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PREDICTION OF SURFACE FINISH IN END MILLING USING RESPONSE SURFACE METHOD BASED ON FISHER'S RATIO

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ABSTRACT

The effect of various process parameter like speed, feed, depth of cut on the surface finish in End Milling process on a Universal Milling Machine is investigated by using standard statistical tool i.e., Response Surface Method. The experimental coefficients are calculated by using regression analysis and the model is constructed. The model is tested for its adequacy by using Fisher's test. By using the mathematical model the main and interaction effect of various process parameters on surface finish was studied by plotting graphs and conclusion were draw.

Keywords: *Surface Response Method, Fisher's Ratio, Surface Roughness and Design of Experiment.*

1. Introduction

Surface finish produced on machined surface plays an important role in production. The surface roughness has a vital influence on most important functional properties such as wear resistance, fatigue strength, corrosion resistance and power losses due to friction [1]. Poor surface roughness will lead to the rapture of oil films on the packs of the micro irregularities which lead to a state approaching dry friction and results in decisive wear of rubbing surface. Therefore finishing processes are employed in machining the surface of many critical components to obtain a very high surface finish.

Surface roughness in end milling depends on spindle rpm, feed, depth of cut, Helix angle. Mainly surface finish depends on spindle rpm, feed and depth of cut. Factors affecting the surface finish are vibrations, material of the work piece, hardness of the work piece, type of machining, rigidity of the system consisting of machine took, fixture, cutting tool and work [2].

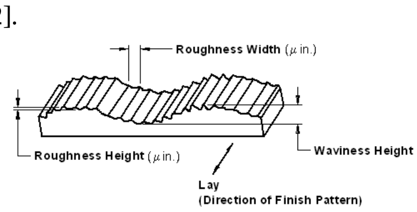

Fig. 1 Average Surface Roughness Obtained from Common Production Methods

Over the years the characterization and evaluation of engineering surface roughness has constituted a challenging metrological problem remained open so far, especially when high precision and/or functional performance requirements exist. This fact is attributed to the usually complicated form of surface roughness and the need to obtain a satisfying description globally, as well as at various levels [3]. Traditionally, surface roughness has been considered more as an index of the variation in the process due to tool wear, machine tool vibration, and damaged machine elements etc. than as a measure of the performance of the component; a stable process combined with the specification of the arithmetic average, Ra, was considered to be enough in industrial practice. A machined surface possesses, more or less depending on the cutting factors employed, recognizable features imparted by the cutting operation previously performed [4]. Since these characteristics cannot be described with a single parameter, a multi parameter surface roughness analysis is recommended. Emerging technological advances put new limits in manufacturing tolerances and better understanding of tribological phenomena on the other hand, implied the need of functional surface characterization, which in turn caused a plethora of parameters [5]. A great amount of research works towards a concise and proper characterization of surface texture is met in literature with an inevitable emphasis on the association of profile characteristics with the manufacturing process parameters. The present article is aimed at presenting a retrospect of works reported by the author on aspects of machined surfaces along with modeling of various texture parameters. It is directed to the ultimate goal that is surface typology, the classification of textures in classes according to their shape followed by an

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exhaustive investigation on the capability of various manufacturing processes of producing these classes [6].

1.1 Surface response technique

Response Surface Methodology or RSM is a collection of Mathematical and statistical techniques that are 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 [7]. For example, suppose that a person wishes to find levels of temperature (x_1) and pressure (x_2) that maximize the yield (Y) of a process. The process yield is a function of the levels of temperature and pressure, say.

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

Where K represents error or noise observed in the response Y. In most RSM problems, the form of the relationship between the response and the independent variable is unknown. Thus the first step in RSM is to find suitable approximation for the true function of relationship between Y and the set of independent variables using Eq.1. Usually, a low-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 [8].

$$Y = \beta + \beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_x x_x + \varepsilon \quad (2)$$

If there is curvature in the system then a polynomial of higher degree must be used, such as the second order model as shown in Eq.3.

$$Y = \beta\alpha + \varepsilon \sum \beta_1 x_1 + \sum \beta\alpha x_1^2 + \sum\sum \beta x_i x_1 + \cdots + \varepsilon \quad (3)$$

2. Proposed Methodology

In order to achieve the desired aim the experimental work was planned to be carried out the following steps:

2.1 Identification of important process control variables

Identification of correct factors is very important to get a good and accurate model. Among many parameters that effect the surface finish the following was important: Speed, feed, nose radius and depth of cut.

2.2 Finding the limits of the process variables

i. Trial experiments were carried out to find out the working range or both surface finish range and material removal range by varying one process variable and keeping other process variable constant.
ii. The various values of factor examined in an experiment are known as limits.
iii. For the convenience of recording and processing the experimental data was observed.
iv. The upper and lower limits were coded as +1, -1 respectively or simply (+) and (-) for the case of recording processing of the observed data by using the Eq.4.

$$\text{Coded Value} = \frac{\text{Natural value - Average value}}{\text{Variation in the value}}$$
$$\text{Natural value} = \text{Value under consideration} \quad (4)$$
$$\text{Average value} = (\text{Upper limit} + \text{Lower limit})/2$$
$$\text{Variation value} = \text{Upper limit - Lower limt}$$

2.3 Development of optimal working zones (upper/lower limits)

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.

2.4. Design of the experiment

It is known that the general quantitative approach is based on a more sound logic than another approach for the generalization of data. Thus, it was decided to take this approach as the basis for designing experiments. There are various techniques available from the statistical theory of experimental design which are well suited to Engineering investigations. One such important technique is a Surface Response 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.

2.5 Developing the design matrix

The design is developed by using independent variables which cover all the possible combinations of the process parameter. The method of designing the matrix is given in Table1.

Experiments are carried as per the Designed Matrix. The experiments were conducted according to the design matrix by using Universal Milling Machine. The number of runs required by a full 2k RSM design increase geometrically as K is increased and the larger the number of trials called for is primarily to provide estimates of the increasing number of higher order interactions number of higher order interactions which most likely do not exist. Therefore experiments for such estimates would be wasted, increasing the cost and time of experiments. Under such conditions it is possible and advantages to use only part of the full factor design i.e., fractional factorial design and the concept of compounding. Surface response 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.

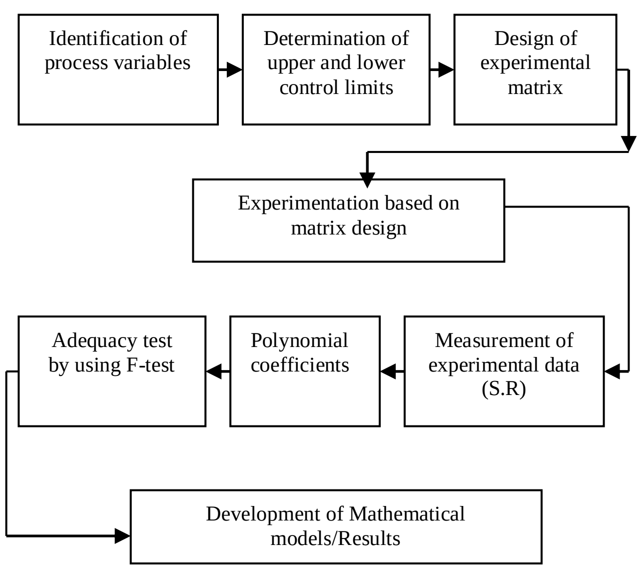

Fig. 2 Flow Diagram for Proposed Methodology

2.6 Experimental setup

A milling machine is a machine tool that removes metal as the work is fed against a rotating multipoint cutter.

The cutter rotates at a high speed and because of the multiple cutting edges it removes metal at a very fast rate. The machine can also hold one or more number of cutters at a time. This is why a milling machine finds wide application in production work. This is superior to other machines as regards accuracy and better surface finish, and is designed for machining a variety of tool room work. In end milling, The cutter in end milling generally rotates on an axis vertical to the work piece. It can be tilted to machine tapered surfaces. Cutting teeth are located on both the end face of the cutter and the periphery of the cutter body.

Fig. 3 Milling Machine used in the Experiment

2.6.1 Materials and cutting tools used in the experiment

High speed steels (HSS) are carbon steels with alloying elements such as Tungsten (W), Chromium (cr), Vanadium (V), Molybdenum (Mo) and Cobalt (Co).

Work piece materials used as part of experimental investigation is (i) Brass (ii) Aluminum (iii) Teflon

(i) Brass: Brass is any alloy of copper and zinc; the proportions of zinc and copper can be varied to create a range of brasses with varying properties. In comparison, bronze is principally an alloy of copper and tin. Despite this distinction, some types of brasses are called bronzes. Brass is a substitutional alloy. It is used for decoration for its bright gold-like appearance; for applications where low friction is required such as locks, gears, bearings, doorknobs, ammunition, and valves; for plumbing and electrical applications; and extensively in musical instruments such as horns and bells for its acoustic properties. It is also used in zippers.

(ii) Aluminum: The best known characteristic of aluminum is its light weight, the density being about one third that of steel or copper alloy. Aluminum has good malleability and formability, high corrosion resistance and high electrical and thermal conductivity. Aluminum in nontoxic, nonmagnetic, and non sparking. Pure aluminum has a tensile strength of about 13000 PSI. However, substantial increases in strength are obtained by sold working or allying some alloys, properly heat – treated, approach tensile strength of 100,000 PSI. One of the most important characteristics of aluminum in its machinability and workability commercially pure aluminum, 11000 alloy (99.0 +%Al) is suitable for applications where good formability or very good resistance corrosion are revised and where high strength is not necessary.

(iii) Teflon : TFE and FEP Fluoro carbon (i.e, Polytetra Fluoro rthylene and Fluinated Ethylene Propylene) Teflon possesses the following properties Teflon has optimum chemical and heat resistance, Teflon have extremely low frictional coefficients, Chemically inert in almost all environments, Excellent electrical properties, Relatively weak and poor cold flow properties.

2.7 Selection of design and mathematical model

Effect of the machining parameters on surface finish being the major part of investigation it was considered best to design the experiments for the phase of study which included the effect of maximum number of parameters could be used for all other phases. With the increase of mechanization and automation in machining process, the solution of parameters must be more specific to ensure that adequate surface quality is achieved and material removal rate obtained. Also to make effective use of automated machining process is essential that high degree of confidence to be achieved in predicting the values. These facts necessities the development of mathematical models for accurately predicting the surface finish and metal removal rate. These equations in which the data is represented can be easily be programmed and fed to a computer which in turn automatic the process. Mathematical model has been developed to represent the experimental data collected by conducting the trails. The models can be used for finding both the individual and interaction model & it is appropriate to mention the effects of various input process parameters.

2.8 Estimation of regression coefficients

The regression coefficient of the model was computed using the following formula based on the method of least squares. In the present case the tabulated value of F-ratio was found out using Eq.5.

Table1: Design Matrix used for Prediction of Surface Finish in End Milling

	A	B	C	AB	AC	BC	ABC
1	-	-	-	+	+	+	-
a	+	-	-	-	-	+	+
b	-	+	-	-	+	-	+
c	-	-	+	+	-	-	+
ab	+	+	-	+	-	-	+
ac	+	-	+	-	+	-	-
bc	-	+	+	-	-	+	-
abc	+	+	+	+	+	+	+

$$F_{ratio} = 2 * s_{ad}^2 / s_y^2 \qquad (5)$$

where

s_{ad}^2 Variance of adequacy or residual variance

s_y^2 Variance of optimization parameter of variance of reproducibility.

The variance of adequacy was calculated using Eq.6.

$$s_{ad}^2 = (y_{avg} - y_{prev})^2 / 2 \qquad (6)$$

Where y_{prev}: value of response predicted.

DOF: Degree of freedom and is equal to (n-(k+1))

N: No of experimental trials

k: No. of independent variables

y_{avg}: Average of response observed

y_1 Other of the values of response parameter

A matrix designed to apply the above formula for the calculation of regression co-efficient of the model is given in table. Because of the orthogonal property of the design, the estimated coefficients are un correlate with one another. Since the method of least squares has been used, the estimates also possess the property of minimum variance. All the regression coefficient of the model is expressed by the above equation were estimated for the response parameter i.e. surface and material removal rate. 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. Experimental Results

3.1 Standard Fisher's ratio table

A ratio has been developed in statistics that is very convenient for testing a hypothesis on the adequacy of the model. The convenience of using the F-ratio consists in that the testing of hypothesis can be reduced to compare N tabulated value. The table constructed as follows. The columns are related to a definite number of degrees of freedom for the number f1 and rows for the denominator f2.

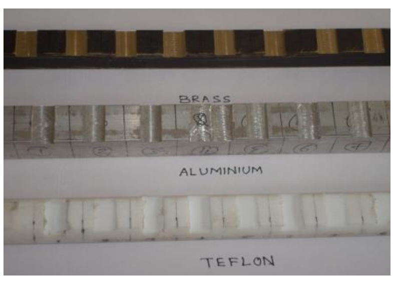

Fig. 4 Test Specimens used in the Experiment

Fig. 5 Surface Roughness Measurement

The critical values of the F-ratio are found at the intersection of the corresponding rows and columns. As a role, a significance level of 5% (confidence level of 95%) is used in technical problems. (F- table shown in table - 1).

3.2 Measurement of surface finish for experimental validation

The instrument used for measuring surface finish was surface indicator. This device consists of tracer head and an amplifier. The head housed a diamond stylus, having a point radius of 0.03 mm, which been against the surface of the work and may be moved by hand or it may be another driven. Any movement of the stylus covered by surface irregularities is converted into electric fluctuations by the tracer head. These signals are magnified by the amplifier and registered on the digital display. The reading shown on the display indicator the average height of the surface roughness or the depth of the surface from the reference line. For accurate determination of the surface finish the indicator must first be calibrated by setting it to a precision reference surface on a block calibrated to ASA standards.

3.3 Development of the final mathematical model

The final mathematical model was constructed by using only significant coefficients and is shown in table. 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 with in the zone and the results obtained were found satisfactory. Then these models were used for drawing graphs and analyzing the results.

3.4 Test conditions in the experiment

Case 1: Experimental details of Aluminium

Linear Regression Equation:

$$y_1 = 1.9 - 0.4x_1 + 0.16x_2 - 0.08x_3 \quad (7)$$

Non-Linear Regression Equation:

$$y_1 = 1.9 - 0.4x_1 + 0.16x_2 - 0.08x_3 - 0.08x_1x_2 + 0.16x_2x_3 - 0.003x_1x_2 - 0.33x_1x_2x_3 \quad (8)$$

Comment 1:

Checking the adequacy using Fishers Table 2. The F values obtained for Aluminium are tabulated in the above table and the values are cross checking in the Fishers table and found within the limit.

Linear Regression Equation:

$$y_1 = 1.21 - 0.26x_1 + 0.30x_2 + 0.01x_3 \quad (9)$$

Non-Linear Regression Equation:

$$y_1 = 1.21 - 0.2x_1 + 0.3x_2 + 0.01x_3 - 0.09x_1x_2 + 0.10x_2x_3 - 0.18x_1x_2 - 0.19x_1x_2x_3 \quad (10)$$

Calculation of Fisher's ratio

Comment 2:Checking the adequacy using Fishers Table. The F values obtained for Brass are tabulated in the above table and the values are cross checking in the Fishers table and found within the limit.

Linear Regression Equation:

$$y_1 = 1.88 - 0.8x_1 + 0.88x_2 - 0.157x_3 \quad (11)$$

Table 1: Values of F- ratio at 5% Significance Level

	1	2	3	4	5	6	12	24	0
1	164	200	216	225	230	234	245	249	254
2	19	19	19	19	19	19	19	19	20
3	10	9.6	9.3	9.1	9	8.9	8.7	8.7	8.5
4	7.7	6.9	6.6	6.4	6.3	6.2	5.9	5.8	5.6
5	6.6	5.8	5.4	5.2	5.1	5	4.7	4.5	4.4
6	6	5.1	4.8	4.5	4.4	4.3	4	3.8	3.7
7	5.5	4.7	4.4	4.1	4	3.9	3.6	3.4	3.2
8	5.3	4.5	4.1	3.8	3.7	3.6	3.3	3.1	2
9	5.1	4.3	3.9	3.6	3.5	3.2	2.9	2.7	2.5
10	5	4.1	3.7	3.5	3.3	3.2	2.9	2.7	2.5
11	4.8	4	3.6	3.4	3.2	3	2.9	2.5	2.3
12	4.8	3.9	3.5	3.3	3.1	3	2.7	2.5	2.3
13	4.7	3.8	3.4	3.2	3	2.9	2.6	2.4	2.2
14	4.6	3.7	3.3	3.1	3	2.9	2.5	2.3	2.1
15	4.5	3.7	3.3	3.1	2	2.8	2.5	2.3	2.1
16	4.5	3.6	3.2	3	2.9	2.7	2.4	2.2	2
17	4.5	3.6	3.2	2.9	2.8	2.7	2.4	2.2	2
18	4.4	3.6	3.2	2.9	2.8	2.7	2.3	2.1	1.9
19	4.4	3.5	3.1	2.9	2.7	2.6	2.3	2.1	1.9
20	4.4	3.5	3.1	2.9	2.7	2.6	2.3	2.1	1.8
22	4.3	3.4	3.1	2.8	2.7	2.6	2.2	2	1.8
24	4.3	3.4	3	2.8	2.6	2.5	2.2	2	1.7
26	4.2	3.4	3	2.7	2.6	2.5	2.2	2	1.7
28	4.2	3.3	3	2.7	2.6	2.4	2.1	1	1.7
30	4.2	3.3	2.9	2.7	2.5	2.4	2.1	1.9	1.6
40	4.1	3.2	2.9	2.6	2.5	2.3	2	1.8	1.5
60	4	3.2	2.8	2.5	2.4	2.3	1.9	1.7	1.4
120	3.9	3.1	2.7	2.5	2.3	2.2	1.8	1.6	1.3
0	3.8	3	2.6	2.4	2.2	2.1	1.8	1.5	1

Table 2: Calculation of Fisher's Ratio

	Brass				Aluminum				Teflon			
K	1.21	SS	DOF	F value	1.90	SS	DOF	F value	1.88	SS	DOF	F value
A	-0.26	0.54	1	0.24	-0.40	1.28	1	3.2	-0.87	6.05	1	46.54
B	0.30	0.72	1	0.32	.16	0.20	1	0.5	0.088	0.06	1	0.46
C	0.01	0.0008	1	0.00036	-0.08	0.05	1	0.125	-0.0157	0.0019	1	0.0146
AB	-0.09	0.06	1	0.027	-0.08	0.05	1	0.125	-0.13	0.14	1	1.07
BC	0.10	0.08	1	0.036	0.16	0.2	1	0.5	-0.0907	0.06	1	0.46
CA	-0.18	0.25	1	0.112	-0.003	0.000072	1	0.00018	-0.191	0.29	1	2.23
ABC	-0.19	0.28	1	0.126	-0.33	0.87	1	2.17	0.0643	0.03	1	0.23
SSR		1.93	7			2.65	7			6.63	7	
SST		4.15	15			3.05	15			6.76	15	
SSE		2.22	8			0.4	8			0.13	8	

3.5 Calculation of optimum value and comparison of resulted surface roughness values

Table 3: Experimental Details of Brass, Aluminum and Teflon

ALUMINIUM			BRASS			TEFLON		
Exp	Linear	Non-Linear	Exp	Linear	Non-Linear	Exp	Linear	Non-Linear
1.33	1.74	1.71	0.90	1.23	1.16	0.74	1.48	1.39
1.85	1.82	1.80	1.43	1.22	1.24	1.20	1.49	1.53
1.50	1.58	1.60	0.67	0.93	0.91	0.87	1.39	1.09
2.97	2.14	2.20	2.38	1.49	1.61	2.99	2.35	2.79
2.65	2.06	2.12	1.18	1.18	1.66	2.21	2.27	1.77
1.49	1.98	1.87	0.9	1.19	1.16	2.87	2.26	1.82
2.15	2.22	2.24	1.36	1.48	1.41	2.95	2.36	2.87
1.35	1.66	1.67	0.82	0.92	0.99	1.23	1.41	1.07

Non-Linear Regression Equation:

$$y_1 = 1.88 - 0.8x_1 + 0.88x_2 - 0.157\,x_3 - 0.13x_1x_2 + 0.0907\,x_2x_3 - 0.19x_1x_2 - 0.0643\,x_1x_2x_3 \quad (12)$$

Calculation of Fisher's ratio

Comment 3:
Checking the adequacy using Fishers Table. The F values obtained for Teflon are tabulated in the above table and the values are cross checking in the Fishers table and found with in the limit.
Fisher's Ratio

$$F = \frac{SS}{\frac{SSE}{DOF}} \quad (13)$$

Calculation of Regression Coefficients:

$$K = (Y_1 + Y_2 + Y_3 + Y_4 + Y_5 + Y_6 + Y_7 + Y_8)/8$$
$$A = (Y_1 + Y_2 + Y_3 + Y_4 - Y_5 - Y_6 - Y_7 - Y_8)/8$$
$$B = (Y_1 - Y_2 - Y_3 + Y_4 - Y_5 - Y_6 + Y_7 + Y_8)/8$$
$$C = (Y_1 + Y_2 - Y_3 - Y_4 + Y_5 - Y_6 - Y_7 - Y_8)/8 \qquad (14)$$
$$AB = (Y_1 - Y_2 - Y_3 + Y_4 + Y_5 + Y_6 - Y_7 - Y_8)/8$$
$$BC = (Y_1 - Y_2 + Y_3 - Y_4 - Y_5 + Y_6 - Y_7 + Y_8)/8$$
$$CA = (Y_1 + Y_2 - Y_3 - Y_4 + Y_5 + Y_6 + Y_7 - Y_8)/8$$
$$ABC = (Y_1 - Y_2 + Y_3 - Y_4 + Y_5 - Y_6 + Y_7 - Y_8)/8$$

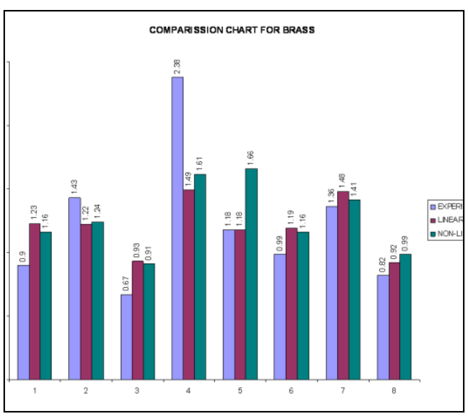

Fig. 6 Comparison of Experimental, Linear and Non Linear Data for Brass

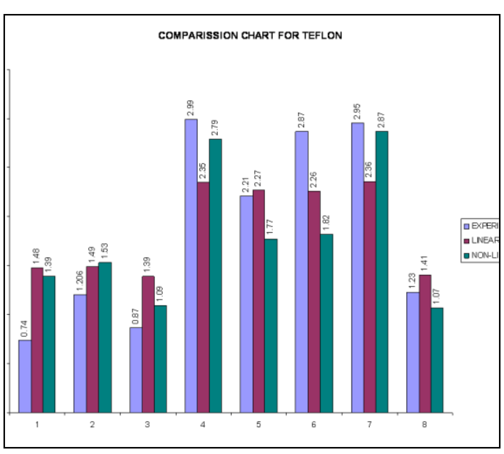

Fig. 7 Comparison of Experimental, Linear and Non Linear Data for Teflon

Table 4: Experimental Details of Brass, Aluminum and Teflon

S.No	Speed (N)	Feed (F)	DOC (D)	Surface finish			Y^2		
				Brass	Al	Teflon	Brass	Al	Teflon
Y1	+	+	+	0.90	1.33	0.74	0.81	1.76	0.55
Y2	+	+	-	1.43	1.85	1.20	2.04	3.42	1.45
Y3	+	-	+	0.67	1.50	0.87	0.44	2.25	0.76
Y4	-	+	+	2.38	2.97	2.99	5.66	8.82	8.94
Y5	-	-	-	1.18	2.65	2.21	1.39	7.02	4.88
Y6	-	-	+	0.9	1.49	2.87	0.98	2.22	8.24
perY7	-	+	-	1.36	2.15	2.95	1.84	4.62	8.70
Y8	+	-	-	0.82	1.35	1.23	0.67	1.82	1.51

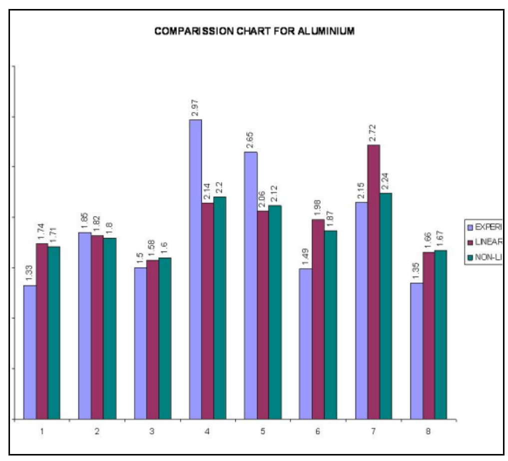

Fig. 8 Comparison of Experimental, Linear and Non Linear Data for Aluminum

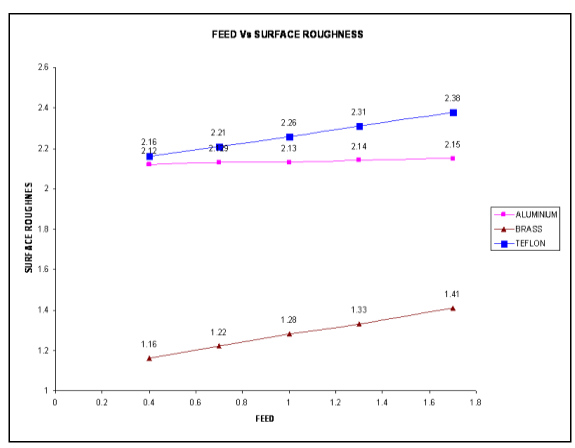

Fig. 9 Graphical Representation of Experimental Data (Feed Vs Surface Roughness)

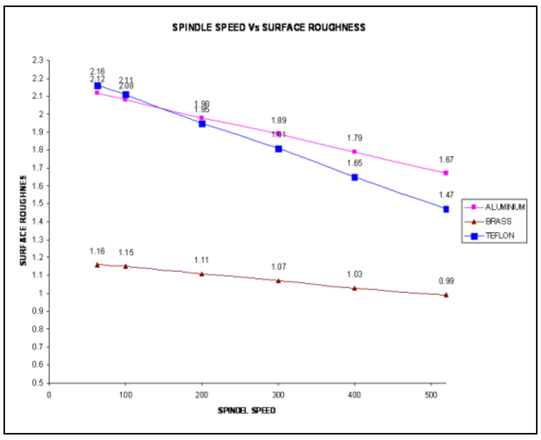

Fig. 10 Graphical Representation of Experimental Data (Speed Vs Surface Roughness)

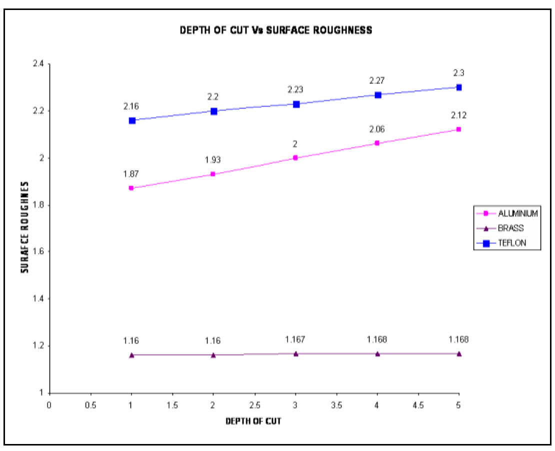

Fig. 11 Graphical Representation of Experimental Data (Depth of Cut Vs Surface Roughness)

4. Conclusions

The optimum values of surface roughness obtained from experimental data are found to be well within the limits for Aluminium, Brass & Teflon. The surface roughness values are higher for aluminum and lower for Teflon. The basic advantage of using RSM Techniques is to determine the optimum conditions for the system or to determine a region of the factor space in which operating conditions are satisfied. The developed model can be used to predict the surface finish in terms of machining process parameters within the range of variables studied. Results also helps to choose the influential process parameters so that desired value of surface finish can be obtained. Response Surface Method is easy and accurate method for developing mathematical models for predicting the surface finish within the working region of the process variables.

5. Future Scope

In the present paper, surface roughness prediction using response surface method with constrained to two limits of maximum and minimum, so in future increase the limits and the Precision will rise. This work can be extended to find the linear and non linear equations for other materials like copper, mild steel and etc.

References

1. *Milton C Shaw (2005), "Metal Cutting Principles", 2nd Edn, Oxford University Press, New York*

2. *Sundaram R M and Lambert B K (1979), "Surface Roughness Variability of AISI 4140 Steel in Fine Turning using Carbide Tools", International Journal of Production Research, Vol. 17(3), 249-258.*

3. *Nowicki Bogdan (1985), "Multiparameter Representation of Surface Roughness", Wear, Vol. 102 (3), 161-176.*

4. *Yusuf Sahin and Riza Motorcu A (2005), "Surface Roughness Model for Machining Mild Steel with Coated Carbide Tool", Materials and Design, Vol. 26(4), 321-326.*

5. *Suryaprakash Ganti and Bharat Bhushan (1995), "Generalized Fractal Analysis and its Applications to Engineering Surfaces", Wear, Vol. 180 (1-2), 17-34.*

6. *Sebastian Mika, Gunnar Ratsch and Klaus-Robert Muller (2001), "Mathematical Programming Approach to the Kernel Fisher Algorithm", Advances in Neural Information Processing Systems, Vol. 13, 591-597, MIT Press.*

7. *Raymond H Myers and Douglas C Montgomery (1975), "Response Surface Methodology: Process and Product Optimization Using Designed Experiments", John Wiley Publication, New York.*

8. *Douglas C Montgomery (1986), "Design and Analysis of Experiments", 5th Edition, John Wiley Student Edition.*

