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Performance Evaluation of Different Tools in Turning of Ti-6Al-4V Alloy Under Different Coolant Condition

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Abstract: ***In any machining operation, a lot of heat is generated due to plastic deformation of work material, friction at the tool-chip interface and friction between the clearance face of the tool and work piece. The friction in machining adversely affects the tool wear and quality of the products produced. Thus, effective control of friction in the cutting zone is essential to ensure less tool wear and good surface quality of the work piece in machining. Cutting fluids have been the conventional choice to deal with this problem. But it shows negative effect on product cost, environment and human health. Later semi-dry i.e., Minimum Quantity Lubrication machining has been tried as a possible alternative to the use of cutting fluid. The usage of coolant in Minimum Quantity Lubrication is typically 100 ml/hr or less. This project work deals the optimization of process parameters for surface roughness in turning of Ti-6Al-4V under different cooling conditions such as dry, flooded and Minimum Quantity Lubrication with different cutting tools such as CVD coated tool, PVD coated tool and Uncoated tools by using Taguchi's robust design methodology. The results reveal that MQL condition shows minimum surface roughness as compared to dry and flooded conditions. Moderate cutting speed, low feed rate and high depth of cut are found to be optimum conditions. The CVD coated tool out performed compared to uncoated and PVD coated tools. The flank wear behavior is observed with optical images and it observed that the tool wear is less in Minimum Quantity Lubricant as compared to dry and flooded machining.***

Keywords: Cutting fluids ,Turning, Titanium alloy; Carbide tools; Taguchi's Design methodology; Surface Roughness;; vegetable based cutting fluid; palm oil; additives.

1. Introduction

Cutting fluids of various types are usually employed to control the heat generated in machining. Cutting fluids in machining process is traditionally based on mineral oil as a base fluid. This is because of their good technical properties and the reasonable price of mineral oils. But the oil crisis found in the year of1979 and 1983 however elucidated that mineral oil is on principle a limited resource. Also mineral oil is its poor biodegradability and thus it's potential For long term pollution of the environment and workers health. The growing demand for biodegradable materials has opened an avenue for using vegetable oils as an alternative to conventional cutting fluids. Vegetable oil-based cutting fluids can be used in the same operations as mineral based fluids. However, compared to mineral oil, vegetable oil can enhance cutting performance, extend tool life and improve part surface finish. The environmental benefits, though important, are secondary. One reason vegetable oil performs better as due to its lubricity. Vegetable oil carries a slight polar charge. This charge draws the vegetable oil molecule to a metallic surface and is tenacious enough to resist being easily wiped off. Mineral oil has no charge and therefore, adheres less tightly to a metal surface.

2. Experimental Details

2.1 Methodology

In this work, Taguchi robust design methodology is used to obtain the optimum conditions for lower surface roughness in turning of titanium Ti-6Al-4V alloy under vegetable based cutting fluids different machining conditions. Statistical software Minitab is used to obtain results for Analysis of Mean (ANOM) and Analysis Of Variance (ANOVA). The experiments are carried out on a GEDEEWEILER LZ350 lathe.

2.2Work Piece Material

The work piece material used is Ti-6Al-4V alloy of 100mm long and 50mm diameter in the form of bar. The composition of Ti-6Al-4V is shown in Table 1 in percentages.

Table 1: Composition of Ti-6Al-4V

C	Fe	N2	O2	Al	V	H2	Ti
<0.0	<0.	<0.0	<0.	6.	4.	<0.0	Balan
8	2	5	2	0	0	1	Ce

2.3Cutting tools

The different types of carbide tools used in this work are made by SECO. The tool holder used for machining is PSBNR16-4R174.3-2525-12 specification and it is made by sandvik coromant. Three different types of carbide tools used are shown in fig 1.

(a) Uncoated (b) CVD Coated (c) PVD Coated
Figure 1: Carbide Tools

2.4 Surface roughness tester

Surface roughness (Ra) is measured using a portable stylus-type profilometer designated by TR 200 surface roughness tester shown in Figure 2. It is portable, self-contained instrument for the measurement of surface texture. It is equipped with a diamond stylus having a tip radius of 5 µm.

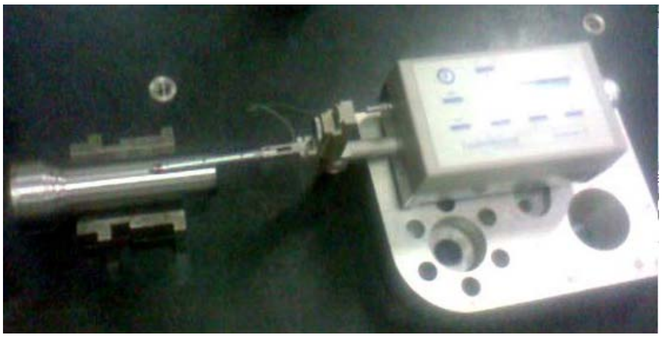

Figure 2: Photographic view of TR 200 surface roughness tester

2.5 Cutting fluid/ lubricant

The cutting fluid used in this work is palm oil with additives under flooded and Minimum Quantity Lubrication conditions. The coolant used at a mixture of 1:10 ratio i.e., one liter of palm oil is mixed with 10 l of water. The additives used Phenol, Lemon juice and wash detergent. At Minimum Quantity Lubrication used coolant 100 ml/hr. The cutting fluid used under flooded machining is vegetable based cutting fluid the flow rate of lubricant is adjusted to 5 l/min

2.6 Selection of control factors, levels and orthogonal array

A total of five process parameters with three levels for each are chosen as the control factors such that the levels are sufficiently covers wide range. The five control factors selected are type of machining (A), cutting speed (B), feed rate (C), depth of cut (D) and type of carbide tool material (E). The control factors and their levels are shown in Table 2. Selection of particular orthogonal array from the standard O.A. depends on the number of factors, levels of each factor and the total degrees of freedom. Based on these factors, the required minimum number of experiments to be conducted are 27, the nearest O.A. fulfilling this condition is L_{27} (3^{13}) and the factors assigned to L_{27} (3^{13}) O.A.

2.7Experimental Procedure

Titanium specimens are prepared for conduct of the experiments. The specimens are turned on lathe according experimental design shown in Table 3 under dry, flooded and Minimum Quantity Lubrication conditions. Surface roughness tester for each experiment. The summary of average surface roughness and its Signal to Noise(S/N) ratio are shown in Table 4. Optimization of process parameters is carried out using Taguchi method and Minitab software [10, 11].

Table 2: Control factors and levels

Factors/ Levels	Type of machining (A)	Cutting Speed (B) (m/min)	Feed rate(C) (mm/ Rev)	Depth of Cut(D) (mm)	Type of Tool Material (E)
1	Dry	63	0.206	0.6	Uncoated
2	Flooded	79	0.274	1	PVD Coated
3	MQL	99	0.343	1.6	CVD Coated

3. Experimental Results and Discussions

In the present work, the performance characteristics namely the surface roughness to be minimized and hence "smaller the better type" quality characteristic has been selected for each of the response. The S/N ratio associated with this response [10], is given in equation (2)

Smaller the better: S/N ratio

$$= -10 \log \left(\frac{1}{n}\right) \sum_{i=1}^{n} y_i^{2} \ldots\ldots (2)$$

Where, y is the observed data.

Table 4: Experimental data of surface roughness and signal to noise ratio

Experiment No.	A	B	C	D	E	Surface roughness (Ra)		AVG	S/N ratio
1	Dry	63	0.206	0.6	Uncoated	2.16	2.07	2.115	-6.502
2	Dry	63	0.274	1.0	CVD	2.08	2.01	2.045	-6.215
3	Dry	63	0.343	1.6	PVD	2.89	2.72	2.805	-8.962
4	Dry	79	0.206	1.0	PVD	3.67	3.73	3.7	-11.36
5	Dry	79	0.274	1.6	Uncoated	1.40	1.87	1.635	-4.359
6	Dry	79	0.343	0.6	CVD	2.16	2.38	2.27	-7.130
7	Dry	99	0.206	1.6	CVD	1.82	1.74	1.78	-5.016
8	Dry	99	0.274	0.6	PVD	3.48	3.32	3.4	-10.63
9	Dry	99	0.343	1.0	Uncoated	2.82	2.71	2.765	-8.835
10	Flooded	63	0.206	0.6	Uncoated	3.29	3.58	3.435	-10.72

11	Flooded	63	0.274	1.0	CVD	2.02	2.27	2.145	-6.643
12	Flooded	63	0.343	1.6	PVD	3.7	3.81	3.775	-11.53
13	Flooded	79	0.206	1.0	PVD	4.08	4.01	4.045	-12.13
14	Flooded	79	0.274	1.6	Uncoated	1.72	1.63	1.675	-4.483
15	Flooded	79	0.343	0.6	CVD	2.08	2.91	2.495	-8.059
16	Flooded	99	0.206	1.6	CVD	1.52	1.82	1.67	-4.489
17	Flooded	99	0.274	0.6	PVD	4.32	4.28	4.3	-12.66
18	Flooded	99	0.343	1.0	Uncoated	2.58	2.05	2.315	-7.347
19	MQL	63	0.206	0.6	Uncoated	1.70	1.60	1.65	-4.353
20	MQL	63	0.274	1.0	CVD	2.06	2.60	2.33	-7.405
21	MQL	63	0.343	1.6	PVD	4.38	4.18	4.28	-12.63
22	MQL	79	0.206	1.0	PVD	2.40	2.12	2.26	-7.098
23	MQL	79	0.274	1.6	Uncoated	1.46	1.36	1.41	-2.989
24	MQL	79	0.343	0.6	CVD	2.42	2.41	2.415	-7.658
25	MQL	99	0.206	1.6	CVD	1.24	1.14	1.19	-1.518
26	MQL	99	0.274	0.6	PVD	3.28	3.18	3.23	-10.18
27	MQL	99	0.343	1.0	Uncoated	2.54	2.74	2.64	-8.438

3.1Optimizationofcutt parameters:

Taguchi's robust design methodology has been successfully implemented to identify the optimum process parameters in order to reduce the surface roughness of the selected tool material for their improved performance. After analysis of data from the robust design of experiments, the optimum process parameters found are tabulated in Table 5. The mean effect plots for surface roughness are shown in Fig. 3. The level of parameter with the highest S/N ratio is the optimal level. It is observed that, the Minimum Quantity Lubrication is found to be optimum compared to dry and flooded conditions and CVD coated tool is found to be optimum compared to uncoated and PVD coated tools. The mean response refers to the average value of the performance characteristic for each parameter at different levels. Thus, the optimal process parameters are
A3, B2, C1, D3 and E2

Table 5: Optimum parameters for surface roughness

Factors/Levels	Type of machining (A)	Speed (B) (m/min)	Feed (C) (mm/rev)	Depth of Cut(D) (mm)	Type of Tool (E)
Optimum Valve	MQL	79	0.206	1.6	CVD Coated

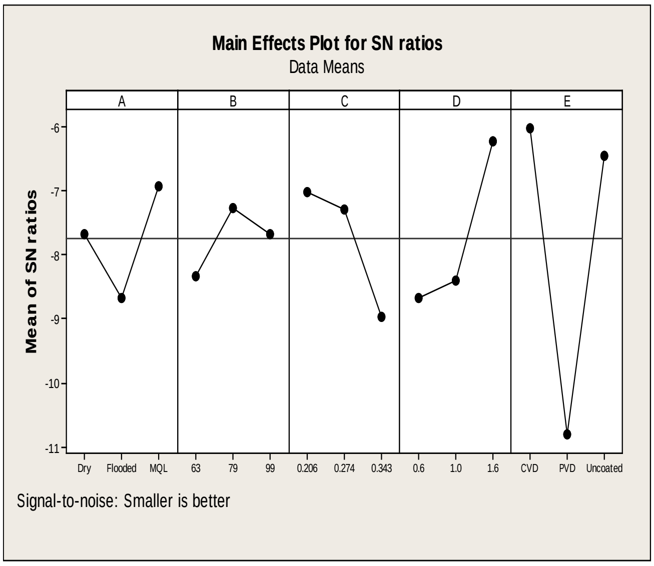

Figure 3: Main effect plots for surface roughness

3.2 Effect of process parameters on surface roughness:

The two factor interaction effects of process parameters on S/N ratio are analyzed to determine the relative importance of the parameters on surface roughness aspects under different coolant conditions.

3.2.1 Effect of cutting speed on surface roughness:

Fig. 4 shows the two factors interaction effects of process parameters on S/N ratio are analyzed to determine the importance of the parameters on surface roughness. The minimum surface roughness is obtained under Minimum Quantity Lubrication machining at 79 m/min. The variation surface roughness is less at flooded condition at 99 m/min.

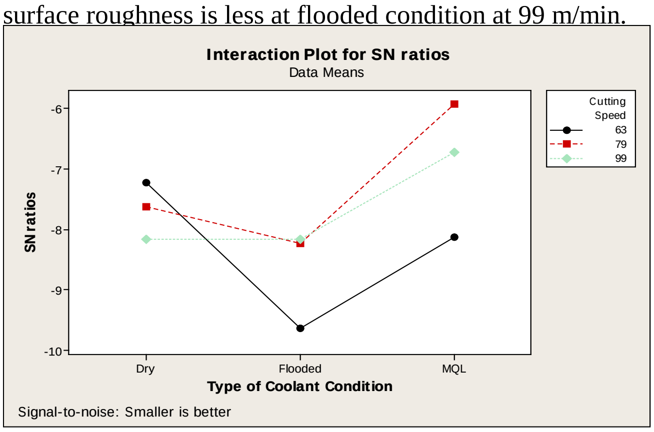

Figure 4: Interaction effect plot of cutting speed and type of coolant

3.2.2 Effect of feed rate on surface roughness:

Fig 5 shows the interaction plots between feed rate and type of coolant condition. Under dry condition, the effect of feed rate on surface roughness from 0.206 to 0.274mm/rev and 0.274 to 0.343 mm/rev is maximum. Similarly under flooded condition, the effect of feed rate on surface roughness from 0.206 to 0.274mm/rev and 0.274 to 0.343 mm/rev is maximum and under Minimum Quantity Lubrication.

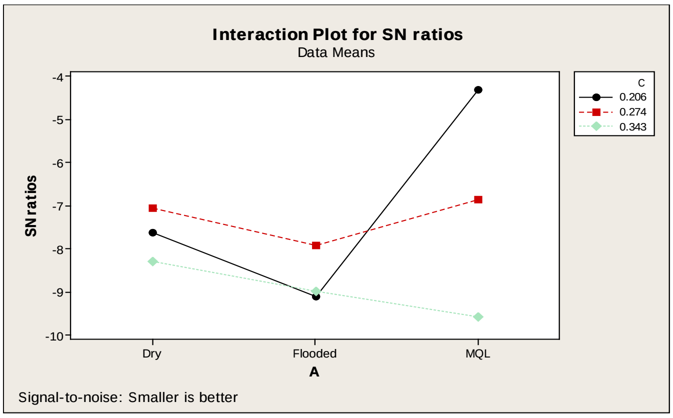

Figure 5: Interaction effect plot of feed rate and type of coolant

3.2.3 Effect of depth of cut on surface roughness:

Fig 6 shows the interaction plots between depth of cut and type of coolant condition. It is observed that the better surface finished obtained at 1.6 mm under dry, flooded and Minimum Quantity Lubrication condition. It is observed that minimum surface roughness is obtained at 1.6 mm depth of cut under Minimum Quantity Lubrication condition. The variation surface roughness is less at Minimum Quantity Lubrication condition at 0.6 mm and 1.0 mm.

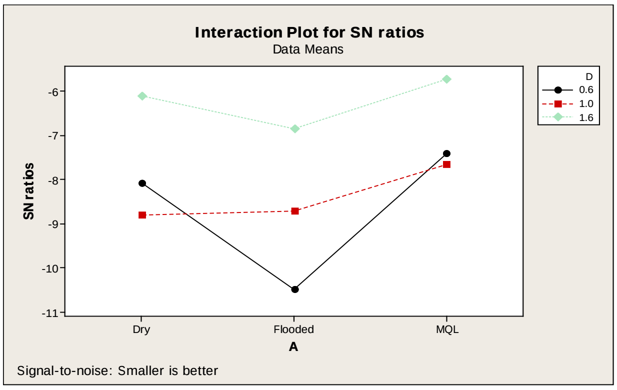

Figure 6: Interaction effect plot of depth of cut and type of coolant

3.2.4 Effect of tool material on surface roughness:

Fig 7 shows the interaction plots between type of tool material and coolant condition. Interaction plots between type of machining and type of tool shown in ANNEXURE – II. It is observed that minimum surface roughness is obtained at CVD coated tool and uncoated tool under Minimum Quantity Lubrication condition. Small variance is observed that between CVD coated tool and uncoated tool at Minimum Quantity Lubrication condition.

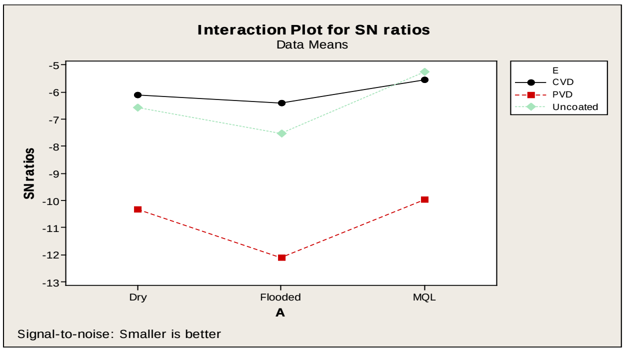

Figure 7: Interaction effect plot of type of tool and type of coolant

Table 6: Analysis of variance

Factor	S.S	D.O.F (D_f)	M.S.S (M_{SS})	F-ratio (Data)	SS^1	ρ %
A	2.3845	2	1.1922	31.03	2.3845	5.2737
B	0.7954	2	0.3977	10.35	0.7954	1.6654
C	2.0978	2	1.0489	27.30	2.0978	5.00825
D	3.2032	2	1.6016	41.68	3.2032	7.6482
E	24.4793	2	12.2397	318.54	24.4793	58.3065
A*B	1.6615	4	0.4154	10.81	1.6615	3.6755
A*C	4.4632	4	1.1158	29.04	4.4632	11.0530
A*D	1.9266	4	0.4816	12.53	1.9266	4.38687
A*E	0.9772	4	0.2443	6.36	0.9772	2.3484
ERROR	1.0375	2 7	0.0384			
S_t	43.0261	53				100
MEAN	360.6168	1				
ST	403.6595					

To minimize the surface roughness, type of tool has major contribution (58.30%) in optimizing the performance characteristics followed by coolant condition, tool material, speed and depth of cut. It is also observed that ANOVA has resulted in (1.0375%) of error contribution. Further the interaction between type of coolant condition with cutting speed, feed rate, depth of cut and tool material are significant. The S/N ratios of optimum conditions are used to develop predictive or additive model to predict the S/N ratio of the optimum condition using equation (3).

$\eta_{predicted}$ =
Y + (A3-Y) + (B2 - Y) + (C1-Y) +(D3-Y) + (E2-Y) (3)

Where Y is average S/N ratio; A3, B2, C1, D3 and E2 are optimum parameters in machining. The predicted S/N ratio is -1.2996 dB. Conducting a verification experiment is essential and final step of the robust design methodology. The predicted results must be conformed to the verification test. Hence, the verification experiment is conducted with the optimum conditions as shown in Table 7 and its S/N ratio is (η_{expt}) -1.3243 dB.

Table 7: Comparison of results of robust design method

Measurement	Starting condition	Optimum condition	Improvement
Surface roughness(Ra)	1.17	1.14	-0.03
S/N ratio	-1.3243	-1.2996	-0.0247

It is found that the S/N ratio of the verification test is within the limits of the predicted value at 95% confidence level and the objective is fulfilled. These suggested optimum conditions can be adopted. Where D. O. F-Degrees of Freedom, S.S - Sum of Squares, P-Predicted value (If the predicted value of a factor is <0.05 then the factor is said to be significant). This analysis is carried out at a significance level of 5% and confidence level of 95%. From Table 6, it is evident that R^2 is 99.87 % and P valves are less than 0.05 are considered to be significant, hence these factors are significant to 95% level of confidence [11]. Table 7 shows the comparison of results of robust design method, it indicates improvement in surface roughness between starting condition and optimum condition.

4. Conclusions

Based on these results of the present experimental investigations, the following conclusions are drawn:

1. The cutting performance of Minimum Quantity Lubrication machining shows favorable and better results as compared to dry and flooded conditions.
2. CVD coated tool out performed than uncoated and PVD coated tool to minimize the surface roughness.
3. The optimum condition are obtained Minimum Quantity Lubrication, moderate cutting speed, low feed rate, high depth of cut and CVD coated tool.
4. The results of ANOVA using Taguchi robust methodology and Minitab are compared and found to be similar.
5. From the ANOVA, it is found that type of tool material is contributed more to optimize surface roughness.
6. Tool wear is very less in Minimum Quantity Lubrication condition as compared to dry and flooded machining conditions.

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