

Optimization of Cutting Parameters for Turning Operation on Thermoplastic Polymer-Delrin 500AL

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ABSTRACT: For any manufacturing industry that uses machining operation like turning operation, Material Removal Rate and Surface Roughness are the important parameter which is to be considered for quality product. The material selected for the experiment is Delrin 500AL. Experiments were conducted using Taguchi optimization technique. L9 orthogonal array is employed by considering three factors speed, feed and depth of cut. For each factor three different levels is selected. For MRR larger-the-better S/N ratio is selected and for Surface Roughness smaller-the-better S/N ratio is selected. After conducting the experiment, response table is generated and graph is plotted. ANNOVA is used to find the significant factors. From the result, the most significant factor that influences the Material Removal Rate is Depth of cut and for Surface Roughness, the most significant factor is feed rate. Confirmation experiments were conducted to compare the optimum theoretical and experimental combinations.

KEYWORDS: Taguchi, S/N ratio, orthogonal array, ANNOVA.

I. INTRODUCTION

Today any component that has been manufactured undergoes some sort of machining process. Turning is one of the important processes that is widely used to create cylindrical components and it is also used for surface finish the product to make it smooth. Nowadays, plastic materials are widely used for making variety of components. To make a component with high dimensional accuracy, turning operation is used. Quality parameters are those parameters which has direct influence on the quality, cost and productivity of the product. Some of the influential parameters for turning operation are Surface Roughness, Material Removal Rate, Cutting Forces, and Tool Life etc. These parameters are in turn affected by various factors such as speed, feed, depth of cut, nose radius, tool material, lubricant etc.

The purpose of this research work is to found out the significant factors which affect the Surface Roughness and Material Removal Rate with the help of optimization technique which is based Taguchi method. Surface Roughness basically deals with the roughness of the surface. To obtain smooth surface, our target is to minimize the surface roughness. Material removal rate defines how fast the material gets removed during turning operation. It has direct influence on production time, cost and quality of the product. So our target is to maximize the Material Removal Rate.

II. LITERATURE SURVEY

I.A. Choudhury *et.al.*¹ developed surface roughness model using response surface method for turning of EN24T steel. First and second order was also established using factorial design technique. Factorial design technique coupled with response surface method is a better approach. For surface roughness, significant factor was feed rate.

Aman Aggarwal *et.al.*² had studied in detail different types of optimization technique and concluded that response surface method and Taguchi method were the most robust optimization methods.

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Kamal Hassana *et.al.*³ investigated the effect of parameters on material removal rate for turning operation of C34000 medium Brass alloy. L27 orthogonal array were selected for conducting the experiment. Feed rate was found to be the significant factor with 42.77 %.

Krishnakant *et.al.*⁴ used taguchi method for conducting turning operation on EN24 steel to optimize the Material Removal Rate (MRR). They showed the optimum value for speed, feed and depth of cut.

Sujit Kumar Jha *et.al.*⁵ used taguchi technique to optimize the material removal rate for aluminium. Manual calculation was used to find the S/N ration and response table. From the result, it is understood that depth of cut had the significant effect.

Vladimir Aleksandrovich Rogov *et.al.*⁶ used taguchi method to investigate the cutting parameter for natural frequency and surface roughness for turning of aluminum alloy AA2024. L9 orthogonal array was used for conducting the experiment. The significant factor for Ra was speed with 81.301% and for natural frequency it was tool overhang with 96.12%.

Rishu Gupta *et.al.*⁷ investigated the effect of nose radius, speed, depth of cut and feed rate on material removal rate and surface roughness for turning of Aluminium Alloy 606. Interpretation plot was also plotted and the conclusion obtained was that feed influences Ra the most and Depth of cut for MRR.

Arun kumar Parida *et.al.*⁸ optimized the cutting paramters on GFRP composites for surface roughness by using taguchi technique. The significant factor was found to be feed rate. The improvement from initial to optimal cutting parameter for Ra is 300% and for Rt is 252%.

Nexhat Qehaja *et.al.*⁹ developed a model based on response surface method to find the effect of nose radius, feed and machining time on surface roughness during turning operation. The result shows that feed has significant impact on surface roughness compared to nose radius and cutting time.

III. EXPERIMENTAL SETUP AND METHODS

A. CNC MACHINE

The Experiment was conducted on CNC machine (BATLIBOI Spring 16 TC). BATLIBOI LIMITED are specialized in manufacturing of CNC machines that require less maintenance. Easy to use controls and robust design have made these machines suitable for and training industries automobile industry.

Table 1: Specifications

Swing over Bed	400 mm
Turning Length	300 mm
Turning Dia	225 mm
Power Chuck	165mm
Spindle Speed	30 - 5000 rpm
Spindle Motor	5.5 / 7.5 kw
X – axis Stroke	125 mm
Z – axis Stroke	325 mm
Rapid Traverse	20 m / min
Max. No. of Tools in Turret	8
Tail stock	Hydraulic

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B. CUTTING TOOL MATERIAL



Figure 1: BATLIBOI Spring 16 TC in Workshop

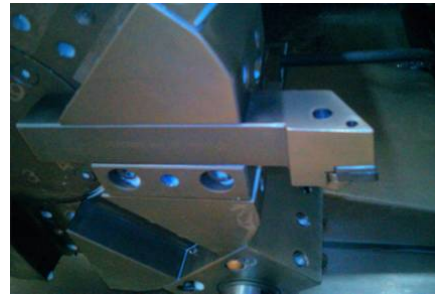


Figure 2: Carbide VNMG Insert Cutting Tool

The above figure 1 shows the CNC machine available on the workshop where experiment is to be conducted and figure 2 shows the tool used for turning operation. The tool Material selected was carbide VNMG insert with 0.4 nose radius because it has high working efficiency, can be reused, save cost, long service life, excellent accuracy of positioning.

C. MATERIAL

The material on which turning operation is to be performed is Delrin 500AL. Density of material is $1.39 \times 10^{-3} \text{ gm/mm}^3$. Delrin rod is cut into 9 pieces each having dimension of length 50mm and diameter 42mm.



Figure 3: Material- Delrin 500AL rod



Figure 4: Material Specimen

The figure 3 shows the rod of material Delrin 500 AL from which specimen for experiment is made. Figure 4 shows 9 specimen on which turning operation is done.

D. FACTORS AND LEVELS

After conducting the literature survey it is seen that three factors Speed, Feed, and Depth of cut are mostly selected since these are primary factors or parameters which mostly affect the turning operation. Also 3 level of each factor is considered. The values for different factors and level are taken with consideration from the expertise of people working on CNC or lathe machine. The values are equally spaced. Following table shows the factors along with the level values.

Table 2: Factors and levels

Factors/Levels	Level 1	Level 2	Level 3
Speed (rpm)	200	250	300
Feed (mm/rev)	0.15	0.20	0.25
Depth of cut (mm)	1	1.2	1.4

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E. SELECTION OF ORTHOGONAL ARRAY

The following table shows the sequence and combination for conducting the experiment.

Table 3: Orthogonal Array

Exp.No.	A	B	C	Speed (rpm)	Feed (mm/rev)	Depth of cut (mm)
1	1	1	1	200	0.15	1
2	1	2	2	200	0.2	1.2
3	1	3	3	200	0.25	1.4
4	2	1	2	250	0.15	1.2
5	2	2	3	250	0.2	1.4
6	2	3	1	250	0.25	1
7	3	1	3	300	0.15	1.4
8	3	2	1	300	0.2	1
9	3	3	2	300	0.25	1.2

For 3 factors and 3 Levels, total number of experiments accounts for is 27, which will give 100% accurate result. In comparison to these, Taguchi orthogonal array make 9 experiments in a very specific order which cover all factors. These 9 experiments will give 99.96% accurate result. By using this technique, the numbers of experiments get reduced from 27 to 9 having almost same accuracy. Due to these the experiment time and cost can be reduced. Hence L9 orthogonal array is selected.

IV. RESULTS AND DISCUSSION

A. FOR SURFACE ROUGHNESS

After conducting the experiment, Surface roughness is measured by a surface tester instrument called Mitutoyo SJ 400. It gives the value of different roughness parameters i.e. Ra, Rz and Rq. We are concentrating on value of Ra that is basically average surface roughness.

B. FOR MATERIAL REMOVAL RATE

Material Removal Rate is found out by taking ratio of difference of initial weight and final weight to the time taken.

$$MRR = \frac{\text{Initial weight} - \text{Final weight}}{\text{Time Taken}} \text{ (gm/min)} \quad MRR = \frac{\text{Initial weight} - \text{Final weight}}{\text{Time Taken} \times \text{Density}} \text{ (mm}^3\text{/min)}$$

Where,

Metal Removal Rate (gms/minute) = Weight of Metal Removed in grams Divided by Cycle time in minutes.

Metal Removal rate (mm³/minute) = Metal Removal rate in Grams/Minute Divided by Density of Work Piece in mm³/grams.

C. S/N RATIO

We have to minimize the Surface roughness; Smaller-the-better type of S/N ratio is selected.

$$S/N \text{ ratio } (\eta) = -10 \log [ny^2] \quad \text{where } n=1$$

We have to maximize the Material Removal Rate; Larger-the-better type of S/N ratio is selected.

$$S/N \text{ ratio } (\eta) = -10 \log [1/ny^2] \quad \text{where } n=1$$

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Table 4: Experiment result of Ra, MRR and S/N ratio calculated using matlab software

Exp.No.	A	B	C	Speed (rpm)	Feed (mm/rev)	Depth of cut (mm)	Ra (μm)	S/N Ratio for Ra (dB)	MRR (mm ³ /min)	S/N Ratio for MRR (dB)
1	1	1	1	200	0.15	1	2.9	-9.2480	1240.38	61.8711
2	1	2	2	200	0.2	1.2	4.61	-13.2740	2263.92	67.0972
3	1	3	3	200	0.25	1.4	5.67	-15.0717	2841.53	69.0710
4	2	1	2	250	0.15	1.2	1.83	-5.2490	1856.57	65.3742
5	2	2	3	250	0.2	1.4	3.03	-9.6289	2975.56	69.4714
6	2	3	1	250	0.25	1	4.66	-13.3677	2376.47	67.5186
7	3	1	3	300	0.15	1.4	2.24	-7.0050	2757.58	68.8106
8	3	2	1	300	0.2	1	2.97	-9.4551	2189.55	66.8071
9	3	3	2	300	0.25	1.2	4.73	-13.4972	2920.43	69.3089

D. RESPONSE TABLE FOR SIGNAL TO NOISE RATIOS

Response table consist of mean S/N ratio for each level of factors speed, feed and depth of cut. In simple terms it gives average values for each level of factors. Overall mean S/N ratio is also calculated. Response table also provide rank to the factors. This is done with the help of delta statistics calculation. Delta is nothing but the value obtained by taking difference of highest average (Max. mean) and lowest average (Min mean) of each factor. After this, rank is assigned on these deltas values. The matlab software assigns Rank 1 to the highest delta value, Rank 2 is assigned to second highest delta value and Rank 3 is assigned to the lowest delta value. Following table shows the mean S/N ratio for each factor, Delta values and Ranks calculated in matlab software.

Table 5: Response Table for Ra. S/N Ratios :- Smaller-the-better

Level	Speed	Feed	Depth of cut
1	-12.531	-7.167*	-10.690
2	-9.415*	-10.786	-10.673
3	-9.986	-13.979	-10.568*
Delta (Max-Min)	3.116	6.812	0.122
Rank	2	1	3

Overall mean S/N ratio is $\eta_{\text{mean}} = -10.6441$ dB

From the above table, Feed is given rank 1, Speed is given rank 2 & Depth of cut is given rank 3. The overall mean of S/N ratio is also calculated, $\eta_{\text{mean}} = 67.2589$ Db

Table 6: Response Table for MRR. S/N Ratios:- Larger-the-better

Level	Speed	Feed	Depth of cut
1	66.01	65.35	65.40
2	67.45	67.79	67.26
3	68.31*	68.63*	69.12*
Delta (Max-Min)	2.30	3.28	3.72
Rank	3	2	1

Overall mean S/N ratio is $\eta_{\text{mean}} = 67.2589$ dB

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From the above table, Depth of cut is given rank 1, Feed is given rank 2 & Speed is given rank 3. Also the overall mean of S/N ratio is also calculated which is $\eta_{\text{mean}} = 67.2589$ dB

E. MAIN EFFECTS PLOT FOR S/N RATIOS

After the Response table generation, graph is plotted. This is called as Main effect plot for S/N ratio. Maximum value of each factor is chosen from the graph. This can also be found out from response table by selecting highest value of each factor as shown by asterik (*) sign.

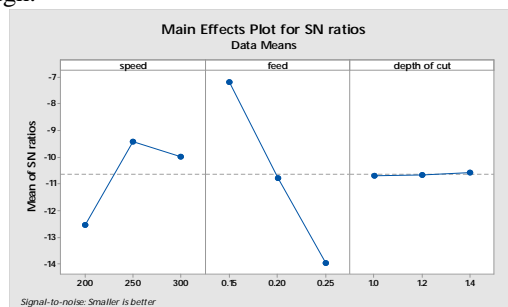


Figure 5: Main Effects Plot for S/N ratios for Ra

From both by Response table and by Graph, the optimum combination for (Ra) obtained is A2B1C3.

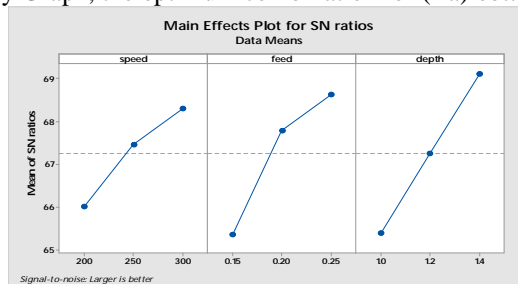


Figure 6: Main Effects Plot for S/N ratios for MRR

From both by Response table and by Graph, the optimum combination for Material Removal Rate (MRR) obtained is A3B3C3.

F. ANNOVA OR ANALYSIS OF VARIANCE

After obtaining the rank of factors through Response table, Analysis of Variance is conducted. ANNOVA or Analysis of Variance is the technique used to give conclusion on the experimental data. Basically, ANNOVA is used to give which factor is significant or which factor has most significant effect.

Table 7: Analysis of Variance for Ra: S/N Ratio versus speed, feed, and depth of cut

Source	DF	SS	MS	F-Value	P-Value	% contribution
Speed	2	16.5144	8.2572	6.36	0.136	18.59%
Feed	2	69.6866	34.8433	26.86	0.036	78.45%
Depth of cut	2	0.0261	0.0131	0.01	0.990	0.029%
Error	2	2.5949	1.2975			
Total	8	88.8220				

S = 1.13906 R-sq = 97.08% R-sq(adj) = 88.31%

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For Surface Roughness, Speed has 18.59% contribution, Feed has 78.45% contribution and Depth of cut has 0.029% contribution. From the above table it is seen that Feed is the most influential factor followed by Speed & Depth of cut for Surface Roughness.

Table 8: Analysis of Variance for MRR: S/N Ratio versus speed, feed, depth in Minitab software

Source	DF	SS	MS	F-Value	P-Value	% contribution
Speed	2	8.078	4.0391	5.69	0.150	16.94%
Feed	2	17.425	8.7125	12.26	0.075	36.55%
Depth of cut	2	20.743	10.3716	14.60	0.064	43.51%
Error	2	1.421	0.7105			
Total	8	47.667				

S = 0.842894 R-sq = 97.02% R-sq(adj) = 88.08%

For Material Removal Rate, Depth of cut has 43.51% contribution, Feed has 36.55% contribution and Speed has 16.94% contribution. From the above table it is seen that Depth of cut is the most influential parameter followed by feed rate and Speed for Material Removal Rate.

G. CONFIRMATION TEST

In order to see the accuracy of the result obtained from the Minitab software, it is necessary to perform a confirmation test. This confirmation test will be used for two comparisons.

1. Comparing Optimum Theoretical or predicted value with the Experimental value.
2. Comparing Initial cutting parameter with Optimum cutting parameter (Experimental).

To obtain the Theoretical optimum value, following formula is used.

$$\eta_{\text{optimum}} = \eta_{\text{mean}} + \sum (\eta_j - \eta_{\text{mean}})$$

Where, η_{optimum} is optimum S/N ratio, η_j is optimal level of factors and η_{mean} is overall mean S/N ratio.

For Surface Roughness, the combination here is A2B1C3, hence the formula becomes;

$$\eta_{\text{optimum}} = \eta_{\text{mean}} + (\eta_{A2} - \eta_{\text{mean}}) + (\eta_{B1} - \eta_{\text{mean}}) + (\eta_{C3} - \eta_{\text{mean}})$$

$$\eta_{\text{optimum}} = -10.6441 + [(-9.415) - (-10.6441)] + [(-7.167) - (-10.6441)] + [(-10.568) - (-10.6441)]$$

$$\eta_{\text{optimum}} = \mathbf{-5.8618 \text{ db}}$$

To find the Surface Roughness of above theoretical value we have to use following formula;

$$Ra_{\text{optimum}} = (10)^{-\eta_{\text{optimum}}/20} = (10)^{-(-5.8618)/20} = \mathbf{1.95 \mu\text{m}}$$

Since this combination of A2B31C3 is not present in L9 orthogonal array, we need to perform experiment on this combination and then find out the Surface Roughness by measuring the Ra value from Mitutoyo SJ 400 surface testor and its S/N ratio is calculated which is given table below.

Table 9: Confirmation Experiment Table for Ra

	Initial Cutting Parameter	Optimum Cutting Parameter	
		Prediction	Experiment
Combination	A2B2C3	A2B1C3	A2B1C3
Ra	3.03	1.95	1.78
S/N Ratio	-9.6289	-5.8618	-5.0084
Improvement in S/N Ratio	4.62		

The percentage error between predicted and experimental value is given as follows;

$$\% \text{ Error} = \frac{1.95 - 1.78}{1.95} = 0.0871 = \mathbf{8.71 \%}$$

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The initial cutting parameter combination used by company was A2B2C3, its value is also given in the table. The improvement of Surface Roughness from initial cutting parameter to optimum cutting parameter is 1.7 times i.e. 170.22 %. Also the improvement of S/N ratio from initial cutting parameter to optimum cutting parameter is 4.62.

For Material Removal Rate, the combination here is A3B3C3, hence the formula becomes;

$$\eta_{\text{optimum}} = \eta_{\text{mean}} + (\eta_{A3} - \eta_{\text{mean}}) + (\eta_{B3} - \eta_{\text{mean}}) + (\eta_{C3} - \eta_{\text{mean}})$$

$$\eta_{\text{optimum}} = 67.2589 + (68.31 - 67.2589) + (68.63 - 67.2589) + (69.12 - 67.2589)$$

$$\eta_{\text{optimum}} = 71.54 \text{ db}$$

To find the Material Removal Rate of above theoretical value we have to use following formula;

$$MRR_{\text{optimum}} = Y^2 = \frac{1}{(10^{-\eta_{\text{optimum}}/10})} = \frac{1}{(10^{-71.54/10})}$$

$$MRR_{\text{optimum}} = Y = 3775.72 \text{ mm}^3/\text{min}$$

Since this combination of A3B3C3 is not present in L9 orthogonal array, we need to perform experiment on this combination and then find out the Material Removal Rate and its S/N ratio which is given table below.

Table 10: Confirmation Experiment Table for MRR

	Initial Cutting Parameter	Optimum Cutting Parameter	
		Prediction	Experiment
Combination	A2B2C3	A3B3C3	A3B3C3
MRR	2975.56	3775.72	3522.91
S/N Ratio	69.47	71.54	70.93
Improvement in S/N Ratio	1.46		

The percentage error between predicted and experimental value is given as follows;

$$\% \text{ Error} = \frac{3775.72 - 3522.91}{3775.72} = 0.0669 = 6.69 \%$$

The initial cutting parameter combination used by company was A2B2C3, its value is also given in the table. The improvement of Material Removal Rate from initial cutting parameter to optimum cutting parameter is 1.18 times i.e. 118.39 %. Also the improvement of S/N ratio from initial cutting parameter to optimum cutting parameter is 1.46.

V. CONCLUSION

In this thesis, the Taguchi method is used for finding the optimum parameters for Surface Roughness and Material Removal Rate in turning operation for material- Delrin 500AL. Three factors i.e. Speed, Feed and Depth of cut along with three levels of each factor were considered. By obtaining the result of S/N ratios, Response table, Graphs, ANNOVA and Confirmation experiment following conclusion is given;

- 1) A Taguchi Design technique is one of the latest optimization techniques which is used in industries for optimum selection of levels of various variables and increasing the profit by increasing the quality and productivity.
- 2) The optimum cutting parameter for Surface roughness obtained at combination of A2B1C3 i.e. Speed at level 2- 200 rpm, Feed at level 1- 0.15 mm/rev and Depth of cut at level 3- 1.4 mm.
- 3) The optimum cutting parameter for Material Removal Rate is obtained at combination of A3B3C3 i.e. Speed at level 3- 300 rpm, Feed at level 3- 0.25 mm/rev and Depth of cut at level 3- 1.4 mm.
- 4) The optimum value for Surface Roughness Ra obtained is 1.78 μm and the optimum value for Material Removal Rate obtained is 3522.91 mm^3/min .
- 5) The dominant factor affecting Surface roughness is feed which has 78.45% contribution, followed by Speed having 18.59% contribution and Depth of cut having 0.029% contribution.

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- 6) The dominant factor affecting Material Removal Rate is Depth of cut which has 43.51% contribution, followed by Feed having 36.55% contribution and Speed having 16.94% contribution.
- 7) The percentage error between predicted and experimental value for Surface roughness is 8.71%, and the percentage error between predicted and experimental value for Material Removal Rate is 6.69 %.
- 8) The improvement of Surface Roughness from initial cutting parameter to optimum cutting parameter is 1.7 times i.e. 170.22 % and the improvement of Material Removal Rate from initial cutting parameter to optimum cutting parameter is 1.18 times i.e. 118.39 %.
- 9) The improvement of S/N ratio from initial cutting parameter to optimum cutting parameter for Surface Roughness is 4.62 and the improvement of S/N ratio from initial cutting parameter to optimum cutting parameter for Material Removal Rate is 1.46.

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