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Parametric Optimization of High Speed CNC Turning Operation for Improving the Surface Quality of (AA6063-T6) Aluminium Alloy Components

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Abstract : This paper elucidates the effect of high speed CNC turning parameters cutting speed, feed rate and depth of cut on the surface quality of AA6063-T6 aluminium alloy. The experiments are conducted based on the three level full factorial design (3^3) and surface finish was tested on the finished components machined by high speed CNC turning centre. A mathematical expression representing surface roughness was developed using non-linear regression analysis. The optimization techniques namely Taguchi method and genetic algorithm have been used to optimize the turning parameters for obtaining best surface roughness of the components. The optimum parametric conditions of turning operation have been tested with the confirmation experiments. It has been well-known from the results that the optimum condition obtained by genetic algorithm outperformed the results obtained from experimental design and Taguchi method.
Keywords : AA6063-T6 aluminium alloy, High speed CNC turning operation, Surface roughness, Taguchi method, Genetic algorithm.

1. Introduction

Aluminium alloys are extensively used in numerous sectors such as aerospace, marine, automotive, defense, etc., due to their enviable properties like more strength, less weight, high wear resistance, high thermal conductivity and low thermal expansion [1-3].

According to economical and dynamic market situation, the production industries are forcefully allocated to cost-effective machining under difficult machining conditions for the parametric optimization of production processes [4-6]. Developing high quality product with low manufacturing cost is the key purpose of all metal processing productions. The high speed machining and recent machining technologies are extensively used to turn the components that require high degree of surface quality [7-9]. The surface texture is one of the major necessities for machined parts because it is used toevaluate the degree of surface quality of the parts. In order to acquireimproved surface finish, the appropriate fixing of cuttingparameters is greatest important earlier tomachining. [10-12].

The turning is one of the furthermost machining process in which a single point cutting tool eliminates undesirable material from a revolving cylinder-shaped work piece. The increasing importance of high speed turning operation gains new dimensions in the present industrial age[13-15]. The high speed CNC turning parameters like cutting speed, feed rate, depth of cut, coolant condition and tool geometry disturbs considerably the surface feature of the turned parts. The proper selection of cutting parameters is essential to optimize the surface quality of the work piece[16-20].

Many attempts have been made by the research communities to obtain better surface quality on the machined components made of aluminium alloys like AA6063, AA7075, A2014, AA6061, AA6351, A356, ENAC43400, etc [21-30].

The present work has been carried out to observe the effect of high speed CNC turning parameters like cutting speed, feed rate and depth of cut on the surface roughness of AA6063-T6 aluminium alloy. The optimization techniques namely Taguchi method and genetic algorithm have been used to optimize the high speed CNC turning operation for attaining superior surface quality on the turned components in this study.

2. Experiment Details

2.1 Work Piece Material

AA6063-T6 aluminium alloy is used as work piece material in this study. It has medium strength, high corrosion resistance and formability. The most commonly available form of this material is with T6 tempering condition. This material is generally used for architectural applications, shop fittings, irrigation tubing, balustrading, window frames, extrusions, doors marine equipment, road and rail transport.This aluminium alloy also corresponds to AA6063, Al Mg0.7Si, GS10, AlMgSi0.5, A-GS, 3.32206, ASTM B210, ASTM B221, ASTM B241, ASTM B345, ASTM B361, ASTM B429, ASTM B483, ASTM B491, MIL G-18014, MIL G-18015, MIL P-25995, MIL W-85, QQ A-200/9, SAE J454, UNS A96063 and HE19.The chemical composition and mechanical properties are specified in Table 1and Table 2 correspondingly.

Table 1 Chemical composition of AA6063-T6 Aluminium Alloy

S.No	Element	% wt	
		Std	Actual
1	Aluminum	Max 97.5	97.25
2	Chromium	Max 0.1	0.05
3	Copper	Max 0.1	0.05
4	Ferrite	Max 0.35	0.30
5	Magnesium	0.45-0.9	0.85
6	Manganese	Max 0.1	0.05
7	Silicon	0.2-0.6	0.50
8	Tin	Max 0.1	0.05
9	Zinc	Max 0.1	0.05

Table 2 Mechanical properties of AA6063-T6 Aluminium Alloy

Property	Value
Density	2.7 g/cm^3
Yield strength	195 MPa
Ultimate strength	240 MPa
Hardness	75 BHN
Shear strength	150 MPa
Fatigue strength	65 MPa
Poisson’s ratio	0.33

2.2 High Speed CNC Turning Centre

The turning operation was done at high speed on cylindrical work piece of AA6063-T6 material with help of a CNC turning machine (EMCO TURN 250) presented in Figure 1. The tungsten carbide insert was used as a cutting tool for executing turning operation presented in Figure 2 and dry condition was maintained throughout the experiments. The cutting conditions of the high speed turning operation are given in the Table 3.

Figure 1 High speed CNC turning centre (EMCO TURN 250)

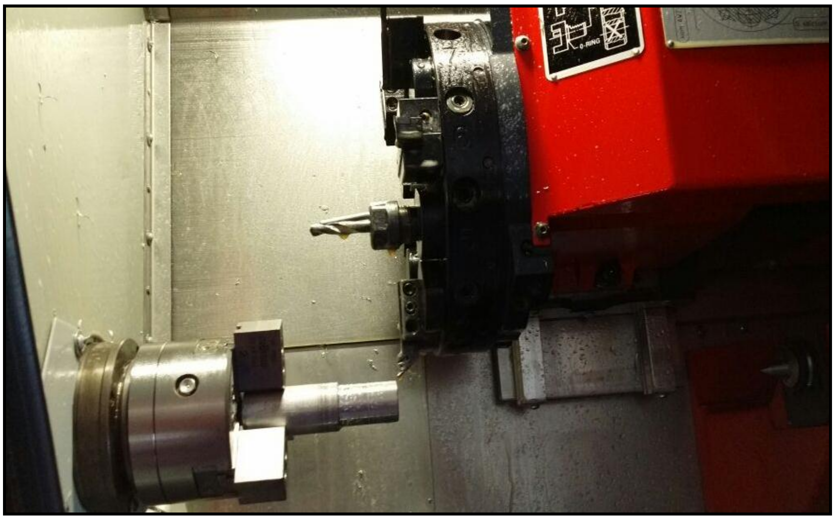

Figure 2 Turning operation on work piece

Table 3 Operating conditions

Conditions	**Details**
Work piece material	AA6063-T6 Aluminium Alloy
work piece geometry	25 mm diameter × 100 mm long
CNC lathe model	CNC EMCO TURN 250
Tool insert	Uncoated Carbide Insert
Measuring instrument	Mitutoyo SJ-210 Profilometer
Cutting condition	Dry

2.3 Design of Experiments

Three significant machining parameters specifically cutting speed (A), feed rate (B) and depth of cut (C), each at three levels considered for this work are given in Table 3. A full factorial design (3^3) was selected for conducting 27 experiments in this study.

Table 3 Parameters and their levels

Parameter	Notation	1	2	3
Cutting speed (rpm)	A	2000	4000	6000
Feed rate (mm/rev)	B	0.15	0.3	0.45
Depth of cut (mm)	C	0.2	0.4	0.6

2.4 Surface Roughness Tester

The surface roughness of the turnedparts are shown in Figure 3 was measured using surface roughness tester (Mitutoyo SURFTEST SJ201) shown in Figure 4.

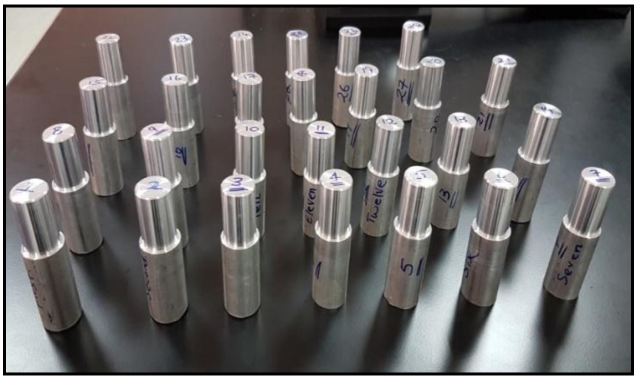

Figure 3 Turned components

Figure 4 Surface roughness tester

3. Results and Discussion

3.1 Optimum Condition by Taguchi Method

The surface roughness was taken as machining response with the category of quality characteristics “smaller the better”. The S/N ratio of the response can be assessed by using the equation (1).

$$S/N_{(dB)} = -10\log_{10}\left(\frac{1}{n}\sum_{i=1}^{n} R_i^2\right) \quad (1)$$

where i=1,2,…, n (here n=4) and R_i is the response value for an experimental condition. For each experimental condition, S/N ratio was calculated and presented in Table 4. Mean value ($\bar{Y}$) of S/N ratios was also calculated using equation (2).

$$\text{Mean}, \bar{Y} = \frac{1}{N}\left(\sum_{j=1}^{N} Y_j\right) \quad (2)$$

where j=1,2,….., N (here N=27) and Y_j is S/N ratio for j^{th} parametric setting. The optimum level of the cutting parameters of turning operation was by calculating the average S/N ratio response was for every level of each parameter and the conforming details are presented in Table 4. Based on the maximum value of S/N ratio, an optimum level for each cutting parameter (A: 2^{nd} level; B: 3^{rd} level and C: 1^{st} level) was noted. The optimum machining condition A_2 B_3 C_1 (spindle speed of 4000 rpm, feed rate of 0.45 mm/rev and depth of cut of 0.2 mm) was noted. The average S/N ratio response graph shown in Figure 5 described the variation of each machining parameter on the performance of the turning operation. The percentage contribution of the machining parameters is depicted in Figure 6.

Table 4 Experiments and S/N ratio

Ex.no	A	B	C	Surface roughness (μm)					S/N Ratio Yj (dB)
				R_1	R_2	R_3	R_4	R_a	
1	1	1	1	1.146	1.166	1.246	1.226	1.196	-1.5598
2	1	1	2	1.237	1.257	1.337	1.317	1.287	-2.196
3	1	1	3	1.144	1.164	1.244	1.224	1.194	-1.5453
4	2	2	1	0.797	0.817	0.897	0.877	0.847	1.4321
5	2	2	2	0.922	0.942	1.022	1.002	0.972	0.2389
6	2	2	3	0.863	0.883	0.963	0.943	0.913	0.7817
7	3	3	1	0.827	0.847	0.927	0.907	0.877	1.1304
8	3	3	2	0.986	1.006	1.086	1.066	1.036	-0.3141
9	3	3	3	0.961	0.981	1.061	1.041	1.011	-0.1022
10	2	3	1	0.745	0.765	0.845	0.825	0.795	1.981
11	2	3	2	0.858	0.878	0.958	0.938	0.908	0.8293
12	2	3	3	0.788	0.808	0.888	0.868	0.838	1.5246
13	3	1	1	1.201	1.221	1.301	1.281	1.251	-1.9499
14	3	1	2	1.384	1.404	1.484	1.464	1.434	-3.1346
15	3	1	3	1.383	1.403	1.483	1.463	1.433	-3.1285
16	1	2	1	1.118	1.138	1.218	1.198	1.168	-1.3543
17	1	2	2	1.198	1.218	1.298	1.278	1.248	-1.929
18	1	2	3	1.093	1.113	1.193	1.173	1.143	-1.1666
19	3	2	1	0.977	0.997	1.077	1.057	1.027	-0.2384
20	3	2	2	1.148	1.168	1.248	1.228	1.198	-1.5743
21	3	2	3	1.135	1.155	1.235	1.215	1.185	-1.4796
22	1	3	1	1.166	1.186	1.266	1.246	1.216	-1.7037
23	1	3	2	1.233	1.253	1.333	1.313	1.283	-2.169
24	1	3	3	1.116	1.136	1.216	1.196	1.166	-1.3394
25	2	1	1	0.923	0.943	1.023	1.003	0.973	0.23
26	2	1	2	1.06	1.08	1.16	1.14	1.11	-0.9124
27	2	1	3	1.013	1.033	1.113	1.093	1.063	-0.5372
							Avg.	1.1027	-0.7476

Table 5 Average S/N ratio response

	A	B	C
Level1	-1.662566667	-1.63707778	-0.22584444
Level2	0.618666667	-0.58772222	-1.24013333
level3	-1.199022222	-0.01812222	-0.77694444
Max-Min	2.281233333	1.618955556	1.014288889
% contribution	46.41863157	32.94257556	20.63879286
Rank	1	2	3
Optimum level	A2	B3	C1

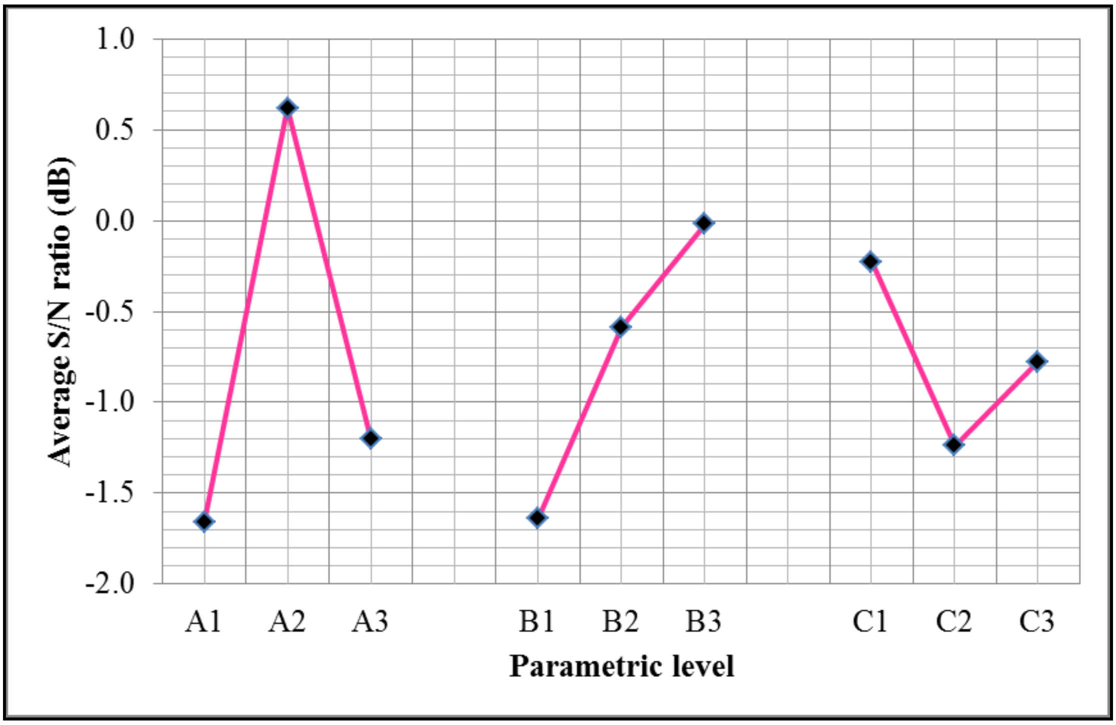

Figure 5 Response Graph

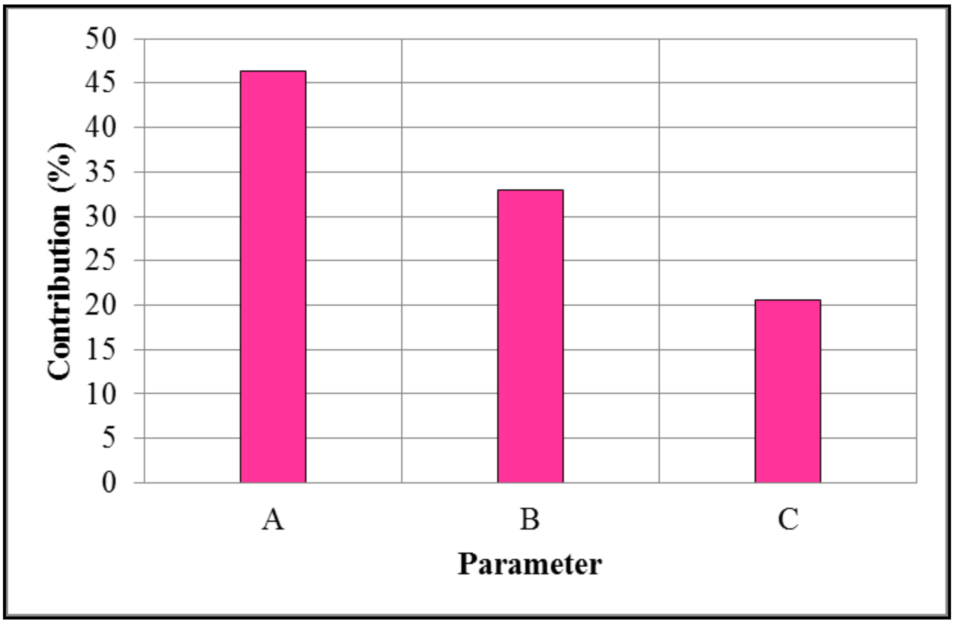

Figure 6 Percentage contribution

3.2 Optimum Condition by Genetic Algorithm

The effect of machining parameters on average surface roughness (R_a) was evaluated by using non-linear regression analysis with the help of MINITAB software, and is given below.

$$R_a = 1.68289 - 0.92311A - 0.02844B + 0.33311C + 0.25083A^2 + 0.03717B^2 - 0.092C^2$$

$$-0.0985AB + 0.04592AC - 0.01192BC \quad (3)$$

It was noticed that $r^2 = 0.99$ where 'r' is correlation coefficient. The value of r^2 specifies the closeness of the model signifying the process. Since r^2 is approaching unity, this equation can be considered as an objective function to use it for genetic algorithm which predicts the better parameter setting. MATLAB genetic algorithm tool was used to find out the optimum parametric condition for the minimization of surface roughness in this study. The mathematical model given in Equation 3 was used as fitness function. The constraints for all machining parameters (A, B and C) were input in MATLAB. Genetic algorithm was run for the evolutionary parameters such as number of iterations (51), population type (double vector), population size (100), cross over probability (0.85), fitness selection function (stochastic) and mutation probability (0.05). It was observed that the fitness value was decreased through generations as shown in Figure 7 and an optimized surface roughness (-0.766 µm) was obtained in the final generation. The optimum condition in the final generation (spindle speed of 4670 rpm feed rate of 0.45 mm/rev and depth of cut of 0.2 mm) was noticed.

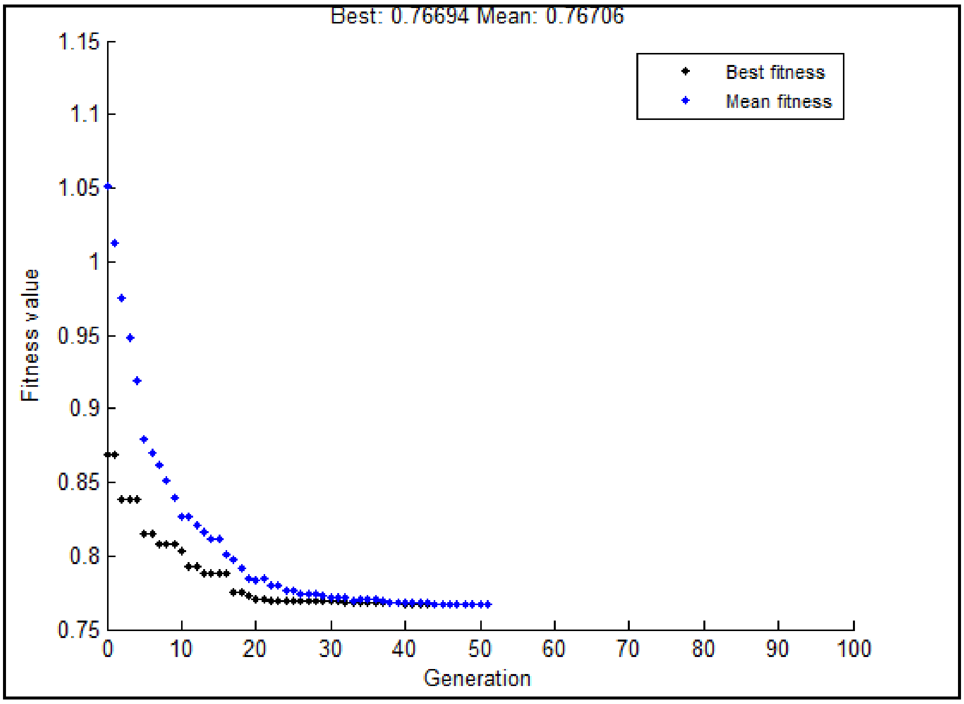

Figure 7 GA generations

3.3 Confirmation Experiments

The confirmation experiments were carried out for the optimum parametric condition determined through Taguchi Method and genetic algorithm. The average surface roughness (predicted and tested) values are given in Table 6. It is noticed that there is a good agreement between the predicted and actual surface roughness since the error is less than 5%.

Table 6 Optimum parametric conditions

S. No	Optimization tool	Optimum parametric condition			Average Surface Roughness, R_a (µm)		% error
		Parameters	Coded	Uncoded	Predicted	Tested	
1	Taguchi method	Cutting speed	2	4000 rpm	0.795	0.815	2.45
		Feed rate	3	0.45mm/rev			
		Depth of cut	1	0.2 mm			
2	Genetic algorithm	Cutting speed	2.335	4670 rpm	0.766	0.775	1.16
		Feed rate	3	0.45mm/rev			
		Depth of cut	1	0.2 mm			

The optimum parametric setting for feed rate (0.45 mm/rev) and depth of cut (0.2 mm) was noted to be same in the Taguchi method and Genetic algorithm. With respect to cutting speed, the optimum setting of Taguchi method is lesser than the setting of genetic algorithm. It is expected that the increase in cutting speed from 4000 rpm to 4670 rpm could result in fine surface finish during machining. From the confirmation experiments, it was verified that genetic algorithm would give better optimized value than Taguchi method with respect to surface quality.

4. Conclusion

The following conclusions were drawn based on the surface roughness test conducted on the aluminium alloy (AA6063-T6) components during high speed CNC turning operation.

i) A non-linear regression model has been developed for predicting surface roughness using the machining parameters like cutting speed, feed rate and depth of cut.
ii) From the experimental results, it has been noticed that the machining time is very less, which would increase the productivity and in turn reduce the cost of the product.
iii) The confirmation experiment has showed that the error occurred was less than 5% between the model and tested value.
iv) The optimal setting of machining parameters of turning operation for optimal surface roughness can be used wherever aluminium alloy (AA6063-T6) requires high degree of surface finish.
v) From the confirmation experiments, it is apparent that GA would exhibit a better result than Taguchi method.
vi) These optimum machining conditions can be employed when the aluminium alloy (AA6063-T6) are turned for the applications like, pistons, piston rings, piston rods, thick cylinders, hollow cylinders, etc.

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