent variables then the approximating function is the first order model.

$$Y = \beta + \beta_1 x_1 + \beta x_2 + \dots + \beta_x x_x + \in \qquad (2)$$

If there is curvature in the system then a polynomial of higher degree must be used, such as the second order model.

$$Y=\beta+\in \sum\beta_1x_1+\sum\beta_2x_2+\sum\sum\beta x_ix+\in \quad (3)$$

2. PLAN OF INVESTIGATION

Step 1: Identification of the important process control variables.
Step 2: Finding the upper and lower limits of control variable.
Step 3: Developing the experimental design matrix.
Step 4: Conducting the experiments as per the design matrix.
Step 5: Recording the responses (surface finish & cutting forces).
Step 6: Development of mathematical models.
Step 7: Checking the adequacy of the developed models by using F –test.

3. MATHEMATICAL MODELLING

3.1. Identification of Important Process Control Variables

Identification of correct factors is very important to get a good and accurate model. Among them the parameters that influence the surface finish are speed, feed, depth of cut and nose radius.

3.2. Finding the Limits of the Process Variables

Trial experiments are carried out to find out the value of cutting forces by changing one parameter and other are kept as constant.

- By varying the parameters, extreme limits are found out.
- For the convenience of recording and processing the experimental data observed.
- The upper and lower limits are coded as +1, -1 respectively or simply (+) and (-) for the case of recording.

Coded Value =(Natural value – Average value) / Variation in the value

Natural Value =Value under consideration

Average Value=(upper limit + lower limit)/2

Variation value = (upper limit – lower limit)

3.3. Development of Optimal Working Zones

The optimum working zone depends on the desired work piece. Experiments were conducted separately for each combination to find the operating working region. Finding of this region was necessary to fix up the limits of the process parameters. The upper and lower limits are denoted as +1 and –1 respectively. Trial runs were conducted by changing one of the factors and keeping the remaining at constant value. The maximum and minimum limits of all the factors were thus fixed.

3.4 Design of the Experiment

There are various techniques available from the statistical theory of experimental design which is well suited to Engineering investigations. One such important technique is a Factorial technique for studying the effects of parameters on response and this is the one which was selected for the experiment.The design of an experiment is the procedure of selecting the number of trails and conditions for running them, essential and sufficient for solving the problem that has been set with the required precision.

3.5. Conducting the Experiments as per the Design Matrix

The experiments are conducted according to the design matrix(shown in table.3.1, table.3.2). The number of passes required by a full 2^k factorial design increase geometrically as K is increased and the larger number of trials called for is primarily to provide estimates of the increasing number of higher order interactions, which are most likely do not exist.

The measure of passes required to achieve the desired dimensional accuracy and surface finish is equal to 2^k.Where k is the number of input parameters. Hence unnecessary expenditure due to the loss of cutting time and operational cost may be saved using this relation. Factorial design constitutes the main parameters of major interests and is compounded (mixed up) with effects of higher order interactions and since these interaction effects are assumed to be small and negligible, the resulting estimates are essentially the main effects of primary interest.

3.6. Selection of Design and Mathematical Model

Finding the effect of the machining parameters on the surface finish being the major part of investigation It was considered best to design the experiments for the phase of study. This included the effect of maximum number of parameters could be used for all other phases.

Table-1: Design Matrix for Cutting Force

Treatment Combination	K	A	B	C	AB	BC	CA	ABC
k	+	+	+	+	+	+	+	+
a	+	+	+	-	+	-	-	-
b	+	+	-	+	-	-	+	-
c	+	+	-	-	-	+	-	+
ab	+	-	+	+	-	+	-	-
bc	+	-	+	-	-	-	+	+
ca	+	-	-	+	+	-	-	+
abc	+	-	-	-	+	+	+	-

Table–2: Design Matrix for Surface Finish

Treatment Combination	K	A	B	C	AB	BC	CA	ABC
k	+	-	-	-	+	+	+	-
a	+	+	-	-	-	-	+	+
b	+	-	+	-	-	+	-	+
c	+	-	-	+	+	-	-	+
ab	+	+	+	-	+	-	-	-
bc	+	+	-	+	-	+	-	-
ca	+	-	+	+	-	-	+	-
abc	+	+	+	+	+	+	+	+

3.7. Checking the Adequacies of the Models:

All the above estimated coefficients were used to construct the models for the response parameter and these models were used to construct the models for the response parameter and these models were tested by applying analysis of variance (ANOVA) technique F-ratio was calculated and compared, with the standard values for 95% confidence level. If the calculated value is less than the F-table values the model is consider adequate.

3.8. Development of the Final Mathematical Model:

The values predicted by this model were also checked by actually conducting experiments by keeping the value of the process parameter at some values other than those used for developing the models but within the zone and the results obtained were found satisfactory. Then these models were used for drawing graphs and analyzing the results.

4. EXPERIMENTAL WORK

Experimental work was conducted on Lathe Machine. Aluminum and Mild Steel are chosen as work piece materials and High Speed Steel Single Point Cutting Tool is chosen as cutting tool material. Machining has been done as per the Design Matrix. In this current paper Speed, feed and Depth of Cut are chosen as the influencing parameters of Cutting Force and Surface Roughness and their minimum and maximum varying values are decided after conducting trail experiments.

Table-3: Working limits of turning parameters

	Speed (rpm), n	Feed (mm/sec), f	depth of cut (mm), d
Maximum value	500	1.5	2
Minimum value	200	0.5	0.5

Fig-1: Conducting Experiments on Lathe

Fig-2: Turned Pieces of Aluminum and Mild Steel

5. EXPERIMENTAL RESULTS

Table-4: Experimental Values for Cutting Force of Mild Steel

Resultant Force	Multi-Linear	Product of Multi-Linear
31.1195	46.8219	47.5393
25.6281	44.3468	45.0964
83.9031	78.1251	76.5543
86.3215	75.6501	75.7539
45.2966	55.8078	55.7441
35.6588	53.3328	51.9296
112.4970	87.1111	88.0283
105.4076	84.6361	85.1859

Table-5: Experimental Values for Cutting Force of Aluminum

Resultant Force	Multi-Linear	Product of Multi-Linear
20.2286	40.1154	38.8943
21.0442	40.3901	40.3348
57.8743	63.4963	61.0954
87.1335	63.7709	67.4482
52.5205	50.8616	53.4396
41.9485	51.1362	49.8346
97.5432	74.2424	75.2864
80.2374	74.5170	72.1965

Table-6: Experimental Values for Surface Roughness of Mild Steel

Surface Roughness	Multi-Linear	Product of Multi-Linear
26.1	16.2679	17.8259
17.01	15.8701	15.6582
13.26	16.1276	14.8494
18.52	15.7298	15.6619
6.2725	10.8207	10.4491
4.28	10.4229	9.44847
9.06	10.6804	10.7722
11.7	10.2826	11.5369

Table -7: Experimental Values for Surface Roughness of Aluminum

Surface Roughness	Multi-Linear	Product of Multi-Linear
15.1	8.7203	9.4763
8.32	8.3404	8.1665
4.23	7.4029	6.6753
9.2632	7.023	7.1684
2.63	6.0071	5.5774
5.28	5.6272	5.4747
5.62	4.6897	5.0910
1.6775	4.3098	4.4906

5.1 Model Calculation:

Multi-Linear:

$F_K = K - AX_1 - BX_2 - CX_3$

= [65.729-(-2.4750*0.5)-(31.3032*0.5)-(8.9859*0.5)]=46.8219

Product of Multi-Linear:

$F_K = [K - AX_1 - BX_2 - CX_3 + ABX_1X_2 + BCX_2X_3 + CAX3X1 - ABCX1X2X3$

= (65.729-(-2.4750*0.5)-(31.3032*0.5)-(8.9859*0.5) + (1.3072*0.25) + (2.9340*0.25) + (-1.70677*0.25)-(-0.6701*0.125)) =47.5393

6. RESULTS AND DISCUSSION

6.1. Variation of Machining Parameters on Cutting Forces:

The effect of machining parameters (speed, feed and depth of cut) on cutting forces(is presented in following Fig 6.1,fig 6.2 and Fig 6.3). It is understood that Cutting forces increases with feed keeping other parameters constant,Cutting forces decreases with spindle speed keeping other parameters constant,Cutting forces increases with spindle speed keeping other parameters constant.

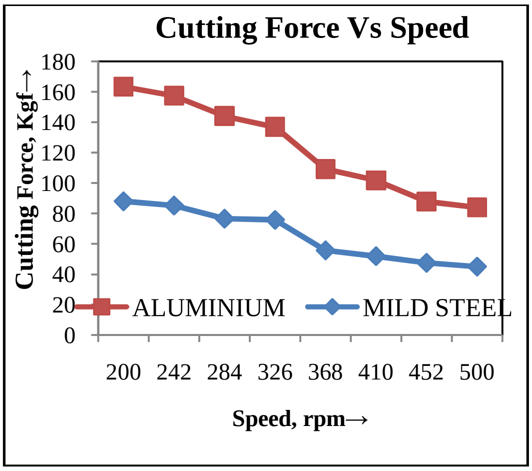

Fig-3: Variation of Cutting Force with Speed

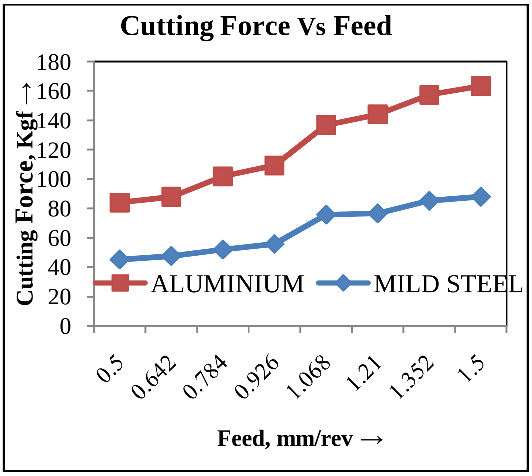

Fig-4: Variation of Cutting Force with Feed

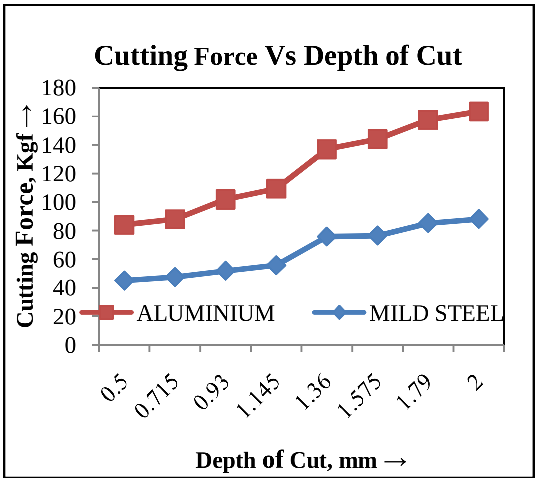

Fig-5: Variation of Cutting Force with Depth of Cut

6.2. Comparison table of Cutting Force Values:

Table-8: Comparison table of Cutting Force values

Aluminum			Mild Steel		
R	**M**	**PM**	**R**	**M**	**PM**
20.22	40.11	38.89	31.11	46.2	47.53
21.04	40.39	40.33	25.62	44.3	45.09
57.87	63.49	61.09	83.90	78.1	76.55
87.13	63.77	67.44	86.32	75.6	75.75
52.52	50.86	53.43	45.29	55.8	55.74
41.94	51.13	49.83	35.65	53.3	51.92
97.54	74.24	75.28	112.4	87.1	88.02
80.23	74.51	72.19	105.4	84.6	85.18

Where:
R= Resultant Force

M= Multi-Linear

PM= Product of Multi-Linear

From the comparison table of experimental, multi linear and product of multi linear, it is understood that the values obtained experimentally are close to the predicted values.

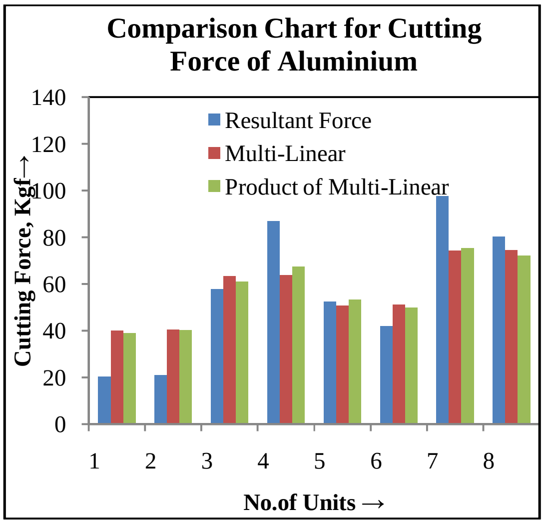

Fig-6: Cutting Forces for Experimental Values of Al.

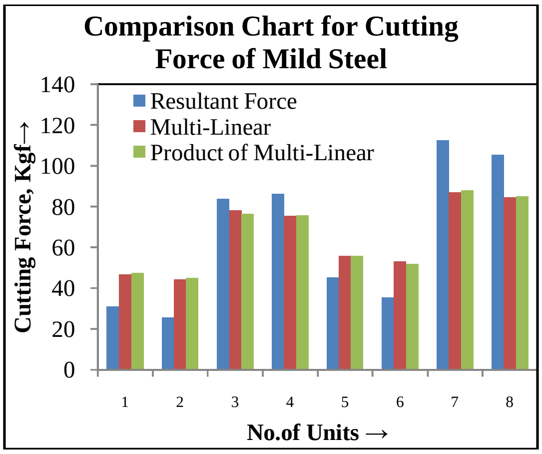

Fig-7: Cutting Forces for Experimental Values of MS

6.3 Variation of Machining Parameters on Surface Finish:

The effect of machining parameters (speed, feed and depth of cut) on surface roughness(is presented in following Fig 6.6,fig 6.7 and Fig 6.8).It is understood that surface roughness increases with feed keeping other parameters constant, Surface roughness decreases with spindle speed keeping other parameters constant , Surface roughness increases with spindle speed keeping other parameters constant.

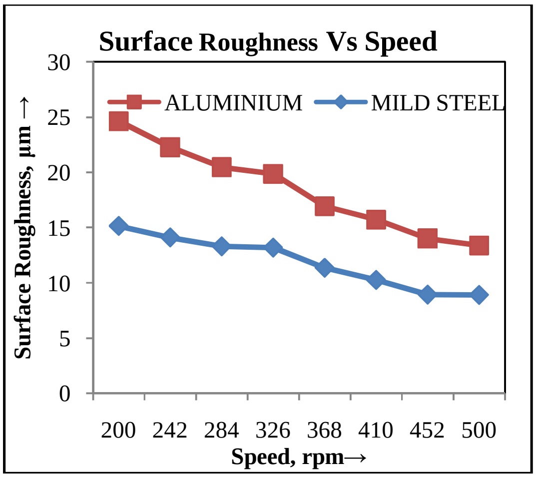

Fig-8: Variation of Surface Roughness with Speed

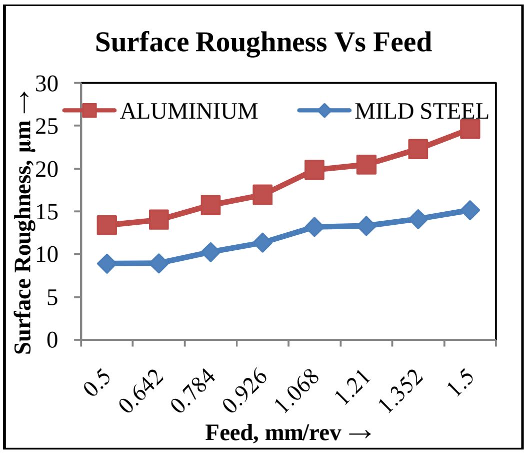

Fig-9: Variation of Surface Roughness with Feed

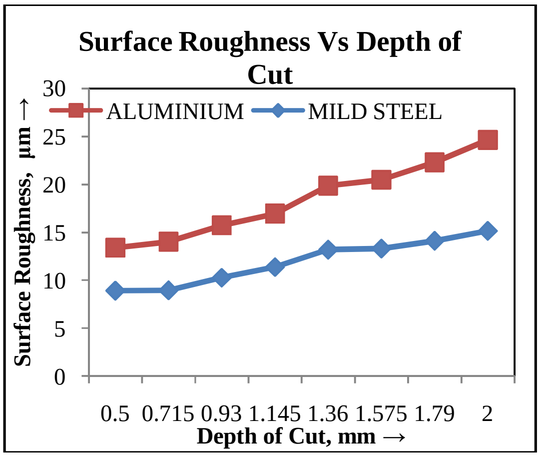

Fig-10: Variation of Surface Roughness with Depth of Cut

6.5. Comparison Table of Surface Roughness Values:

Table -9: Comparison table of Surface Roughness values

Aluminum			Mild Steel		
R	**M**	**PM**	**R**	**M**	**PM**
15.1	8.72	9.47	15.18	12.83	13.18
8.32	8.34	8.16	17.01	13.80	14.11
4.23	7.40	6.67	13.26	14.06	13.30
9.263	7.02	7.16	18.52	15.04	15.14
2.63	6.00	5.57	6.27	8.75	8.90
5.28	5.62	5.47	4.28	9.73	8.932
5.62	4.68	5.09	9.06	9.99	10.25
1.67	4.30	4.49	11.7	10.97	11.36

From the comparison table of experimental, multi linear and product of multi linear, it is understood that the values obtained experimentally are close to the predicted values.

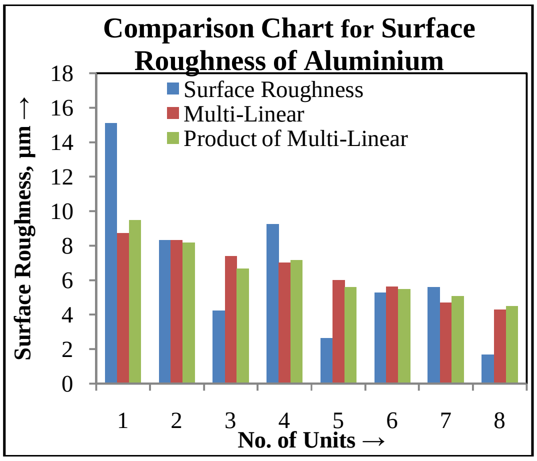

Fig-11: Comparison of Surface Finish for Al.

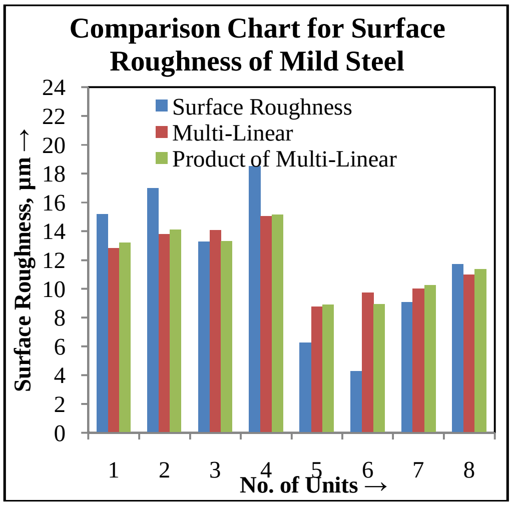

Fig-12: Comparison of Surface Roughness for MS

- The experimental values and optimum values of surface finish and cutting forces are well within the limits for Aluminum and Mild Steel.
- The surface finish and cutting force values are higher for Mild Steel when Compared to Aluminum.
- As feed increases, the surface finish and cutting forces are increased by keeping speed and depth of cut as constant.
- As speed increases, the surface finish is decreased and cutting forces are increased by keeping feed and depth of cut as constant.
- As depth of cut increases, the surface finish and cutting forces are increased by keeping speed and feed as constant
- Surface finish and cutting forces in turning also depends on other parameters like tool geometry, type of cutting fluid used.

CONCLUSIONS

The developed model can be used to predict the surface finish and cutting forces in terms of machining parameters within the range of variables studied. Alternately, it also helps to choose the influential process parameters so that desired value of surface finish and cutting forces can be obtained. The effect of various process parameters like spindle speed, feed, depth of cut on surface finish and cutting forces were studied with their predicted values. In the future work the experiments can be carried out to determine the effect of parameters like spindle diameter, cutting fluid, cutting angle, Material Removal Rate etc., on the machined surfaces in Turning operation.

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