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Optimization of cutting for surface finish obtained using uncoated and diamond coated carbide end mills

Shivanshu Srivastava, Kommineni Uday Venkat Kiran*, Ravikumar Dumpala

Department of Mechanical Engineering, Visvesvaraya National Institute of Technology, Nagpur 440010, India

Corresponding author: udayvenkatkiran@gmail.com

Abstract. Aim of this paper is to optimize the machining parameters for surface finish during end milling of Al 6061 using Taguchi method. Uncoated and Diamond Coated carbide end mills were used for conducting machining experiment. Preliminary experiments were conducted to decide the range of speed, feed & depth of cut. Stylus profilometer was used to measure the surface roughness of the machined surface. A Taguchi orthogonal array was designed with three levels of machining parameters and analysis of main effect plot for means, ANOVA, response table and regression equations were developed with the help of Minitab.

1. Introduction

In this growing world of competition no one is willing to compromise on quality due to which industries are also working towards providing the consumers with standard products. Thus, the current scenario in every firm is to maximize productivity and keep machining cost and time as minimum as possible. In other words the industries are optimizing the resources available to them. Optimization implies decision making and is for analysis of physical systems. Before implementing it, an objective must be identified. The objective can be either maximizing or minimizing any output or combination of it. Responses depend on certain characteristics called variables. Manufacturing technology has also come a long way in field of automation which has reduced the human effort. The lesser is the involvement of human more will be the quality or the surface finish of the product. There are number of machining processes which can be used to improve the surface finish of the products. Out of the machining processes one is the milling process. Aluminium alloy have high strength to weight ratio therefore used in aerospace and good corrosion resistance enables its usage in automobile industries. Surface roughness is an important factor in evaluating machining accuracy. Machining parameters such as cutting speed, feed rate, and depth of cut have a significant influence on surface roughness for a given cutting tool and work setup. [1-3] various researchers have studied the effect of above mentioned parameters on surface finish. Yang et al. [4] optimized cutting parameters in turning operations using Taguchi method and shown significant improvement in tool life and surface roughness from initial cutting parameters to the optimal cutting parameters. Lin et al. [5] applied Taguchi method for optimizing cutting speed, Feed rate & depth of cut by considering performance characteristics surface roughness, removed volume and burr height.

The objectives of the present research work are as follows:

- To conduct the preliminary experiments and establish the levels of machining parameters.
- To conduct the experiments using uncoated carbide end mills and then measure the surface roughness.
- To create a regression model and optimize machining parameters for surface roughness of uncoated carbide end mills.
- To repeat the above steps for diamond coated end mills.

2. EXPERIMENTAL DETAILS

The milling process was carried out on Al 6061. The chemical composition and mechanical properties of aluminium 6061 alloy are given in 'Table 1' and 'Table 2' respectively. Uncoated and diamond coated carbide end mills as shown in 'Figure 1' and 'Figure 2' of 6 mm diameter were used for milling test. Four flute carbide end mills were preferred because such tools are ideal for surface finish. Experiments were performed on SMARTMILL 500 ASKAR MICRONS as shown in 'Figure 3' under dry cutting conditions. Surface roughness was measured using surface roughness tester model SJ 500 as in 'Figure 4'. L27 orthogonal array was used from Minitab software to design the experiments and then experiments were performed

Table 1. Composition of Aluminium 6061 alloy.

Element	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al
%Composition	0.4	0.7	0.4	0.15	1.2	0.35	0.25	0.15	96.4

Table 2. Mechanical properties of Aluminium 6061 alloy.

Brinell Hardness	**Ultimate Tensile Strength**	**Modulus of Elasticity**
95	310 MPa	68.9 GPa

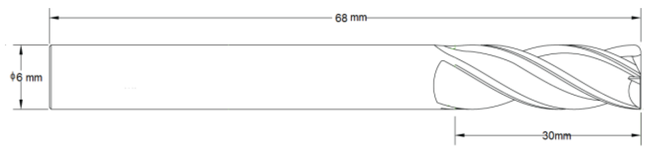

Figure 1. Diamond coated End Mill

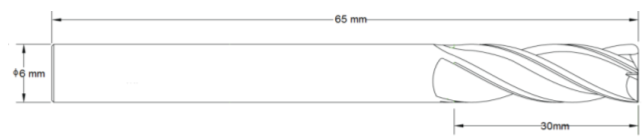

Figure 2. Uncoated End Mill

Figure 3. SMART MILL 500 ASKAR MICRONS.

Figure 4. Surface roughness tester SJ500.

Preliminary experiments were conducted to establish the final machining levels of parameters as Shown in 'table 3' & 'table 4' respectively.

Table 3. Machining Levels for Carbide End Mill.

Parameters	**Low Level**	**Medium Level**	**High Level**
Speed (rpm)	1500	2000	2500
Feed (mm/min)	80	160	240
Depth of cut (mm)	0.2	0.4	0.6

Table 4. Machining Levels for Diamond Coated End Mill.

Parameters	**Low Level**	**Medium Level**	**High Level**
Speed(rpm)	2500	3000	3500
Feed(mm/min)	80	160	240
Depth of cut (mm)	0.2	0.4	0.6

3. Results & Discussion

The response (Ra) measured at various settings of parameters using uncoated and coated end mills are tabulated below, in 'table 5' & 'table 6' respectively. The data collection was followed by statistical analysis using Minitab, creation of regression models and then optimization was carried out by Taguchi method.

Table 5. Response (Ra) obtained at various machining levels using Uncoated Carbide End Mill.

S.No	**Cutting Speed(rpm)**	**Feed Rate (mm/min)**	**Depth of Cut (mm)**	**Ra (µm)**	**S.No.**	**Cutting Speed(rpm)**	**Feed Rate (mm/min)**	**Depth of Cut (mm)**	**Ra (µm)**
1	1500	80	0.2	0.168	15	2000	160	0.6	0.238
2	1500	80	0.4	0.171	16	2000	240	0.2	0.411
3	1500	80	0.6	0.137	17	2000	240	0.4	0.363
4	1500	160	0.2	0.343	18	2000	240	0.6	0.266

5	1500	160	0.4	0.317	19	2500	80	0.2	0.182
6	1500	160	0.6	0.191	20	2500	80	0.4	0.198
7	1500	240	0.2	0.458	21	2500	80	0.6	0.131
8	1500	240	0.4	0.483	22	2500	160	0.2	0.304
9	1500	240	0.6	0.319	23	2500	160	0.4	0.334
10	2000	80	0.2	0.181	24	2500	160	0.6	0.211
11	2000	80	0.4	0.205	25	2500	240	0.2	0.302
12	2000	80	0.6	0.12	26	2500	240	0.4	0.273
13	2000	160	0.2	0.351	27	2500	240	0.6	0.179
14	2000	160	0.4	0.378					

Table 6. Response (Ra) obtained at various machining levels using Diamond coated End Mill.

S.No.	Cutting Speed(rpm)	Feed Rate (mm/min)	Depth of Cut(mm)	Ra(μm)	S.No.	Cutting Speed(rpm)	Feed Rate (mm/min)	Depth of Cut(mm)	Ra(μm)
1	2500	100	0.2	0.207	15	3000	200	0.6	0.348
2	2500	100	0.4	0.174	16	3000	300	0.2	0.281
3	2500	100	0.6	0.244	17	3000	300	0.4	0.278
4	2500	200	0.2	0.464	18	3000	300	0.6	0.276
5	2500	200	0.4	0.408	19	3500	100	0.2	0.175
6	2500	200	0.6	0.426	20	3500	100	0.4	0.155
7	2500	300	0.2	0.503	21	3500	100	0.6	0.199
8	2500	300	0.4	0.420	22	3500	200	0.2	0.207
9	2500	300	0.6	0.473	23	3500	200	0.4	0.169
10	3000	100	0.2	0.176	24	3500	200	0.6	0.2
11	3000	100	0.4	0.184	25	3500	300	0.2	0.173
12	3000	100	0.6	0.19	26	3500	300	0.4	0.148
13	3000	200	0.2	0.304	27	3500	300	0.6	0.167
14	3000	200	0.4	0.321					

3.1. Statistical Analysis for Carbide End Mill

Based on surface roughness measured ANOVA is carried using MINITAB 16 software. The results obtained are enlisted in the 'Table 7'

Table 7. Analysis of Variance Data showing F & P Values.

Source	DF	Seq SS	F	P
Speed	2	0.014385	15.39	0.002
Feed	2	0.146843	157.1	0
Depth	2	0.062587	66.96	0
Speed*Depth	4	0.031811	17.02	0.001

Speed*Depth	4	0.000341	0.18	0.0941
Feed*Depth	4	0.007604	4.07	0.043
Residual Error	8	0.003739		
Total	26	0.26731		

R-Sq = 98.6% R^2(adjusted) = 95.5%

Where, the R^2 and R^2(adjusted) values signifies accuracy of the model. The values that are closer 100% imply regression fit and estimates are pretty good. T test or F test [6] for significance of design variable is performed with sequence begin with full model. Insignificant variables with the highest p value (> 0.05) are removed from the full model. From the 'Table 8' we can get the rank of parameters, i.e. which parameter is more significant and which is least significant. Feed rate is ranked as 1 followed by depth of cut as 2 and cutting speed as 3.

Table 8. Response Table for Means for uncoated carbide End Mill.

Level	**Speed**	**Feed**	**Depth**
1	0.2874	0.1659	0.3
2	0.2792	0.2963	0.3024
3	0.2349	0.3393	0.1991
Delta	0.0526	0.1734	0.1033
Rank	3	1	2

The aim is to minimize the surface roughness, so from the main effect plot for means as shown in 'Figure 5' the optimum parameter settings are concluded to be the highest levels of speed and depth of cut and lowest level of feed.

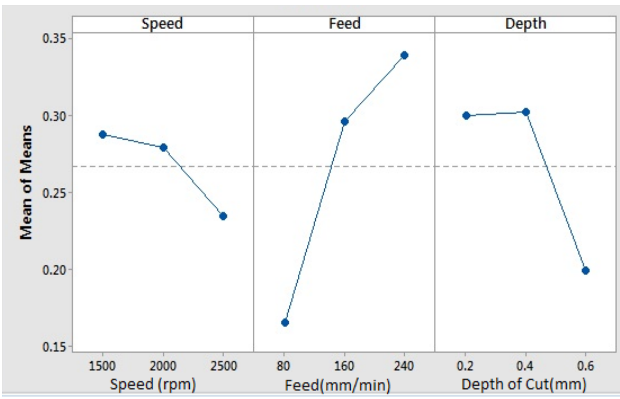

Figure 5. Main effect Plot for Means for Carbide End Mill.

As seen from the above graph in 'Figure 5' the optimum parameters obtained are tabulated in the 'table 9' below.

Table 9. Optimum Machining Parameters using carbide end mill.

Cutting speed (rpm)	**Feed Rate (mm/min)**	**Depth of cut (mm)**
2500	80	0.6

Regression Model for surface finish using Uncoated Carbide End Mill is shown below
Ra= – 0.71115 + 0.000398*speed + 0.006074*feed + 0.933889*depth – 0.000000072*speed^2 – 0.0000068*feed^2 – 1.32222*depth^2 – 0.0000011*speed*feed – 0.00138*feed*depth + 0.000458*depth*speed.

In order to validate the results obtained, optimum values obtained were put into the above model as it is the best model obtained and experiment was carried out by using the optimum values of speed, feed and depth of cut from 'Table 9' and obtained responses were recorded.

Table 10. Data of Model Validation.

	Ra (µm)	Error%
Calculated by model	0.143	8.39%
Obtained from experiment	0.131	

As it can be seen from 'Table 10' that Ra value calculated by the model comes out to be 0.143 µm and Ra value obtained from experiment comes to be 0.131 µm. When error is calculated it comes out to be 8.39 % which is acceptable. Hence, the regression model is validated

Table 11. Data of Experimental validation.

S.No.	Ra (for validation)	Ra (Experimental)	Error%
1	0.138	0.131	5.34
2	0.136	0.131	3.81
3	0.134	0.131	2.29

As it can be seen from 'Table 11' that Ra value calculated by the model comes out to be 0.138 µm, 0.136 µm and 0.134 µm respectively. Ra value obtained from experiment comes to be 0.131 µm. When error is calculated it comes out to be 5.34 %, 3.81% and 2.29% respectively which is acceptable. Hence, the experiments are validated.

3.2. Statistical Analysis for Diamond coated Carbide End Mill

Based on surface roughness measured ANOVA is carried using MINITAB 16 software. The results obtained are enlisted below.

Table 12. Analysis of Variance Data showing F & P Values.

Source	DF	Seq SS	F	P
Speed	2	0.166216	363.34	0
Feed	2	0.08715	190.51	0
Depth	2	0.004672	10.21	0.006
Speed*Depth	4	0.062606	68.43	0
Speed*Depth	4	0.003165	3.46	0.064
Feed*Depth	4	0.001179	1.29	0.351
Residual Error	8	0.00183		
Total	26	0.326817		

R-Sq = 99.4% R^2(adjusted) = 98.2%
The values that are closer 100% imply regression fit and estimates are pretty good.

From the 'Table 13' we can get the rank of parameters, i.e. which parameter is more significant and which is least significant. Speed is ranked as 1 followed by feed rate as 2 and depth of cut as 3.

Table 13. Response Table for Means for Diamond coated carbide End Mill.

Level	Speed	Feed	Depth
1	0.3688	0.1893	0.2767
2	0.262	0.3163	0.2508
3	0.177	0.3021	0.2803
Delta	0.1918	0.127	0.0296
Rank	1	2	3

The response is needed to be minimized so from the main effect plot of means as shown in 'Figure 6' the optimum parameter setting is concluded as the highest level of speed, lowest level of feed and depth of cut needs to be maintained at 0.4.

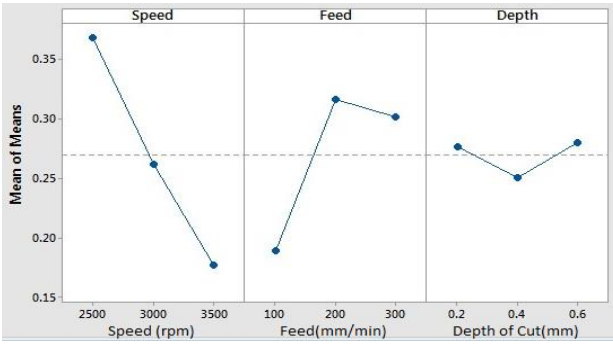

Figure 6. Main effect Plot for Means for Diamond coated Carbide End Mill.

Table 14. Optimum Machining Parameters.

Cutting speed (rpm)	Feed Rate (mm/min)	Depth of cut (mm)
3500	100	0.4

Regression Model for surface finish using Diamond coated Carbide End Mill is shown below
Ra= 0.161259 - 0.0001964*speed + 0.007642*feed – 0.553611*depth + 0.000000043*speed^2 – 0.00000706*feed^2 + 0.6930555*depth^2 – 0.00000135*speed*feed – 0.0004833*feed*depth + 0.000035*depth*speed

In order to validate the results obtained, optimum values obtained were put into the above model as it is the best model obtained and experiment was carried out by using the optimum values of speed, feed and depth of cut from 'Table 14' and obtained responses were recorded.

Table 15. Data of Model Validation.

	Ra (µm)	Error%
Calculated by model	0.145	6.45
Obtained from experiment	0.155	

As it can be seen from 'Table 15' that Ra value calculated by the model comes out to be 0.145 µm and Ra value obtained from experiment comes to be 0.155 µm. When error is calculated it comes out to be 6.45 % which is acceptable. Hence, the regression model is validated

As it can be seen from 'Table 16' that Ra value calculated by the model comes out to be 0.159 µm, 0.157 µm and 0.163 µm respectively. Ra value obtained from experiment comes to be 0.155 µm. When error is calculated it comes out to be 2.58 %, 1.29% and 5.16% respectively which is acceptable. Hence, the experiments are validated.

Table 16. Data of Experimental Validation.

S.No.	Ra (for validation)	Ra (Experimental)	Error%
1	0.159	0.155	2.58
2	0.157	0.155	1.29
3	0.163	0.155	5.16

4. Conclusions

In this work machining studies have been carried out to compare the performance of uncoated and diamond coated tungsten carbide tools in end milling. Based on the experiment the following specific conclusions are drawn:

i. Due to low adhesion of diamond coated tool to the work piece the sticking of work material to the rake surface of the end mill is less as compared to carbide end mill.
ii. For carbide end mill the surface roughness decreases at steady rate from 1500 rpm to 2000 rpm and then there is drastic decrease in surface roughness from 2000 to 2500 rpm. Ra increases with feed rate and it remains constant from 0.2 to 0.4 mm with depth of cut then decreases with it.
iii. For diamond coated end mill the surface roughness decreases at constant rate with speed, increases with feed rate (till 200 mm/min) and then decreases, for depth of cut there is decrease from 0.2 to 0.4 mm and then increase from 0.4 mm to 0.6 mm.
iv. The regression results obtained from ANOVA was found to be giving the surface prediction with 98.6 % accuracy for uncoated tool and 99.4 % for diamond coated tool.

5.References

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