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Optimization in Turning of Ti-6AL-4V Using Anova and Regression Analysis

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Abstract-Surface roughness is an important factor to evaluate cutting performance. The primary factors such as speed, feed, depth of cut, type of material, tool geometry etc. have high impact on surface roughness. So it is a measure of product quality since it greatly influences the performance of mechanical parts as well as production cost. This paper developed a regression model and carried out Analysis of variance (ANOVA) to investigate the machining parameters such as cutting speed, feed rate, depth of cut and nose radius, affecting the roughness of surface produced in wet turning process of Ti-6Al-4V work material using CVD coated carbide inserts. The experiment has been designed and carried out on the basis of a three level, Taguchi's 27 Orthogonal Array ((OA) design.
Key words: Wet turning, ANOVA, Regression analysis

I. INTRODUCTION

Titanium alloys are considered to be difficult-to-machine metals in the industry. The low thermal conductivity, low elastic modulus, high temperature strength, and high chemical reactivity of titanium alloys induce many challenges in machining processes. Ti-6Al-4V one of the most important titanium alloy. Ti-6Al-4V alloy belongs to the group of $\alpha + \beta$ titanium alloys (E O Ezugwu et al.,2003). Ti-6Al-4V are light weight metals with excellent material properties such as high strength-to-weight ratio at elevated temperatures, excellent creep strength, corrosion resistant, good thermal stability, heat treatable, good forge-ability, and good fabricability. These material properties offer the performance required by the aerospace industry (Vinayagamoorthy R and Anthony Xavior M, 2013). Engine manufacturing industries are also use titanium alloys to make most of the front section of the engine. Most of the titanium products within the engine manufacturing industries are produced by turning and milling processes. Due to inherent material properties of this alloy, it has many machining problems occur. To ensure quality of machined products at minimum machining costs and maximum machining effectiveness, it is very important to select optimum parameters when metal cutting machine tools are employed. Process modeling and optimization are the two important issues in manufacturing products. The selection of optimal cutting parameters, like depth of cut, feed, cutting speed and tool insert, is a very important issue for every machining process. In today's manufacturing environment, many industries have attempted to introduce flexible manufacturing systems (FMS) as their strategy to adapt to the ever changing competitive market requirements. To ensure quality of machined products to reduce the machining costs and to increase the machining effectiveness, it is very important to select appropriate machining parameters when machine tools are selected for machining.
Optimal combination of machining parameters in machining process gives the lower surface roughness. Surface finish is an essential requirement in determining the surface quality of a product.

II. LITERATURE REVIEW

Recent research studies on metal cutting have focused on the different aspects of tool wear, tool life, cutting forces and on the effect of varying different machining parameters on the resulting surface roughness. The literature reported several ways to improve and ensure efficient and economic machining of different type of materials. Ersan Aslan et al., 2006 have optimized cutting parameters (speed, feed, depth of cut) on two performance measures-flank wear and surface roughness in hard turning of steels with ceramic tools. This was achieved by using Taguchi techniques. The combined effects were then studied using ANOVA. Al-Refaie A et al., (2010) conducted series of experiments that aimed at determining the optimal parameter design by regression and grey relational analysis. Based on the experimental result multiple regression analysis were carried out and designed the optimal combination. Also the grey relational analyses were done and they found that the proposed approach provided almost similar results as the grey analysis.
Kaladhar M et al., (2012) conducted a turning experiment on AISI 304 austenitic stainless steel using PVD coated cermet (TiCN -

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TiN) inserts. They found that the effect of process parameters such as cutting speed, feed, depth of cut and nose radius on surface finish and material removal rate. Analysis Of Variance (ANOVA) were carried out for finding the percentage contribution of process parameters. Their study showed that the feed is the most dominant factor followed by nose radius for surface roughness. In case of material removal rate, depth of cut is the significant one followed by the feed. Also they developed a multiple linear regression model. Sudhansu Ranjan Das et al.,(2013) developed the prediction model for surface roughness in turning operation. The regression model was developed based on the cutting parameter. By using multiple regression and Analysis of Variance (ANOVA) a strong linear relationship among the parameters (velocity, feed rate and depth of cut) and the response (surface roughness) was found.

Krishan Prasad D V V (2013) investigated the influence of cutting parameters on turning process using ANOVA analysis. The machining parameters chosen for the study are rake angle, speed, feed and depth of cut. Using ANOVA analysis he revealed that feed is the most significant parameter for surface roughness. Rishu Gupta and Ashutosh Diwedi (2007) applied Taguchi method for finding out the optimal value of surface roughness and material removal rate under optimum cutting condition in turning of Aluminium Alloy 6061. The experiment was designed by using Taguchi method and experiments were conducted and results were analyzed with the help of ANOVA. After the analysis of experimental observations they found that the depth of cut followed by cutting speed influence material removal rate. They also found that feed and nose radius influences the surface roughness.

Nexhat Qehaja etal. (2014), presented the effect of feed rate, tool geometry, nose radius, and machining time on surface roughness by developing model based on response surface method during dry turning of cold rolled steel using coated tungsten carbide tool inserts. The experiment has been designed and carried out on the basis of a three level factorial design. Also the regression analysis in modeling of surface roughness was carried out. Based on the regression equation generated, they found that the best combination of independent variables for achieving the optimization of cutting processes. Many research works are carried out based on the regression analysis and ANOVA. But only few researchers taken the input parameters cutting speed, feed, depth of cut and nose radius in the turning of Ti-6Al-4V using regression and ANOVA analysis. Therefore proposed work fill this research gap by including the machining parameters cutting speed, feed, depth of cut and nose radius. The methodology adopted for generating results are regression and ANOVA.

III. EXPERIMENTAL SETUP

Ti-6Al-4V cylindrical piece of 37.9 mm diameter and 125 mm length was used as a work piece material. Chemical composition of work piece material is shown in Table 1.

Table 1: Chemical composition of Ti-6Al-4V

Chemical composition of Ti-6Al-4V									
Elements	Ti	Al	V	Fe	O	C	N	Y	H
Percentage	89.598	6.1	4	.16	.11	.02	.01	0.001	0.001

The multi layered CVD coated carbide inserts which produced by Taegutech, Japan were used in turning tests. Different nose radius of 0.1mm, 0.4mm, 0.5mm are selected for this study. The inserts were clamped with a designation of TDJNR 2525 M15 tool holder. The turning tests were performed (Figure 1) on Schaublin 130-CNC lathe having a maximum spindle speed of 3000 rpm in wet conditions. Surface roughness (*Ra*) was measured by using Taylor/Hobson Precision Form Talysurf. Before and after the machining diameter of work piece are taken for finding the material removal rate.

Figure 2: Schaublin 130-CNC

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Cutting speed, feed, depth of cut and nose radius are chosen as the input parameters. The machining parameters and their levels used in the machining tests are given in Table 2. Design of experiment was determined with the help of the statistical software Minitab 16. Taguchi's L27 Orthogonal Array was selected for the experimental work.

Table 2: Experimental machining parameters

Machining Parameters	Levels		
	1	2	3
Cutting speed (m/min)	50	60	70
Feed rate(mm/rev)	0.010	0.020	0.030
Depth of cut(mm)	0.02	0.035	0.05
Nose radius(mm)	0.1	0.4	0.5

IV. RESULTS AND DISCUSSIONS

Experimental results and its S/N ratio values are given in the below Table 3. "Lower the better" criteria were used to finding the S/N Ratio values of surface roughness. Taguchi's S/N Ratio for (LB) Lower-the-better is expressed as $S/N_S = -10\log\frac{1}{n}\sum_{i=1}^{n} y_i^2$.

Table 3: Experimental observations and S/N values

Trial No.	Velocity m/min	Feed mm/rev	Depth of cut Mm	Nose radius mm	Ra μm	S/N Ratio of Surface Roughness
1	50	0.010	0.02	0.1	0.2501	12.0377
2	50	0.010	0.02	0.1	0.2486	12.0899
3	50	0.010	0.02	0.1	0.2600	11.7005
4	50	0.020	0.035	0.4	0.3377	9.4294
5	50	0.020	0.035	0.4	0.3218	9.8483
6	50	0.020	0.035	0.4	0.3196	9.9079
7	50	0.030	0.05	0.5	0.4306	7.3185
8	50	0.030	0.05	0.5	0.4438	7.0563
9	50	0.030	0.05	0.5	0.4282	7.3671
10	60	0.010	0.035	0.5	0.1856	14.6284
11	60	0.010	0.035	0.5	0.1898	14.4341
12	60	0.010	0.035	0.5	0.1782	14.9818
13	60	0.020	0.05	0.1	0.4001	7.9566
14	60	0.020	0.05	0.1	0.4120	7.7020

15	60	0.020	0.05	0.1	0.4134	7.6726
16	60	0.030	0.02	0.4	0.4923	6.1554
17	60	0.030	0.02	0.4	0.4989	6.0398
18	60	0.030	0.02	0.4	0.5001	6.0206
19	70	0.010	0.05	0.4	0.2000	13.9794
20	70	0.010	0.05	0.4	0.2006	13.9534
21	70	0.010	0.05	0.4	0.2112	13.5061
22	70	0.020	0.02	0.5	0.2699	11.3759
23	70	0.020	0.02	0.5	0.2769	11.1755
24	70	0.020	0.02	0.5	0.2961	10.5712
25	70	0.030	0.035	0.1	0.5790	4.7464
26	70	0.030	0.035	0.1	0.5901	4.5815
27	70	0.030	0.035	0.1	0.5961	4.4936

A. ANOVA Analysis

Table 4: ANOVA for Surface Roughness

Parameters	DF	Seq SS	Adj SS	Adj MS	F Value	P Value
Cutting speed	2	0.437	0.437	0.218	3.85	0.040
Feed rate	2	253.635	253.635	126.817	2237.15	0.000
Depth of cut	2	0.027	0.027	0.014	0.24	0.790
Nose radius	2	37.969	37.969	18.984	334.90	0.000
Error	18	1.020	1.020	0.057		
Total	26	293.088				

S = 0.238090 R-Sq = 99.65% R-SQ(adj) = 99.50%

From Table 4 it is observed that feed is the most significant factor followed by nose radius on surface roughness and depth of cut having very less effect on surface roughness. The data are further analyzed with the help of main effect plot formed with the help of Minitab 16 software. Figure 2 shows the main effect plot for surface roughness. In the plots, the x-axis indicates the value of each process parameter at three level and y-axis is the response (surface roughness) value. The main effects plots are used to determine the optimal design conditions to obtain the optimum surface finish. The results show that with the increase in feed there is a continuous increase in surface roughness value. Here also, the main effect plot shows the decrease in roughness with increased nose radius. According to this main effect plot, the optimal conditions for surface roughness are: cutting speed at level-3 (70 m/min, feed rate at level-1 (0.010 mm/rev), depth of cut at level-1 (0.02mm) and nose radius at level-3 (0.4 mm).

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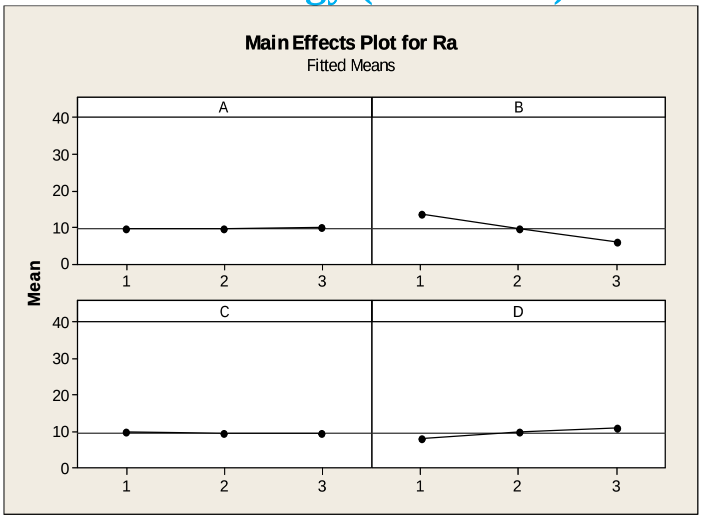

Figure 2: Main effect plots for surface roughness

B. Regression Analysis

A general multiple linear regression equation is implemented to explore the relationship between the machining parameters and the measured surface roughness (Vikas Upadhyay et al.,2013). The regression equation is as follows:

Ra = 0.0881014 + 0.000997222 Velocity + 14.6389 Feed + 0.174074 DOC -0.281449 NR

(R-Sq = 98.06%)

For finding the statistical validity of the model, normal probability plot and residuals plot for surface roughness is developed. The residuals are found to follow a straight line in normal plot which indicated that the errors are distributed normally which is shown in Figure 3. However the residuals versus predicted plot found randomly scattered within constant variance are shown in Figure 4.

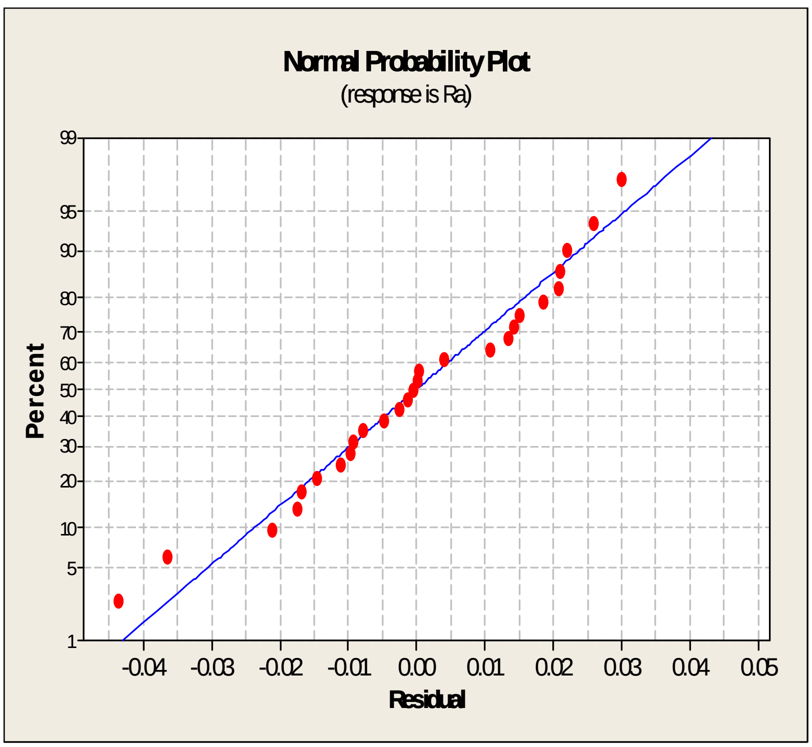

Figure 3: Normal probability plots of the residuals

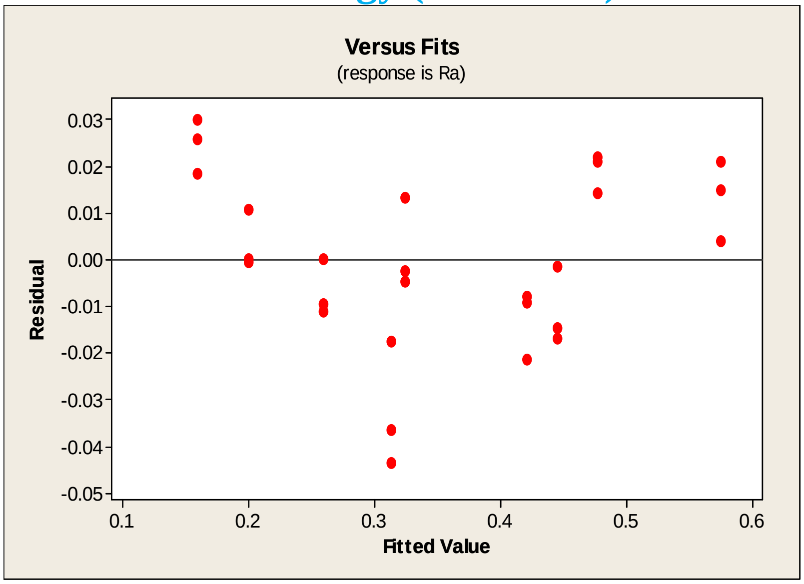

Figure 4: Residuals versus Fitted Values for surface roughness

V. CONCLUSION

The experimental investigation conducted to turn Ti-6Al-4V using CVD coated carbide inserts at three levels. Analysis of variance revealed that the feed rate is the most significant factor followed by nose radius for the selected output parameter, surface roughness. The machining parameter depth of cut has less effect on surface roughness. The optimal combination of process parameters for minimum surface roughness is obtained at 70m/min cutting speed, 0.010 mm/rev feed rate, 0.02 mm depth of cut and 0.5mm nose radius. A multiple linear regression model is developed for surface roughness. The developed model is found reasonably accurate and can be used for prediction within the limit.

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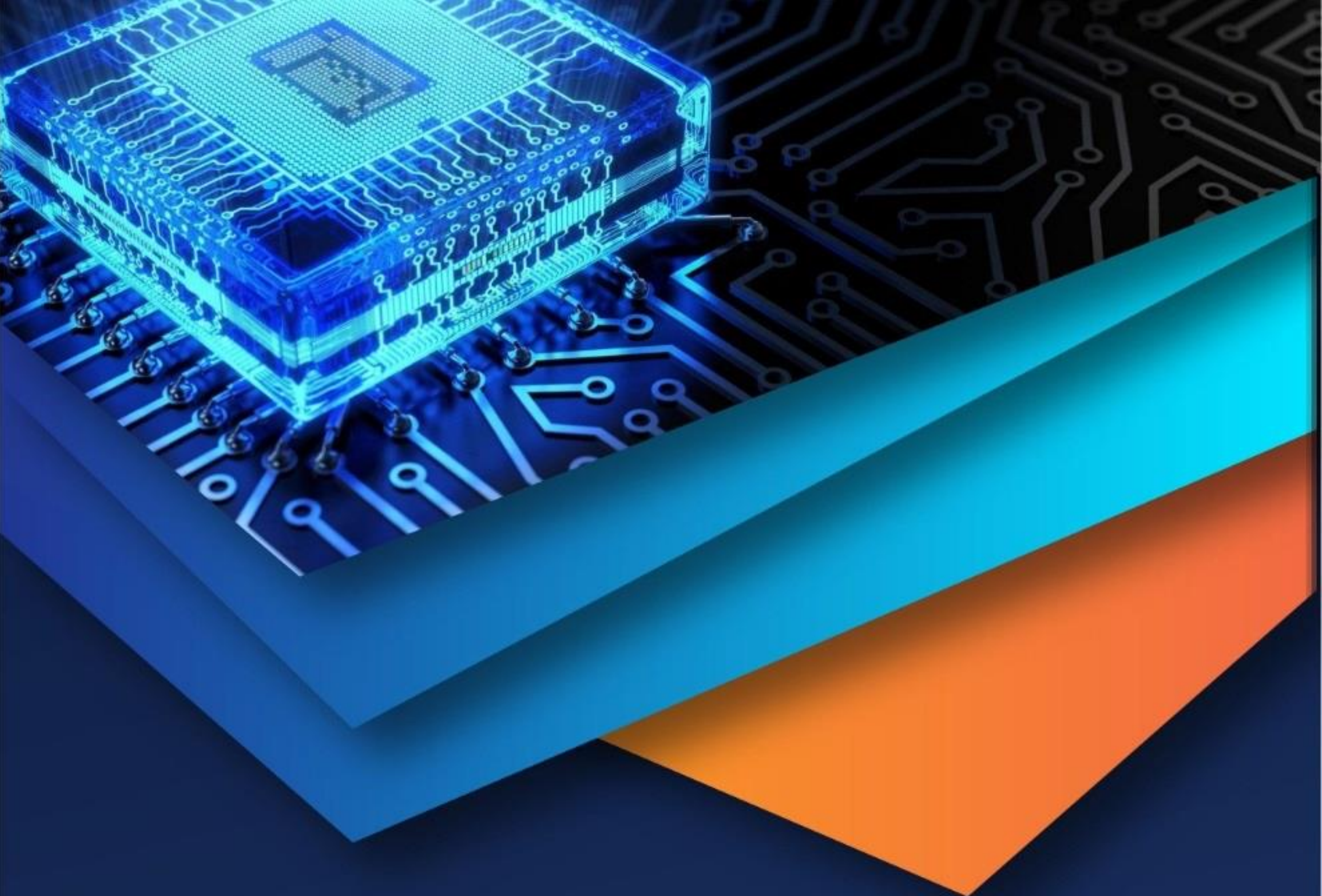

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