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Design Optimization of Process Parameters for Machining Titanium Ti-6Al-4VAlloy using Uncoated Carbide Tip Tool

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Abstract: Machining hard material like TI-6AL-4V Titanium alloy, maintaining good surface finish is challenging and expensive consuming considerable amount of tool life, man and machine hours. This work presents the results of influence of process parameters like speed ,feed ,and depth of cut on cutting force and surface finish in machining TI-6AL-4V Titanium alloy on CNC lathe .Machining is carried out on work pieces for a fixed tool geometry and work piece material. IEICOS Multi –component force indicator , phase II SRG -1000 Surface roughness tester used in experimentation .The effect of cutting parameters on the surface roughness and cutting force of titanium alloy TI-6AL-4V, when turning using un coated carbide tip tool in dry environment. Response surface methodology, design of experiment was used for Turning parameters studied were cutting speed (100,150,200 m/min), feed rate (0.1,0.15,0.2 mm/rev) and depth of cut(0.4,0.6,0.8 mm) . Quadratic and second order model of the surface roughness and cutting force has been developed in terms of cutting speed and feed. The results show that the feed rate was the most impact factor controlling the cutting force and surface roughness produced. Design of experiments software was used to develop a quadratic and second order model of surface roughness and cutting force. Optimum condition was at 137.45m/min of cutting speed, 0.16mm/rev of feed rate0.48 depth of cut. Surface roughness 0.74 µm and cutting force 121.28 N were obtained at the optimum condition. A good agreement between the experimental and predicted surface roughness and cutting force were observed.

Keywords:Response Surface method (RSM), ANOVA, Box BehnkenDesign (BBD), ti-6al-4v alloy. Design of Experiment (DoE).

1. INTRODUCTION:

The surface finish of machined parts is known to have considerable effect on some properties such as wear resistance and fatigue strength. Thus, the quality of the surface is a significantly importance for evaluating the productivity of machine tools, and mechanical parts. A proper cutting condition is extremely important task because these determine surface quality of manufactured parts. In order to know surface quality and dimensional precision properties in advance, it is necessary to employ theoretical models making it feasible to do predictions in function of operation conditions. The response surface method (RSM) is practical, economical and relatively easy for use.An investigation has revealed that when the cutting speed is increased, productivity can be maximized and, meanwhile, surface quality can be improved (Alauddin*et al.*, 1997). Many researchers have conducted experiments to determine the effect of parameters such as average roughness (R_a), Root Mean Square (RMS) and maximum peak to valley. The theoretical arithmetic average surface roughness (mm), *f is* the feed rate (mm/rev); R is the tool nose radius in (mm).Machinability of a material provides an indication of its adaptability to be manufactured by a machining process..Titanium and its alloys are considered as important engineering materials for industrialapplications, becauseofexcellentcombinationofpropertiessuchashighstrength-to-weight ratio, good fracture toughness, excellent resistance to corrosion, and good fatigue resistance. They are widely used in various fields such as aerospace, marine, biomedical, chemical, and racing. Even though they are used in a variety of engineering applications, machining for these materials are difficult to find.

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2. EXPERIMENTAL SETUP:

Plan of Experiments

The three cutting parameters the cutting speed (*Vc-m/min*), feed (*f- mm/rev*), and depth of cut (d-*mm*) were raised to three level as per BBD.

Table 1: process parameters

Notation	CUTTING PARAMETERS	LEVEL 1	LEVEL 2
A	Cutting speed(V_c), (m/min)	100	200
B	Feed(f), (mm/rev)	0.1	0.2
C	Depth of cut(d) (mm)	0.4	0.8

Table2: Design layout

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ID	Run	Speed (m/min)	Feed (mm/rev)	Depth of cut (mm)	Surface roughness (μ)	Cutting force (N)
8	1	200	0.15	0.8	0.81	172
15	2	150	0.15	0.6	0.76	132
5	3	100	0.15	0.4	0.6	82
10	4	150	0.2	0.4	0.83	168
9	5	150	0.1	0.4	0.65	97
17	6	150	0.15	0.6	0.74	128
4	7	200	0.2	0.6	0.85	179
2	8	200	0.1	0.6	0.53	122
14	9	150	0.15	0.6	0.72	129
6	10	200	0.15	0.4	0.79	152
16	11	150	0.15	0.6	0.75	122
12	12	150	0.2	0.8	0.87	159
1	13	100	0.1	0.6	0.49	76
3	14	100	0.2	0.6	0.61	98
11	15	150	0.1	0.8	0.67	92
13	16	150	0.15	0.6	0.75	129
7	17	100	0.15	0.8	0.55	103

3. ANALYSIS OF EXPERIMENT:

A statistical analysis software DESIGN-EXPERT was employed for design and analyze the experiment. In DESIGN-EXPERT, Response surface methodology is used to find a combination of factors which gives the optimal response. Uncoated carbide insert and titanium ti-6al-4v alloy. The experimental results were analyzed with (ANOVA), which is used for identifying the factors significantly affecting the performance measures.

4. ANOVA OUTPUT:

Table 3: ANNOVA for surface roughness

Source	Sum of Squares	Df	Mean Square	F Value	p-value Prob> F	
Model	0.078	9	8.634E-003	24.82	0.0002	Significant
A-speed	*6.801E-003*	*1*	*6.801E-003*	*19.55*	*0.0031*	
B-feed	*5.706E-004*	*1*	*5.706E-004*	*1.64*	*0.2411*	
C-depth of cut	*2.542E-003*	*1*	*2.542E-003*	*7.31*	*0.0305*	
AB	*3.188E-003*	*1*	*3.188E-003*	*9.16*	*0.0192*	
AC	*4.875E-004*	*1*	*4.875E-004*	*1.40*	*0.2751*	
BC	*2.202E-005*	*1*	*2.202E-005*	*0.063*	*0.8086*	
A^2	*0.015*	*1*	*0.015*	*44.05*	*0.0003*	
B^2	*1.592E-003*	*1*	*1.592E-003*	*4.58*	*0.0697*	
C^2	*2.438E-003*	*1*	*2.438E-003*	*7.01*	*0.0331*	
Residual	2.435E-003	7	3.479E-004			
Lack of Fit	*2.124E-003*	*3*	*7.079E-004*	*9.10*	*0.0293*	*Significant*
Pure Error	*3.113E-004*	*4*	*7.783E-005*			
Cor Total	0.080	16				

The Model F-value of 24.82 implies the model is significant. There is onlya 0.02% chance that an F-value this large could occur due to noise.Values of "Prob> F" less than 0.0500 indicate model terms are significant.In this case A, C, AB, A^2, C^2 are significant model terms.Values greater than 0.1000 indicate the model terms are not significant.If there are many insignificant model terms (not counting those required to support hierarchy),model reduction may improve your model.

5.LACK OF FIT:

Source	Sequential p-value	Lack of Fit p-value	Adjusted R-Squared	PredictedR-Squared	
Linear	0.0014	0.0018	0.6123	0.3856	
2FI	0.6462	0.0012	0.5697	-0.1941	
<u>Quadratic</u>	<u>0.0011</u>	<u>0.0293</u>	<u>0.9305</u>	<u>0.5699</u>	<u>Suggested</u>
Cubic	0.0293		0.9845		Aliased

Table 4: Lack of fit for surface roughness

The "Lack of Fit F-value" of 9.10 implies the Lack of Fit is significant. There is only a2.93% chance that a "Lack of Fit F-value" this large could occur due to noise. Significant lack of fit is bad -- we want the model to fit.The "Pred R-Squared" of 0.5699 is not as close to the "Adj R-Squared" of 0.9305 as one might normally expect; i.e. the difference is more than 0.2. This may indicate a large block effector a possible problem with your model and/or data. Things to consider are model reduction, response transformation, outliers, etc. All empirical models should be tested by doing confirmation runs."Adeq Precision" measures the signal to noise ratio. A ratio greater than 4 is desirable. Your ratio of 16.688 indicates an adequate signal. This model can be used to navigate the design space.

Table 5: ANNOVA for cutting force

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob> F	
Model	31.11	9	3.46	13.75	0.0011	Significant
A-speed	*18.14*	*1*	*18.14*	*72.19*	*< 0.0001*	
B-feed	*11.63*	*1*	*11.63*	*46.28*	*0.0003*	
C-depth of cut	*0.20*	*1*	*0.20*	*0.80*	*0.4000*	
AB	*0.33*	*1*	*0.33*	*1.32*	*0.2883*	
AC	*0.024*	*1*	*0.024*	*0.094*	*0.7680*	
BC	*2.245 E-003*	*1*	*2.245 E-003*	*8.934 E-003*	*0.9273*	
A^2	*0.44*	*1*	*0.44*	*1.73*	*0.2295*	
B^2	*0.22*	*1*	*0.22*	*0.89*	*0.3764*	
C^2	*0.12*	*1*	*0.12*	*0.49*	*0.5069*	
Residual	1.76	7	0.25			
Lack of Fit	*1.65*	*3*	*0.55*	*20.65*	*0.0068*	*Significant*
Pure Error	*0.11*	*4*	*0.027*			
Cor Total	32.87	16				

The Model F-value of 13.75 implies the model is significant. There is onlya 0.11% chance that an F-value this large could occur due to noise.Values of "Prob> F" less than 0.0500 indicate model terms are significant.In this case A, B are significant model terms.Values greater than 0.1000 indicate the model terms are not significant.If there are many insignificant model terms (not counting those required to support hierarchy),model reduction may improve your model.

6. LACK OF FIT:

Table 6: Lack of fit for cutting force

Source	Sequential p-value	Lack of Fit p-value	Adjusted R-Squared	Predicted R-Squared	
Linear	< 0.0001	0.0154	0.8916	0.8235	Suggested
2FI	0.7098	0.0100	0.8765	0.6361	
Quadratic	0.4352	0.0068	0.8777	0.1905	
Cubic	0.0068		0.9870		Aliased

The "Lack of Fit F-value" of 20.65 implies the Lack of Fit is significant. There is only a0.68% chance that a "Lack of Fit F-value" this large could occur due to noise. Significant lack of fit is bad -- we want the model to fit.The "Pred R-Squared" of 0.1905 is not as close to the "Adj R-Squared" of 0.8777 as one might normally expect; i.e. the difference is more than 0.2. This may indicate a large block effectors a possible problem with your model and/or data. Things to consider are model reduction, response transformation, outliers, etc. All empirical models should be tested by doing confirmation runs."Adeq Precision" measures the signal to noise ratio. A ratio greater than 4 is desirable. Yourratio of 14.105 indicates an adequate signal. This model can be used to navigate the design space.

In this three machining parameters namely cutting speed, feed rate, and depth of cut were correlated. The minimum response is achieved by using the relations as below. The final equation for surface roughness terms of actual factors is modeled as:

Final equation for surface roughness:

$$0.38030+0.00598655(A)+1.73406(B)-0.91508(D)+0.011292(AB)0.00110393(AD)+0.23463(BD)-0.0000241294(A)^2-7.77881(B)^2+0.60161(D)^{2.}$$

Final equation for Cuttingforce:

$$0.95531+0.056041(A)\ 35.94251(B)-2.82278(D)+0.11520(AB)-0.0076843(AD)-0.0001286(A)^{2}-92.28899(B)^2+4.27094(D)^{2.}$$

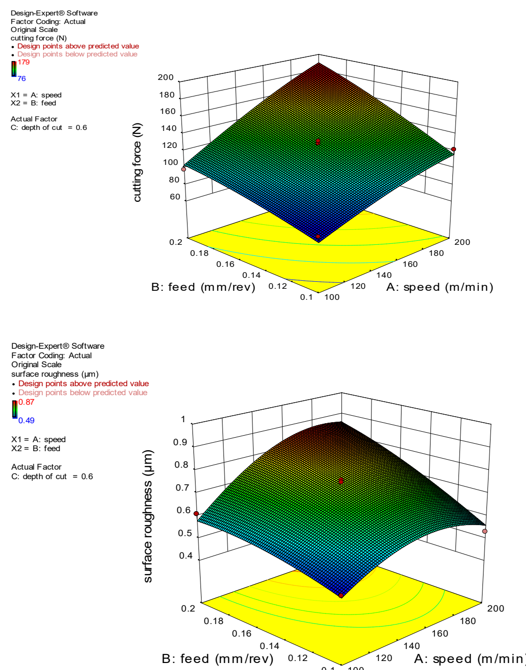
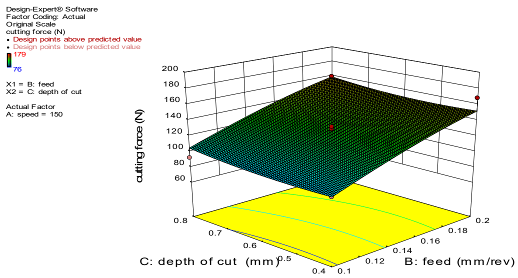


Fig 6:3Dsurface graphs for Ra&Fc data



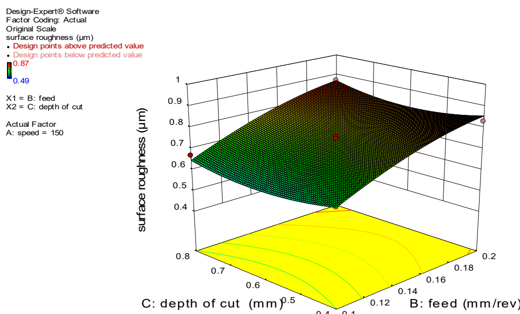


Fig 7:3Dsurface graphs for Ra&Fc data

Table 6: conformation results for Ra&Fc data

Confirmation Report						
Factor	Name	Level	Low Level	High Level	Std. Dev.	Coding
A	Speed	137.45	100	200.0	0.000	Actual
B	Feed	0.16	0.10	0.20	0.000	Actual
C	depth of cut	0.48	0.40	0.80	0.000	Actual
D	Surface roughness	0.740	0.53	0.85	0.0320964	Actual
E	cutting force	121.280	76.0	179.0	11.0358	Actual

7. CONCLUSIONS

The following can be concluded from the results obtained when turning of titanium alloy Ti-6Al-4V under dry environment using uncoated carbide inserts cutting tool.Feed rate is the most significant factor influencing the surface roughness. In this experiment the range values ofsurface roughness between 0.53–0.85µm. The optimum cutting parameters was obtained using DOE software, at cutting speed of 121.28 m/min and feed rate of 0.16mm/rev. Optimum parameters have produced the accepted surface roughness, Ra, of 0.740µm was obtained and cutting force. Fc, 121.28.An improvement in surface quality and lower cutting forces are observed at higher cutting speed with lower feed rate. The developed model has high square values of the regression coefficients which showed high association with variances in the predictor values.

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