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Effect of Milling Parameters on Surface Quality of AA6063-T6 Aluminium Alloy During High Speed CNC Face Milling

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Abstract : This paper aims to carry out analytical and experimental study on the effects of high speed face milling parameters like cutting speed, feed rate anddepth of cut on the surface quality of AA6063-T6 aluminium alloy components. The experiments were conducted based on full factorial design (3^3=27) of experiments and surface roughness was measured with profilometer on the components milled by a high speed CNC vertical machining centre. A mathematical model was developed using non-linear regression analysis with the help of MINITAB software. The face milling parameters were optimized for better surface quality of the milled components by employing Taguchi method and genetic algorithm. The optimum parametric conditions obtained from the analytical study have been confirmed with the experimental results.
Keywords : High speed machining, AA6063-T6 aluminium alloy, face milling, Taguchi method, Surface roughness.

1. Introduction

The surface quality has always been one of the most important responses in machining operations. In view of the present economical and dynamic market situation, the continuous improvement in surface quality has become a major priority in the industries[1-4]. The numerous technologies involved in the machining sectors continues to grow with the introduction of improved equipment and tools in order to produce high degree surface quality with specific characteristics such as dimensional accuracy, surface roughness, etc[5-8].

One of the most promising advanced manufacturing technologies in the last decade is the high speed machiningbecause of its benefits like faster production rates with improved surface quality, reduced costs and shorter lead times. Since this technique combines high spindle speeds with increased feed ratesresults in lowercutting forcesand high chip-forming rate, producing an improved surface quality and tighter tolerances[9-15].

In recent days, aluminum alloys have developed as the precursor for a variety of applications due to their desired propertiessuch ashigh wear resistance, great thermal conductivity, more strength, less weight,and short thermal expansion[16-20].From analyzing the literature, it has been observed that numerous research activities were carried out regarding high speed machining on the various aluminium alloys like AA7075, AA6060, AA6061, AA5083, LM26, etc. In addition, very few research activities on high speed machining of heat treated aluminium alloys like AA6063-T6 has also been noticed from the literature[21-30].

In the production industries, numerous processes are adapted for machining heat treated aluminium alloys. Out of them, high speed face milling is one of the processes because of its ability to remove materials in a faster way with reasonably good surface finish. Surface quality can be significantly improved with the accurate control of face milling parameters like cutting speed, feed rate, and depth of cut, type of coolant, coolant rate, tool geometry, work piece material and tool material[30-35].

The influence of high speed CNC face milling parameters like cutting speed, feed rate and depth of cut on surface roughness of AA6063-T6 aluminium alloy was investigated in this study. The suitable face milling conditions for optimum surface quality is found out using the optimization tools like Taguchi method and genetic algorithm.

2. Experiment Details

2.1 Work Piece Material

AA6063-T6 aluminium alloy has medium strength, high corrosion resistance and formability. The most commonly available form of this material is with T6 tempering condition, which is generally used for architectural applications, shop fittings, irrigation tubing, window frames, extrusions, doors marine equipment, road and rail transport. This aluminium alloy also corresponds to Al Mg0.7Si, ASTM B210, ASTM B221, ASTM B241, ASTM B345, ASTM B361, ASTM B429, ASTM B483, ASTM B491, SAE J454, UNS A96063 and HE19.The chemical composition and mechanical properties are specified in Table 1and Table 2 correspondingly. The geometry of the work piece is shown in Figure 1.

Table 1Chemical composition ofAA6063-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	2.7g/cm^3
Yield strength	195MPa
Ultimate strength	240MPa
Hardness	75 BHN
Shear strength	150MPa
Fatigue strength	65MPa
Poisson's ratio	0.33

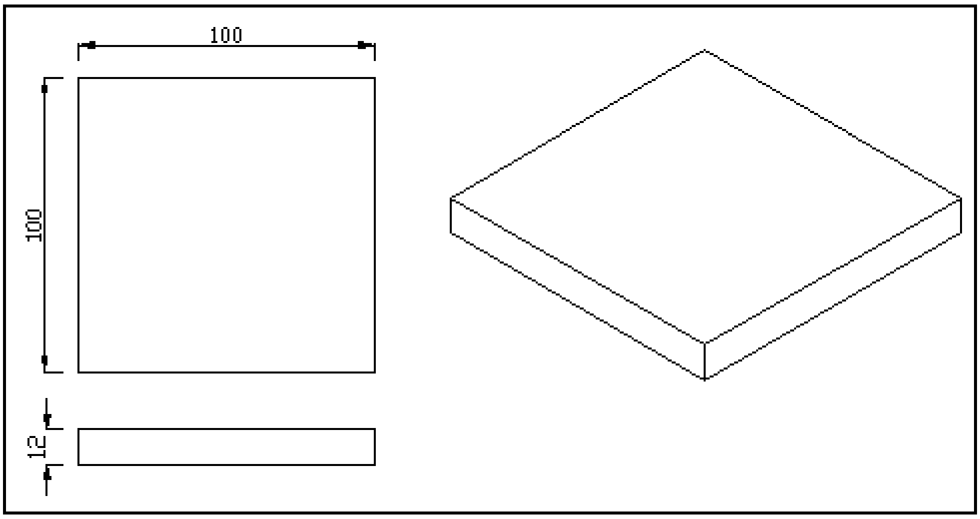

Figure 1Work piecegeometry

2.2 High Speed CNC Machining Centre

CNC vertical machining centre shown in Figure 2 is used with uncoated tungsten carbide insert as cutting tool for high speed face milling on the AA6063-T6 aluminium alloy. Blastocut 500 (water and coolant in 80:20 ratio by volume) is used as coolant during all the machining process. Profilometer is used for measuring the surface roughness of the milled work pieces shown in Figure 3. The face milling operation parameters are given in the Table 3.

Figure 2 High speed CNC vertical milling machine

Figure 3Face milled components

Table 3Operating conditions

Condition	**Specification**
Work piece material	AA6063-T6 aluminium alloy
Geometry of work piece	100 mm × 100 mm × 12 mm
Milling Machine	CNC vertical machining centre (EMCO 450 Mill)
Cutter used	Uncoated Carbide Insert
Measuring instrument	Profilometer (Surftest), Mitutoyo SJ-210
Coolant	Blastocut 500 (water and coolant in 80:20 ratio by volume)

2.3 Experimental Design

Threemain facemilling parameters such as cutting speed (A), feed rate (B) and depth of cut (C), each at three levels consideredforthe entire machining process are given in Table 4. A full factorial design (3^3) was selected for conducting27 experiments in this study.

Table 4 Parameters and their levels

Parameter	**Notation**	**1**	**2**	**3**
Cutting speed (rpm)	A	3500	4750	6000
Feed rate (mm/min)	B	500	1000	1500
Depth of cut (mm)	C	0.15	0.275	0.4

3. Results and Discussion

3.1 Optimum Machining Conditions by Taguchi Method

The surface roughness was assumed as output machining response with "smaller the better" characteristics. The S/N ratio of the response can be assessed with the use of equation (1).

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

In which i=1,2,3…, n (here n=4) and R_i is the surface roughness value for an experimental condition. For each experiment, S/N ratio was estimated and presented in Table 5. The mean value ($\bar{Y}$) of S/N ratios was also estimated with the help of 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} experiment condition. The optimum level of the machining parameters of high speed face milling operation was determined based on the average S/N ratio response for every level of each parameter and the conforming details are presented in Table 6. Based on the maximum value of S/N ratio, an optimum level for each machining parameter (A: 2^{nd}level; B: 3^{rd}level and C: 3^{rd}level) was found. The optimum machining condition A_2 B_3 C_3 (cutting speed of 4750 rpm, feed rate of 1500 mm/min and depth of cut of 0.4 mm) was noticed. The average S/N ratio response graph shown in Figure 4 described the variation of each machining parameter on the performance of the face milling operation. The percentage contribution of the machining parameters is depicted in Figure 5.

Table 5 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_{avg}**	
1	1	1	1	0.152	0.176	0.156	0.172	0.164	15.6864
2	1	1	2	0.154	0.176	0.159	0.174	0.166	15.5969
3	1	1	3	0.146	0.17	0.15	0.166	0.158	16.0088
4	2	2	1	0.133	0.157	0.136	0.151	0.144	16.7967
5	2	2	2	0.129	0.153	0.133	0.149	0.141	16.993
6	2	2	3	0.121	0.145	0.125	0.141	0.133	17.4975
7	3	3	1	0.143	0.167	0.147	0.163	0.155	16.1746
8	3	3	2	0.14	0.164	0.144	0.16	0.152	16.3436
9	3	3	3	0.131	0.155	0.135	0.151	0.143	16.8712
10	2	3	1	0.136	0.16	0.14	0.156	0.148	16.5742
11	2	3	2	0.127	0.151	0.131	0.147	0.139	17.1164
12	2	3	3	0.112	0.136	0.116	0.132	0.124	18.1023
13	3	1	1	0.141	0.165	0.145	0.161	0.153	16.2869
14	3	1	2	0.152	0.176	0.156	0.172	0.164	15.6864
15	3	1	3	0.157	0.181	0.161	0.177	0.169	15.4265
16	1	2	1	0.154	0.178	0.158	0.174	0.166	15.5815
17	1	2	2	0.147	0.171	0.151	0.167	0.159	15.9542
18	1	2	3	0.133	0.157	0.137	0.153	0.145	16.7512
19	3	2	1	0.139	0.163	0.143	0.159	0.151	16.4007
20	3	2	2	0.144	0.168	0.148	0.164	0.156	16.119
21	3	2	3	0.141	0.165	0.145	0.161	0.153	16.2869
22	1	3	1	0.161	0.185	0.165	0.181	0.173	15.224
23	1	3	2	0.148	0.174	0.154	0.167	0.161	15.8593
24	1	3	3	0.126	0.15	0.13	0.146	0.138	17.1788
25	2	1	1	0.131	0.155	0.135	0.151	0.143	16.8712
26	2	1	2	0.133	0.153	0.142	0.156	0.146	16.696
27	2	1	3	0.136	0.16	0.14	0.156	0.148	16.5742
							Avg.	0.1516	16.3948

Table 6Average S/N ratio response

	A	B	C
Level1	15.98234444	16.09258889	16.17735556
Level2	17.02461111	16.48674444	16.26275556
level3	16.17731111	16.60493333	16.74415556
Max-Min	1.042266667	0.512344444	0.5668
% contribution	49.13081963	24.15111535	26.71806502
Rank	1	3	2
Optimum level	A2	B3	C3

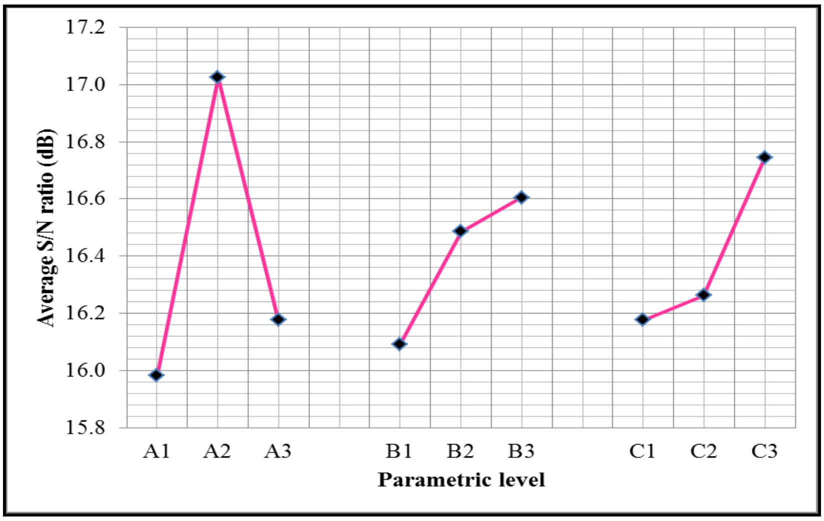

Figure 4 Response Graph

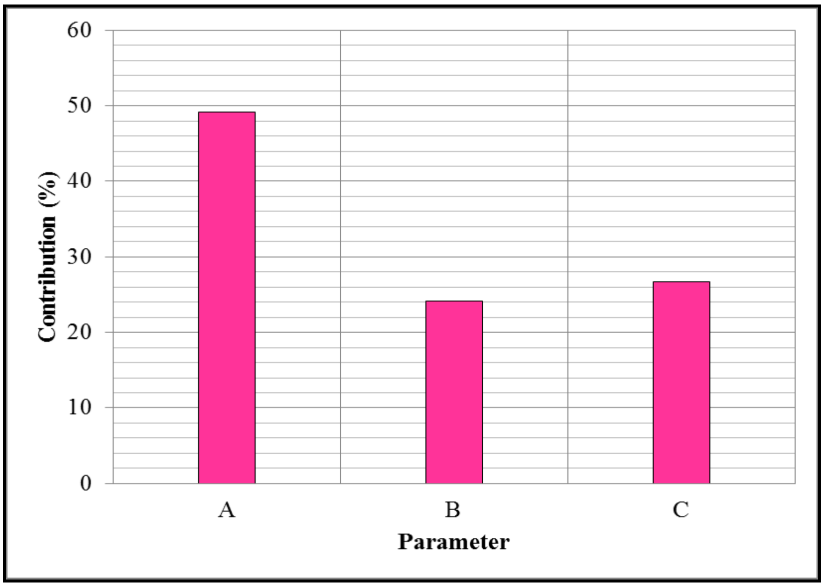

Figure 5 Percentage contribution

3.2 Optimum Machining Condition by Genetic Algorithm

The effect of face millingparameters on average surface roughness (R_{avg}) was evaluated by using non-linear regression analysis with the help of MINITAB software. Non-linear regression model developed is shown in Figure 6 and is given in the form Equation (3).

R_{avg} = 0.213111-0.075222A+0.002667B+0.0115556C+0.016333A^2+0.002667B^2-0.003333C^2

-0.001667AB+0.005667AC-0.007167BC(3)

It was noticed that r^2 = 0.996 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.

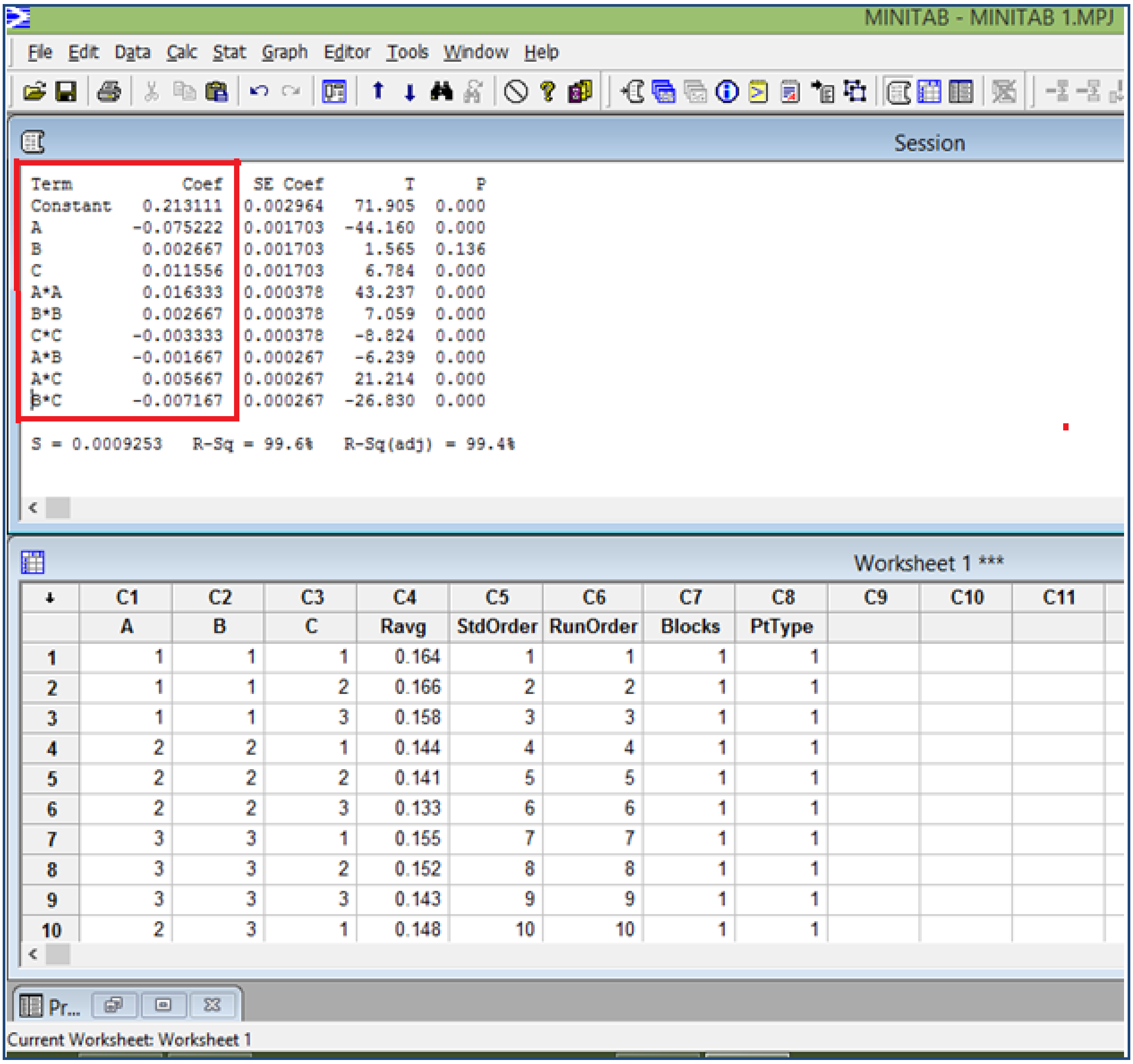

Figure 6Non-linear Regression Model

The optimum machining parametric conditions for lesser surface roughness was determined in the study by using MATLAB genetic algorithm tool. The nonlinear regression equation given in equation 3 was used as fitness function in the mathematical model.The constraints for all machining parameters (A, B and C) were given as input in MATLAB. The evolutionary parameters like number of iterations (52), population type (double vector), population size (1000), cross over probability (0.95), fitness selection function (stochastic) and mutation probability (0.05) were found by running Genetic algorithm.Figure 7 depicts that there is a subsequent reduction in the fitness value through generations and the optimized surface roughness in the final generation is 0.1241 µm. It is observed from the final generation that the optimal conditions for the parameters like cutting speed, feed rate and depth of cut were found as 4665 rpm, 1500 mm/min and 0.4mm respectively.

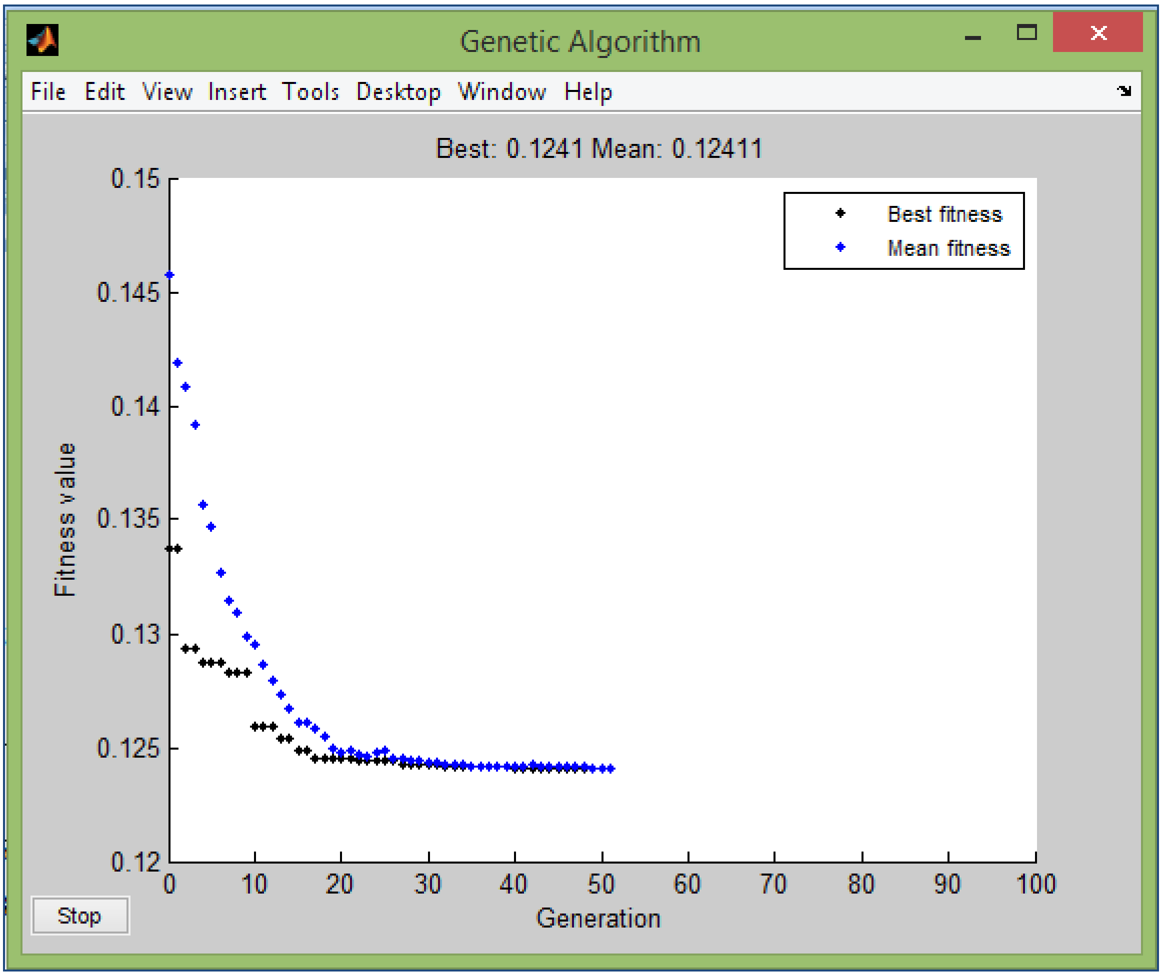

Figure 7 GA generations

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 7. It is evident that the experimental results on the surface roughness are found to be in good agreement with predictions from Analytical models.

Table 7 Optimum parametric conditions

Serial number	Optimization tool	Optimum parametric condition			Average Surface Roughness, (µm)		% error
		Parameters	Coded	Uncoded	Predicted	Tested	
1	Taguchi method	Cutting speed	2	4750 rpm	0.1242	0.124	0.16
		Feed rate	3	1500mm/min			
		Depth of cut	3	0.4 mm			
2	Genetic algorithm	Cutting speed	1.932	4665 rpm	0.1241	0.122	1.72
		Feed rate	3	1500mm/min			
		Depth of cut	3	0.4 mm			

The optimum parametric setting for feed rate (1500 mm/min) and depth of cut (0.4 mm) was noted to be same in the Taguchi method and Genetic algorithm. With respect to cutting speed, the optimum setting of genetic algorithm is lesser than the setting of Taguchi method. It is expected that the decrease in cutting speedfrom4750 rpm to 4665 rpm could result in fine surface finish during face milling operation. From the confirmation experiments, it was verified that genetic algorithm would give better optimized value than Taguchi method with respect to surface quality.

4. Conclusions:

Following are the conclusions drawn based on the surface roughness test conducted on AA6063-T6 aluminium alloy during high speed facing operation with uncoated carbide insert.

i) From the results obtained, a regression model has been developed for surface roughness. From the equation, the value of surface roughness can be predicted if the values of cutting speed, feed rate and depth of cut are known.
ii) From the confirmation experiments, it is evident that the error occurred was less than 5% between predicted and tested value.
iii) The optimal settings of face milling process parameters for optimal surface roughness can be used wherever AA6063-T6 aluminium alloy require high degree of surface finish.
iv) These optimum conditions can also be used when AA6063-T6 aluminium alloy are milled for the typical applications likepatterns for moulding, guide ways, slide ways, parts with flat surface, etc.

Nomenclature

A	: Cutting speed
B	: Feed rate
C	: Depth of cut
N	: Number of experiments
n	: Number of observations
R	: Readings measured
R_{avg}	: Average surface roughness
S/N	: Signal to noise ratio
$\bar{Y}$	: Mean

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References

1. Munoz De Escalona, P. and Maropoulos, P.G., 2015. A geometrical model for surface roughness prediction when face milling Al 7075-T7351 with square insert tools. Journal of Manufacturing Systems, 36, pp.216-223.
2. Azuddin, M. and Abdullah, W., 2009. A Study on surface roughness and burr formation of Al6061 with different spindle speed and federate for small end milling cutter. International Journal of Integrated Engineering, 1(1).
3. Satishkumar, P., Dharmalingam, S., Raja, K., Lingadurai, K. and Padmanaban, G., 2015. Investigation on Electrochemical Micro Machining of Al 6061-6% wt Gr based on Taguchi design of experiments, Vol.7, No.01, pp 203-211, International Journal of Chem Tech Research.
4. Atul, S.C.,2016. Investigation on Chromizing of C45 Steel using Response Surface Methodology, Vol.9, No.01 pp.82-91, International Journal of Chem Tech Research.
5. Rawangwong, S., Chatthong, J., Burapa, R. and Boonchouytan, W., 2012. An investigation of optimum cutting conditions in face milling aluminum 7075-t6 using design of experiment. Lecture Notes in Management Science, 4, pp.125-135.

6. Rawangwong, S., Chatthong, J., Burapa, R. and Boonchouytan, W., 2012. An investigation of optimum cutting conditions in face milling semi-solid AA 7075 using carbide tool. International Journal of Innovation, Management and Technology, 3(6), p.692.
7. Sequeira, A.A., Prabhu, R., Sriram, N.S. and Bhat, T., 2012. Effect of Cutting Parameters on Cutting Force and Surface Roughness of Aluminium Components using Face Milling Process-a Taguchi Approach. IOSR Journal of Mechanical and Civil Engineering, 3(4), pp.7-13.
8. Rezvani, E., Ghayour, H. and Kasiri, M., 2016. Effect of cutting speed parameters on the surface roughness of Al5083 due to recrystallization. Mechanical Sciences, 7(1), pp.85-91.
9. Kuttolamadom, M., Hamzehlouia, S. and Mears, L., 2010. Effect of machining feed on surface roughness in cutting 6061 aluminum. SAE International Journal of Materials and Manufacturing, 3(2010-01-0218), pp.108-119.
10. Adalarasan, R. and Santhanakumar, M., 2015. Response surface methodology and desirability analysis for optimizing µ-WEDM parameters for Al6351/20% Al2O3 composite, Vol.7, No.6, pp 2625-2631. International Journal of Chem. Tech. Research.
11. Syed, K.H. and Kuppan, P.,2015, Performance of Environmental Friendly Dielectric Fluid in Powder-Mixed Electrical Discharge Machining,Vol.8, No.7, pp 406-412, International Journal of Chem Tech Research.
12. Nimase, R.N. and Khodke, D.P., 2015. Effect of Machining Parameters on Surface Roughness of Al-7075 Alloy in End Milling. International Research Journal of Engineering and Technology (IRJET) e-ISSN, pp.2395-0056.
13. Okokpujie Imhade, P. and Okonkwo Ugochukwu, C., 2015. Effects of cutting parameters on surface roughness during end milling of aluminium under minimum quantity lubrication (MQL). International Journal of Science and Research, 4(5), pp.2937-2942.
14. Singh, C., Pabla, B.S., Bhogal, S.S. and Kumar, P., 2014. Empirical modeling of surface roughness and metal removal rate in CNC milling operation. IJITR, 2(4), pp.1120-1126.
15. Hricova, J., Kovac, M. and Sugar, P., 2014. Experimental investigation of high speed milling of aluminium alloy. Tehnički vjesnik, 21(4), pp.773-777.
16. Liu, Y., Zhang, L.T. and Xu, Z.H., 2012. Experimental investigation on high-speed milling of aluminum alloys. In Advanced Materials Research (Vol. 418, pp. 1141-1147). Trans Tech Publications.
17. De Lacalle, L.L., Angulo, C., Lamikiz, A. and Sanchez, J.A., 2006. Experimental and numerical investigation of the effect of spray cutting fluids in high speed milling. Journal of Materials Processing Technology, 172(1), pp.11-15.
18. Puvanesan, M., 2013. Experimental investigation of minimum quantity lubrication on tool wear in aluminum alloy 6061-t6 using different cutting tools.
19. Yan, B., Li, Y., Wang, W. and Feng, H., 2012. Experimental investigation on cutting performance of face milling cutter. In Applied Mechanics and Materials (Vol. 217, pp. 2133-2137). Trans Tech Publications.
20. Rao, B. and Shin, Y.C., 2001. Analysis on high-speed face-milling of 7075-T6 aluminum using carbide and diamond cutters. International Journal of Machine Tools and Manufacture, 41(12), pp.1763-1781.
21. Kannan, S. and Baskar, N., 2013. Modeling and Optimization of Face Milling Operation Based on Response Surface Methodology and Genetic Algorithm. International J Eng. and Tech, 5(5), pp.959-971.
22. Florence, T., Dharmalingam, S., Ragupathy, V. and Satishkumar, P., 2015. Machinablity study on Electrochemical Machining–A Review, Vol.7, No.6, pp 2596-2600, International Journal of Chem. Tech. Research.
23. Babu, B., Raja, K., Dharmalingam, S., Udhayaraj, S. and Vairamani, V., 2015. Electrochemical Micro Machining on Hybrid Metal Matrix Composites.Composites, Vol.8, No.2, pp 508-518, International Journal of Chem Tech Research.
24. Simunovic, G., Simunovic, K. and Saric, T., 2013. Modelling and simulation of surface roughness in face milling. International Journal of Simulation Modelling, 12(3), pp.141-153.
25. Ghan, H.R. and Ambekar, S.D., 2014. Optimization of cutting parameter for Surface Roughness, Material Removal rate and machining time of Aluminium LM-26 alloy. International Journal of Engineering Science and Innovative Technology, 3(2), pp.294-298.
26. Pare, V., Agnihotri, G. and Krishna, C., 2015. Selection of optimum process parameters in high speed CNC end-milling of composite materials using meta heuristic techniques–a comparative study. Strojniški vestnik-Journal of Mechanical Engineering, 61(3), pp.176-186.

27. Jomaa, W., Songmene, V. and Bocher, P., 2014. Surface finish and residual stresses induced by orthogonal dry machining of AA7075-T651. Materials, 7(3), pp.1603-1624.
28. Marimuthu, P., Senthilvelan, N. and Chandrasekaran, K.,2016. Performance of Uncoated and Baln/Tin Coated Tool on Aisi410 in CNC Turning, Vol.9, No.05 pp 439-445, International Journal of Chem Tech Research.
29. Ramadoss, K. and Elansezhian, R.,2014. Study on the Influence of Nanoadditives on Surface roughness of newly synthesized Magnesium Alloy during turning operation, Vol.6, No.3, pp 1739-1742, International Journal of Chem Tech Research.
30. Agarwal, N., 2012. Surface roughness modeling with machining parameters (speed, feed and depth of cut) in CNC milling. MIT International Journal of Mechanical Engineering, 2(1), pp.55-61.
31. Begić-Hajdarević, Đ., Ahmet, Č. and Kulenović, M., The effect of cutting parameters on surface roughness in high speed machining.
32. Chen, C.H., Wang, Y.C. and Lee, B.Y., 2013. The effect of surface roughness of end-mills on optimal cutting performance for high-speed machining. Strojniški vestnik-Journal of Mechanical Engineering, 59(2), pp.124-134.
33. Goh, H.W., 2004. The study on milling machining for aluminium alloy.
34. Varatharajulu, M., Loganathan, C. and Baskar, N.,2015, Influence of cutting parameters on burr height and burr thickness in drilling of Duplex 2205 using Solid Carbide,Vol.8, No.2, pp 768-777, International Journal of Chem Tech Research.
35. Vijay, I., Chockalingam, K., Kailasanathan, C. and Sivabharathy, M., 2014. Optimization of Surface roughness in selective laser sintered stainless steel parts, Vol.6, No.5, pp 2993-2999, International Journal of Chem Tech Research.

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