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Experimental Investigation of Surface Roughness and Cutting Force on Conventional Dry Turning of Aluminium (6061)

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***ABSTRACT**: This paper aims to scrutinize the effect of the cutting speed, feed rate and depth of cut on surface roughness, in turning of Aluminium (6061). The optimized values for these cutting parameters for minimum surface roughness are also obtained.Design of experiments (DOE) were conducted for the analysis of the influence of the turning parameters on the surface roughness by using Taguchi design and then followed by optimization of the results using Analysis of Variance (ANOVA) to find minimum surface roughness. The speed was identified as the most influential process parameter on surface roughness. The optimum surface roughness was reached when the feed rate and depth of cut were set as low as possible.*
***Keywords:** Surface Roughness, Cutting Parameters, Turning, Optimization, ANOVA, Taguchi Techniques, Aluminium (6061)*

I. INTRODUCTION

Surface roughness is used to determine and evaluate the quality of a final product in faced parts. In order to get better surface finish, the proper setting of cutting parameters is crucial before the process takes place. The drastic increase of consumer needs for quality metal cutting related products (more precise tolerance and better surface finish) has driven the metal cutting industry to continuously improve quality control of the metal cutting processes. The quality of surface roughness is an important requirement of many work pieces in machining operations. Within the metal cutting processes, the facing process is one of the most fundamental metal removal operations used in the manufacturing industry. Surface roughness which is used to determine and evaluate the quality of a product is one of the major quality attributes of a faced product. Surface roughness of a machined product could affect several of the product's functional attributes such as contact causing surface friction, wearing, light reflection, heat transmission, ability of distributing and holding a lubricant, coating and resisting fatigue. Therefore, surface roughness is one of the important quality aspects in turning operations. In order to obtain better surface roughness, the proper setting of cutting parameters is crucial before the process takes place [1].

II. LITERATURE REVIEW

Ilhan Asiltürk.et.al., [2011] have presented a paper on title "Determining the Effect of Cutting Parameters on Surface Roughness in Hard Turning Using the Taguchi Method". The study focuses on optimizing turning parameters based on the Taguchi method to minimize surface roughness (Ra and Rz). Experiments have been conducted using the L9orthogonal array in a CNC turning machine. Dry turning tests are carried out on hardened AISI 4140 (51 HRC) with coated carbide cutting tools. Each experiment is repeated three times and each test uses a new cutting insert to ensure accurate readings of the surface roughness. The statistical methods of signal to noise ratio (SNR) and the analysis of variance (ANOVA) are applied to investigate effects of cutting speed, feed rate and depth of cut on surface roughness. Results of this study indicate that the feed rate has the most significant effect on Ra and Rz. In addition, the effects of two factor interactions of the feed rate-cutting speed and depth of cut-cutting speed appear to be important. S/N ratios and level values were calculated by using Eq. "the smaller-the better" in the MINITAB 14 Program. The results obtained in this study are as below:

• L9 orthogonal array was selected for three different levels of cutting speed, feed rate and depth of cut, which were cutting factors, by using the Taguchi method. As a result, nine experiments were conducted instead of the full factorial 27 experiments. Ra and Rz‟ S/N ratios were found as a result of experiments conducted according to the L9 orthogonal array. The maximum value was found by using the S/N ratio equation of „„„the smaller-the better,"" the maximum S/N ratio yielded optimum cutting parameters. Optimum cutting conditions-which correspond to maximum 2.32 S/N value of the smaller Ra value for the smaller surface roughness in hard turning operation (2 1 2) were found to be 120 m/min for the cutting speed, 0.18 mm/rev for the feed rate and 0.4 mm for the depth of cut. Optimum cutting conditions-which correspond to maximum 18.75 S/N value of Rz value (3 1 1) were found to be120 m/min for the cutting speed, 0.18 mm/rev for the feed rate and 0.4 mm for the depth of cut.

• Variance analysis was applied to S/N ratios to discover interactions between cutting parameters relating to Ra and Rz. According to the ANOVA analysis, the feed rate has an effect on Ra and Rz at a reliability level of 95%. Any difference (variance) was not observed for the cutting speed and the depth of cut at the reliability level of 95%.

• The numbers of experiments in the same or similar area in hard turning operations were reduced by using the Taguchi experimental design to determine optimum cutting conditions. Satisfying results were obtained sothat they may be used in future academic and industrial studies.

• Their study suggest that developed model can be used in the metal machining industries in order to determine the optimum cutting parameters for minimum surface roughness.

M Kaladhara. et. al. [2012], have presented a paper on title" Determination Of Optimum Process Parameters During Turning Of AISI 304 Austenitic Stainless Steels Using Taguchi Method ANOVA" [Ref 9].They have tried to Investigate the process parameters on surface finish and Material Removal Rate to obtain the optimal setting of these parameters. They have used ANOVA to analyze the influence of cutting parameters during machining. In their work AISI 304 Austenitic Stainless Steels work pieces were turned on CNC lathe by using physical vapor deposition coated ceramic insert (TiCN-TIN) of 0.4, and 0.8 Nose Radii. The analysis has been made with the help of a software package MINITAB 14.Their result revealed that the feed and Nose radius is the most significant process parameter on work piece surface roughness and the depth of cut and feed are the significant factor on MRR. They have also predicted optimal range and optimal level of parameters for responses with TAGUCHI Approach.

Ananthakumar. P et.al.,[2013] have presented a paper on title "Optimization Of Turning Process Parameters Using Multivariate Statistical Method-PCA Coupled With Taguchi Method[Ref 3]The work applies to optimize the process parameter for turning medium carbon steel bar using HSS tool bit via conventional machining. Optimizing one quality attribute may lead to loss of other quality attribute. Hence in order to simultaneously satisfy all the three quality requirements a multi objective optimization is required. To achieve this exploration of grey relational theory, utility concepts are attempted. To meet the basic assumption of Taguchi method that quality attributes should be uncorrelated the study applies PCA based multivariate statistical method and eliminates correlation that exists in between the responses. Experiments have been conducted based on Taguchi"s L9 Orthogonal array design with different combinations of process control parameters: (Cutting speed, Feed, Depth of cut). Surface roughness, Material removal rate, Tool Flank wear are the response parameters that will be optimized. The obtained result will be verified through confirmatory test. This work highlights the effectiveness of proposed method for solving multi objective optimization of turning process. The above said methodology has been found fruitful in the cases where simultaneous optimization of huge responses is required. Back rack angle 10°,Side rack angle 12°,Side relief angle 07°,End relief angle 07°,Major cutting edge 15°,Minor cutting edge 15°,Nose radius 0.8 mm, Size of square tool bit 12 *12 mm2,Length of tool bit 100 mm. In this experiment HSS TOOL BITS with 10% Cobalt (SAE T42) is used. This quality of tool bits retains its hardness even at very high temperatures and is recommended where the generation of heat is very high and the tool should not get blunt at high temperatures. Work piece of standard dimensions was used for machining. Diameter of work piece: 38 mm, length of work piece: 100 mm. length of turning: 40 mm. AISI: 1040 (ISO 683-1:C40) medium carbon steel is selected for workpiece material because it is used wide variety of general purpose engineering.

These steels are of particular importance because of unique combination of strength and toughness after heat treat treatment. Medium Carbon Steels are similar to low carbon steel except that the carbon ranges from 0.30 to 0.60 & the manganese from 0.50 to 0.90%. The instrument used to measure surface roughness was "Time surface roughness tester TR 100". Surface roughness readings were recorded at three locations on the work piece and the average value was used for analysis Specifications of Instrument used: Tracing length 6 mm, tracing speed 1 mm/sec, cutoff lengths 0.25 mm/0.8 mm/ 2.5 mm. Measuring range Ra:0.05- 10μm, Rz:0.1-50μm. Metzer tool maker"s microscope is used to measure the cutting tool flank wear. All statistical works and including principal component analysis with proposed algorithm are performed with the help of MINITAB R14 statistical software. At the end, results of proposed algorithm are compared with the results of confirmatory test and existing methods. Here larger the better criterion is used for optimizing the overall MP Index.

From the analyses, the following conclusions have been given

1. Here the application of PCA with grey or utility based Taguchi method has been recommended for the optimization of manufacturing processes like turning processes which are having correlated multiple responses to find the optimum combination of process parameters with experimental objectives.
2. PCA has been utilized here to eliminate the correlation between the responses by converting correlated responses in to uncorrelated quality indices called principal components to meet the basic assumption of Taguchi optimization.
3. By comparing the existing Taguchi based multi response optimization method the proposed approach meet the objectives of multiple responses simultaneously and produce best optimum combination of process parameter.
4. Over all multi response performance index based on PCA serves as a single response for solving multi response problem, really it will helpful where large number of responses to be optimized simultaneously.
5. From the experimentation and analysis depth of cut and feed showing greater influence than speed on surface roughness tool flank wear & material removal rate simultaneously.
6. The proposed approach can be recommended for off line quality control of process and product to improving the quality.

III. EXPERIMENTAL WORK

Workpiece material

Standardized material were selected to ensure consistency of the alloy, which was a common mils steel alloy used in industry in the form of bars with the size of diameter 40 mm, 100mm length so as to fit under the chuck. The Aluminium (6061) chosen for turning is actually a Heat Treatable Alloy manufactured in the form of bars. The inputs which were fed manually include dimensions of the work piece, cutting parameters depth of cut in mm, Speed available was 50-1500 rpm and feed in mm/min.This standard structural alloy, one of the most versatile of the heat-treatable alloys, is popular for medium to high strength requirements and has good toughness characteristics. Applications range from transportation components to machinery and equipment applications to recreation products and consumer durables.

Table1: Chemical Composition of Aluminium (6061) alloy

Copper	0.15-0.4%
Magnesium	0.7-1.2%
Silicon	0.4-0.8%
Iron	0.7% max
Manganese	0.2-0.8%
Other	0.4%

Fig. 1: Aluminium (6061)workpiece

Experimental plan

The experiment was conducted on a centre lathe with work piece mounted between 3-jaw chuck and tailstock using HSS tool. The cutting force was measured by lathe tool dynamometer during the turning operation. The surface roughness of machined surface has been measured by a Surface Roughness Measuring instrument, the Surtronic 3+, is a portable, self-contained instrument for the measurement of surface texture and is suitable for use in both the workshop and laboratory. Parameters available for surface texture evaluation are: Ra, Rq, Rz (DIN), Ry and Sm. The parameters evaluations and other functions of the instrument are microprocessor based. The measurements results are displaced on an LCD screen and can be output to an optional printer or another computer for further results.

Fig. 2: Lathe tool dynamometer (top) and Surtronic 3+, roughness testing machine in use

Design of Experiment

Taguchi’s parametric design is the effective tool for robust design. It offers a simple and systematic qualitative optimal design to a relatively low cost. Taguchi method of off-line (Engineering) quality control encompasses all stages of product/process development. However the key element for achieving high quality at low cost is Design of Experiments (DOE). In this paper, Taguchi’s (DOE) approach is used to analyze the effect of process parameters like cutting speed, feed and depth of cut on Surface Roughness of Aluminium (6061) work material while turning it to obtain an optimal setting of these parameters that may result in good surface finish. As per Taguchi’s method, the selected orthogonal array must be greater than or equal to the total degree of freedom required for the experiment. So, an L27 orthogonal array was selected for the present work. The non-linear relationship among the process parameters can be revealed when more than two levels of the parameters are considered. Hence each selected parameter was analyzed at three levels. The process parameters and their values at three levels are given in Table 2.

Table 2: Cutting parameters and levels

Code	Cutting parameter	Level 1	Level 2	Level 3
A	Depth of cut ‘d’ (mm)	0.6	1.2	1.8
B	Speed‘s’ (rpm)	156	289	409
C	Feed ‘f ‘ (mm/rev)	0.05	0.10	0.15

Analysis

ANOVA was used for analyzing the results obtained. ANOVA is used in the analysis of comparative experiments, those in which only the difference in outcomes is of interest. The statistical significance of the experiment is determined by a ratio of two variances. This ratio is independent of several possible alterations to the experimental observations. Adding a constant to all observations does not alter significance. Multiplying all observations by a constant does not alter significance. So in ANOVA, statistical significance results are independent of constant bias and scaling errors as well as the units used in expressing observations.

IV. RESULTS AND DISCUSSION

The pieces of work material were set so as to conduct turning process three times on a single work piece while calculating the average roughness value, simultaneously by the stylus of the measuring instrument. To more closely replicate typical finish turning processes and to avoid excessive vibrations due to work place dimensional inaccuracies and defects, each work piece was rough-cut just prior to the measured finish cut. Thus simultaneously we could choose the machining zero required for generating cutting profile with reference to our work piece dimensions. On each piece, there were three different values of feed at one depth of cut and at a single speed. Surtronic 3+ instrument, used for surface roughness measurement, has a pick-up with a skid which is used to travel automatically through a drive motor. Thus such travel would at least require a distance of at least 8 mm. Thus we require appropriate surface travel distance on turned Aluminium (6061) work piece. These dimensions were taken so as to keep travel the stylus on the best surface. The obtained results were analyzed using Minitab software and all the values are shown in the Table 3.

Table3: Machine readings and calculations of Roughness

S. No.	Depth of Cut (d) Mm	Speed (s) Rpm	Feed (f) mm/rev	Roughness (Ra) µm	Cutting force (Fc) kgf
1	0.6	156	0.05	2.2	3
2	0.6	289	0.1	3.21	3.67
3	0.6	409	0.15	4.25	5.33
4	1.2	156	0.05	1.77	5
5	1.2	289	0.1	2.46	5.67
6	1.2	409	0.15	3.99	6.67
7	1.8	156	0.05	2.53	6.67
8	1.8	289	0.1	2.95	10.33
9	1.8	409	0.15	3.64	14.67

The main effects plot for Means andSN Ratios are shown in Fig. 3 and Fig. 4 respectively.They show the variation of individual response with three parameters i.e. speed, feed and depth of cut separately. In the plot x-axis represents the value of each process parameter and y-axis is response value. Horizontal line indicates the mean of the response. The main effect plots are used to determine the optimal design conditions to obtain the optimal surface finish. In Fig. 4, the main effect plot for SN ratios of the Surface roughness is shown. Signal-to-Noise ratio of common interest for optimization for surface roughness is smaller the better.

Table 4: **Response Table for Signal to Noise Ratios**

Level	A	B	C
1	16.636	6.948	6.948
2	5.820	9.228	9.228
3	2.465	8.746	8.746
Delta	14.171	2.279	2.279
Rank	1	2.5	2.5
Nominal is best (10×Log10(Ybar^2/s^2))			

Table 5: **Response Table for Means**

Level	A	B	C
1	3.612	3.532	3.532
2	4.260	4.714	4.714
3	6.795	6.422	6.422
Delta	3.183	2.890	2.890
Rank	1	2.5	2.5

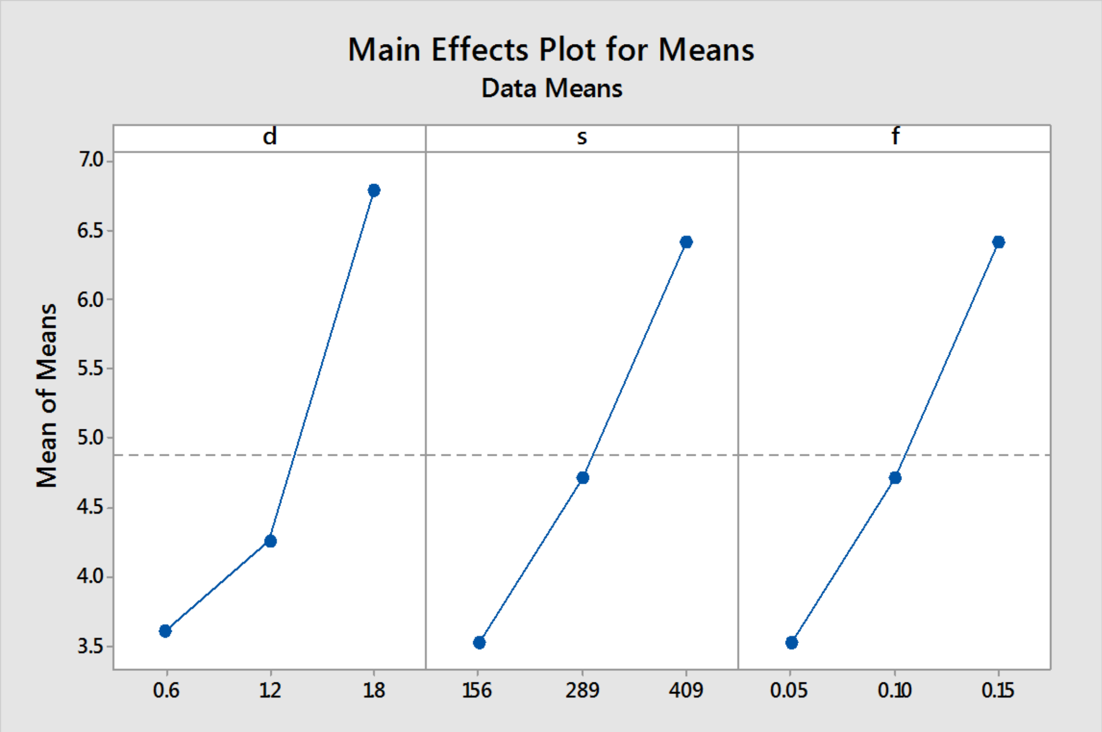

Fig. 3: Main effect plot for Means

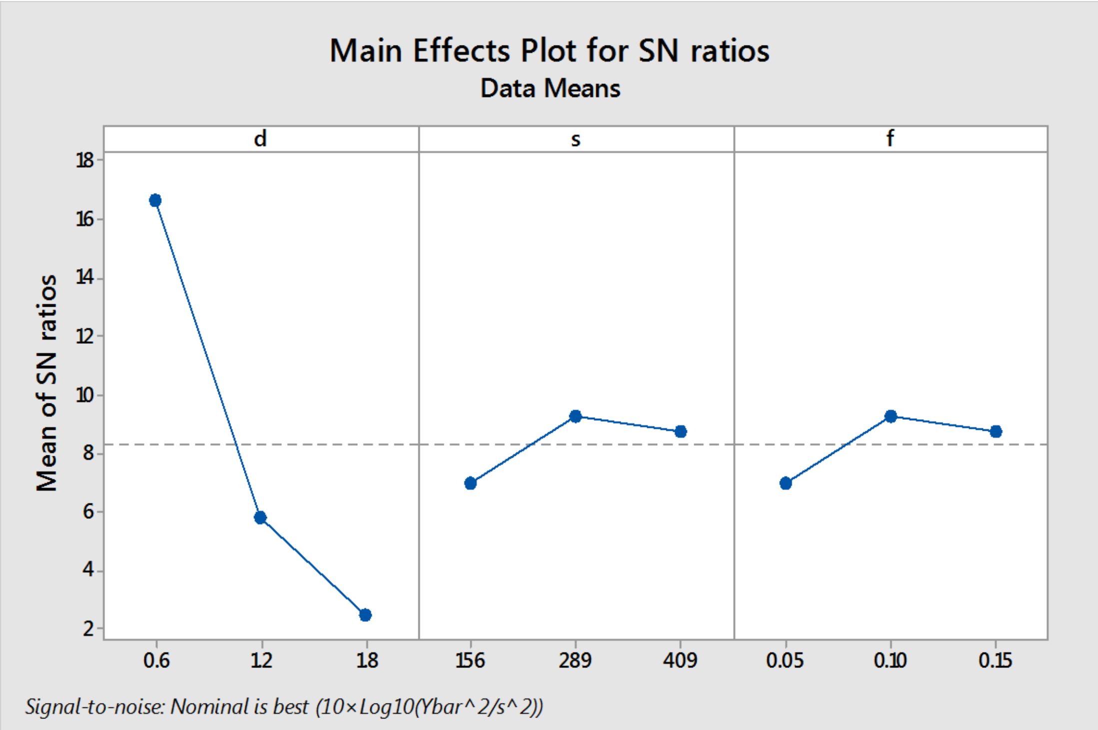

Fig. 4: Main effect plot for S/N ratios

Cutting force, C_f versus d, s, f

Table 6: Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
d	2	68.90	34.450	11.38	0.022
s	2	24.18	12.090	3.99	0.111
Error	4	12.11	3.026		

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
1.73963	88.49%	76.98%	41.74%

Table 7: Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	6.778	0.580	11.69	0.000	
D					
0.6	-2.778	0.820	-3.39	0.028	1.33
1.2	-0.998	0.820	-1.22	0.291	1.33
S					
156	-1.888	0.820	-2.30	0.083	1.33
289	-0.221	0.820	-0.27	0.801	1.33

Regression Equation

$C_f = 6.778 - 2.778\, d_{0.6} - 0.998\, d_{1.2} + 3.776\, d_{1.8} - 1.888\, S_{156} - 0.221\, S_{289}$
$+ 2.109\, S_{409}$

Surface roughness, R_a versus d, s, f

Table 8: Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
d	2	0.3578	0.1789	1.76	0.283
s	2	4.8457	2.4228	23.84	0.006
Error	4	0.4066	0.1016		
Total	8	5.6101			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.318814	92.75%	85.51%	63.31%

Table 9: Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	3.000	0.106	28.23	0.000	
d					
0.6	0.224	0.150	1.49	0.210	1.33
1.2	0.260	0.150	-1.73	0.158	1.33
s					
156	0.827	0.150	-5.50	0.005	1.33
289	0.129	0.150	-0.86	0.438	1.33

Regression Equation

$R_a = 3.000 + 0.224\, d_{0.6} - 0.260\, d_{1.2} + 0.036\, d_{1.8} - 0.827\, S_{156} - 0.129\, S_{289}$
$+ 0.956\, S_{409}$

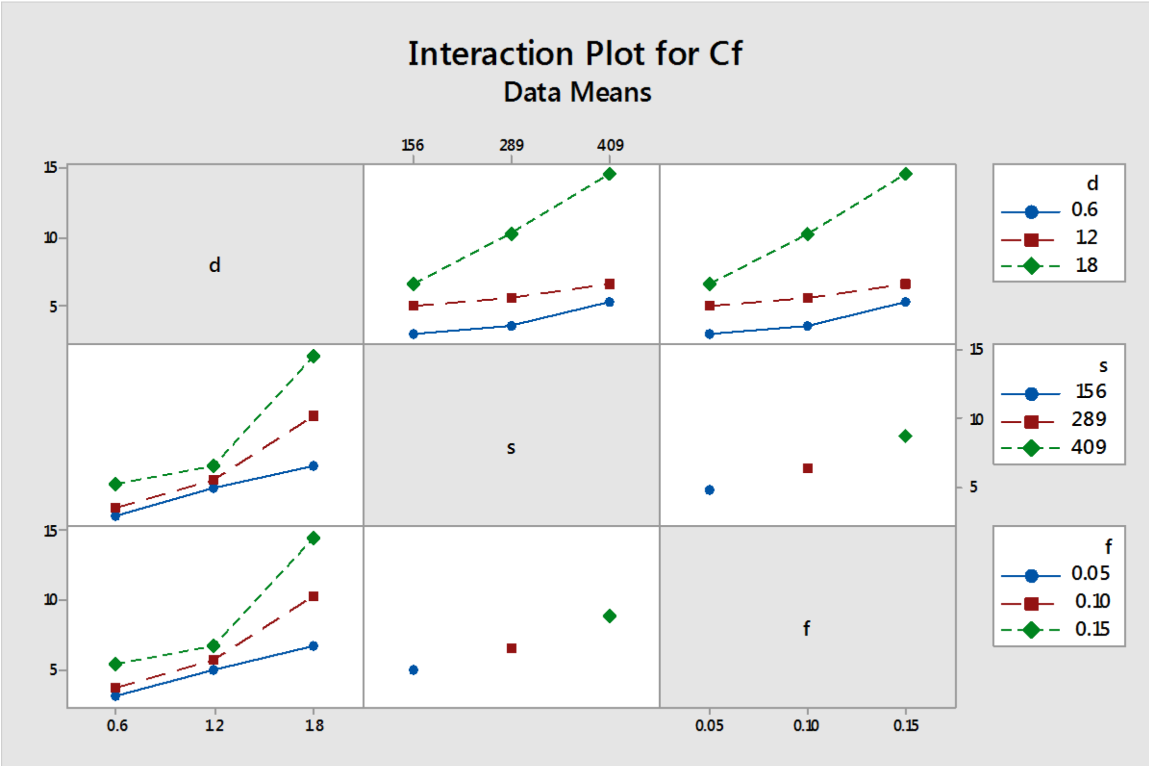

Fig. 5: Interaction Plot for C_f

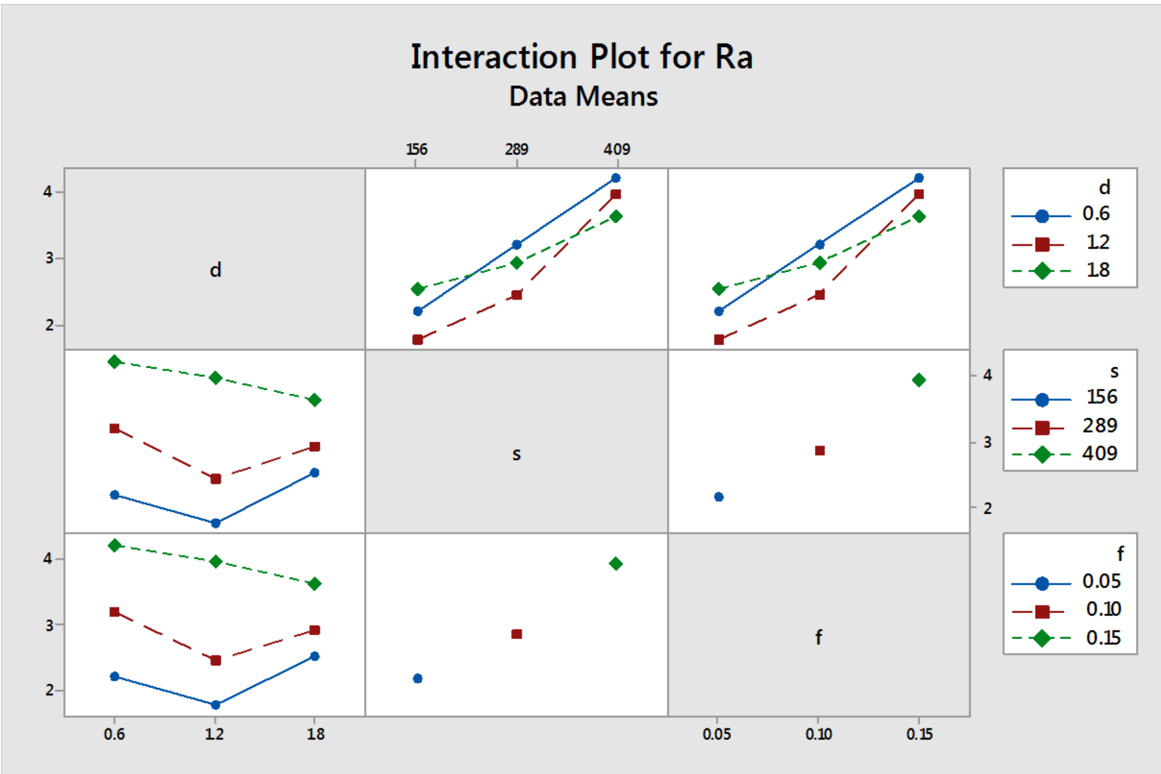

Fig. 6: Interaction Plot for R_a

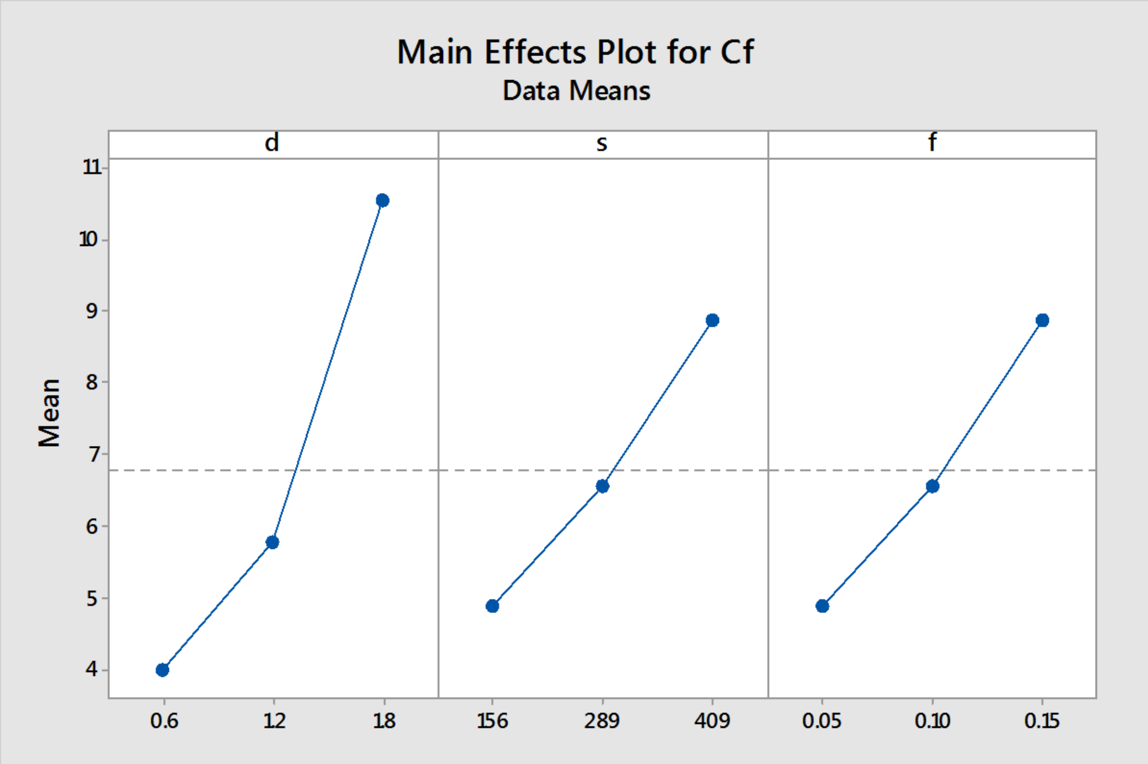

Fig. 7: Main Effect Plot for C_f

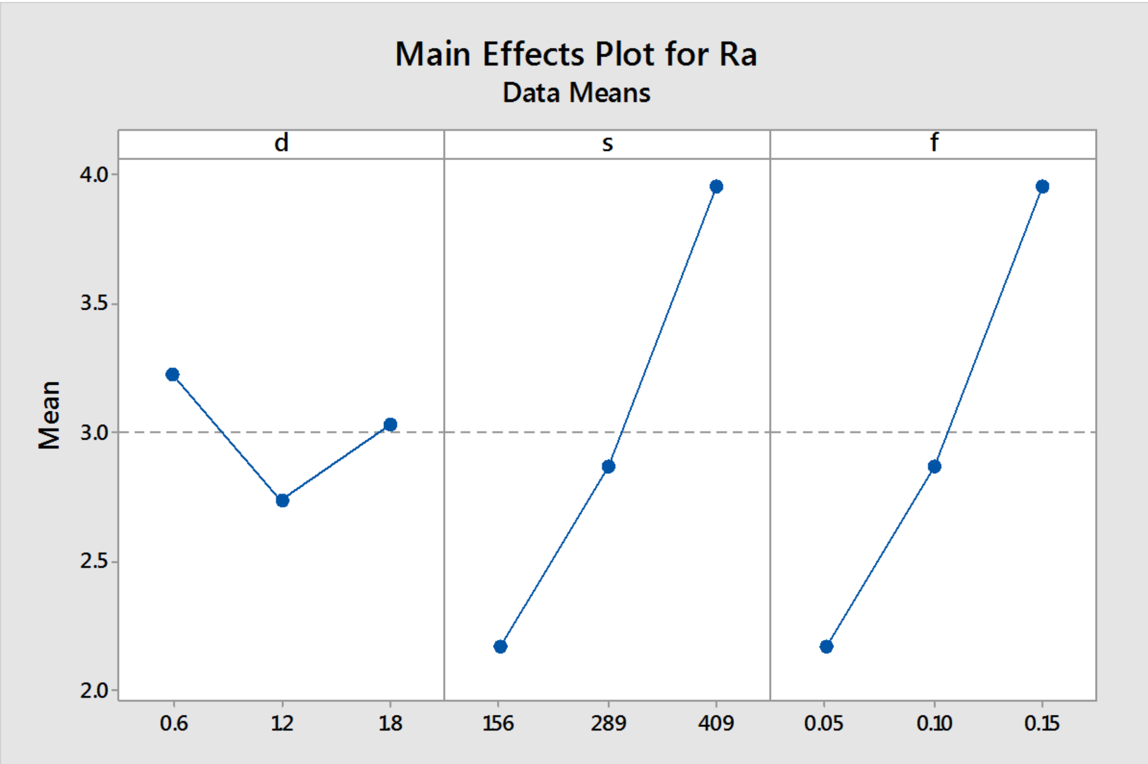

Fig. 8: Main Effect Plot for R_a

It is evident from Fig. 7 that C_f is minimum at the first level of depth of cut (*A*), speed (*B*) and feed (*C*).
It is evident from Fig. 8 that R_a is minimum at the second level of depth of cut (*A*), first level of speed (*B*) and first level of feed (*C*).

V. CONCLUSIONS

This work presented an experimentation approach to study the impact of machining parameters on surface roughness and cutting force. A Systematic approach was provided to design and analyze the experiments, and to utilize the data obtained to the maximum extent. The following are conclusions drawn based on the experimental investigation conducted at three levels by employing Taguchi technique to determine the optimal level of process parameters.

- Increase in cutting speed increase the surface roughness, but as speed increases the cutting force also increases.
- Increase in feed rate adversely affects the surface finish slightly, but a large increase deteriorates surface finish to a large extent.
- Surface roughness initially decreased and then increased on increase in depth of cut whereas cutting force increases substantially on increase in depth of cut.
- ANOVA and F-test reveals that the Speed is dominant parameter. Feed is highly correlated with other terms.
- The optimal combination process parameters for the work piece under consideration with regards to minimum surface roughness or maximum surface finish is obtained at depth of cut 1.2 mm, speed 156 rpmand feed rate 0.05 mm/rev. The minimum cutting force is obtained at depth of cut 0.6 mm, speed 156 rpm and feed rate 0.05 mm/rev.

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