Effect of Milling Process Parameters on the Multiple Performance Characteristics

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Abstract
In the present work an investigation has been made to explore the effect of speed, feed and depth of cut on the multiple responses of material removal rate (MRR) and surface roughness (R_a). A series of experiments were carried out on CNC milling machine using a carbide end mill cutter. Wrought alloy AA8011 has been taken as the work piece for the experiments and L27 orthogonal array (OA) has been followed. The effect of process parameters on the performance characteristics was analyzed using single objective taguchi method and ANOVA. The optimal designs for the performance characteristics were predicted using the estimated averages of the responses and they are found to be more accurate and adequate.

Keywords: *Material Removal Rate (MRR), Surface Roughness (R_a), Taguchi method and ANOVA.*

INTRODUCTION

Milling is the process of machining flat, curved or irregular surfaces by feeding the work-piece against a rotating cutter containing a number of cutting edges. Milling is one of the basic machining processes that allow large amounts of material to be removed quickly. [1-2] At all types of milling machines, the cutting tool performs a rotational motion, which is the cutting motion. The rotation axis of the tool could be horizontal or vertical, depending on machine tool version. [3-4] Geometrically complex & hard material components can be machined with an ease and high product accuracy, Surface finish can be achieved. Better tool handling, less time consumption for tool changing, different operation on single work piece can be easily done by automatic tool changer in case of milling. Milling is most effectively used process for multipass operations. Some turning operations like external step turning and boring, and some of the milling operations, such as face milling and deep shoulder milling in which a significantamount of stock material is removed, are good Examples of the operations which are commonly required to be machined using multipass operations. Industries strongly believed that only those capable of effective manufacturing would withstand international and global competition. [5-7] In the modern machining the challenge is mainly focused on quality in terms of surface finishing. Surface texture is concerned with geometric irregularities. The quality of surface is most significant for any product. The surface roughness is main affecting thing such as for contact causing surface friction, wearing, holding the lubricant etc. There are many factors which affect the surface roughness (SR) and material removal rate (MRR), i.e. tool (material, nose radius, geometry, tool vibration), work piece (hardness, mechanical properties), cutting condition (speed, feed, depth)etc. [8-12] Determination of the optimal cutting parameters (cutting conditions) like the number of passes, depth of cut for each pass, speed and feed is considered as a crucial stage of multipass machining as in the case of all chip removal processes and especially in process planning. The effective

optimization of these parameters affects dramatically the cost and production time of machined components as well as the quality of the final products. [13-14]
In the present work the milling operations were carried on AA8011 wrought alloy using carbide end mill cutter to investigate the effect of process parameters on the responses. Single objective taguchi method and analysis of variance (ANOVA) are employed to optimize and to find the significance of the process parameters on the responses respectively.

EXPERIMENTAL DETAILS

Aluminium and its alloys are using extensively in the market because of their extensive properties such as low weight, corrosion resistance, and easy maintenance of final product, etc. In the present work wrought alloy AA8011 has been used as a work piece in the shape of a plate having thickness of 10 mm shown in the figure 1. The chemical composition and mechanical properties of AA8011 is given in the table 1 and 2.

Table 1.*Chemical Properties of AA8011*

Element	**Content (%)**
Aluminium, Al	97.3-98.9
Iron, Fe	0.60-1
Silicon, Si	0.5-0.90
Manganese, Mn	≤0.20
Zinc, Zn	≤0.10
Copper, Cu	≤0.10
Titanium, Ti	≤0.080
Chromium, Cr	≤0.050
Magnesium, Mg	≤0.050
Remainder (each)	≤0.050
Remainder (Total)	≤0.15

Table 2.*Physical Properties of AA8011*

Density	2.7 gm/cm^3
Hardness	25-50 BHN
Tensile strength	100-180 MPa
Yield strength	34-170 MPa
Poisson's ratio	0.33
Elongation	1.7-2.8%

Fig 1.*AA8011 Work Piece*

The experiments were done on CNC milling machine using carbide end mill cutter of 20 mm in size and the length of machining was fixed to 50mm. The experiments were carried out by taking three process parameters at three different levels as given in the table 3and L27 OA has been followed as per the table 4. The work piece after machining was shown in the figure 2.

Table 3.*Process Parameters and Their Levels*

Parameter	Level-1	Level-2	Level-3
Speed, rpm	1500	3000	4500
Feed, mm/min	150	600	1350
Depth of cut, mm	0.5	1	1.5

Table 4.L27 OA

S.No.	s, rpm	f, mm/min	d, mm
1	1500	150	0.5
2	1500	150	1
3	1500	150	1.5
4	1500	600	0.5
5	1500	600	1
6	1500	600	1.5
7	1500	1350	0.5
8	1500	1350	1
9	1500	1350	1.5
10	3000	150	0.5
11	3000	150	1
12	3000	150	1.5
13	3000	600	0.5
14	3000	600	1
15	3000	600	1.5
16	3000	1350	0.5
17	3000	1350	1
18	3000	1350	1.5
19	4500	150	0.5
20	4500	150	1
21	4500	150	1.5
22	4500	600	0.5
23	4500	600	1
24	4500	600	1.5
25	4500	1350	0.5
26	4500	1350	1
27	4500	1350	1.5

Fig 2.*AA8011 after Machining*

After machining the machined portions are tested for the surface roughness using SJ-210 tester shown in the figure3. The roughness values were taken at three different places for each experiment and the average is taken as the final value.

***Fig 3**. The SJ-210 Surface Tester*

METHODOLOGY

In general, Material Removal Rate and Surface Roughness are mainly depends on cutting variables, tool variables and work piece variables. Among these, cutting variables includes speed, feed and depth of cut which can be manually adjustable. In present study, cutting variables are taken as inputs and tool variables and work piece variables are fixed. Intaguchi method the experimental results are transformed into Signal-to-Noise ratios to measure the quality characteristic deviations the desired value. In the present work, Larger-the-Better and Smaller-the-Better characteristics proposed by the taguchihave been used for the analysis of Material Removal Rate (MRR) and Surface Roughness (R_a) respectively.

Larger-the-Better: (S/N) $=-10log_{10}\left[\frac{1}{y_i^2}\right]$

Smaller-the-Better: (S/N) $=-10\ log_{10}[y_i^2]$

Nominal-the-Better: (S/N) $= -10\ log_{10}\left[{\mu^2}/{\sigma^2}\right]$

Where,y_i is the response, μ is mean and σ is the variance.

EXPERIMENTAL RESULTS

The results material removal rate (MRR) measured in cm^3/min and surface roughness (R_a) for each experiment were given in the table 5. The experimental results of the responses were analyzed using larger-the-better and smaller-the-better characteristics given by taguchi.

***Table 5.** Experimental Results of MRR and R_a*

S.No.	MRR, cm^3/min	R_a, μm
1	0.94	1.00
2	1.88	0.97
3	2.57	1.01
4	2.31	0.66
5	4.62	0.66
6	7.50	0.81
7	3.75	0.98
8	6.00	0.94
9	12.86	1.36
10	1.00	1.10
11	2.00	2.11
12	2.65	1.63
13	2.73	0.64
14	5.00	0.59
15	6.43	0.50

16	4.29	0.62
17	7.50	0.55
18	11.25	0.50
19	0.83	1.30
20	1.67	1.20
21	2.43	1.35
22	2.50	0.50
23	5.00	0.38
24	7.50	0.57
25	3.75	0.53
26	7.50	0.45
27	11.25	0.35

The response table for means of MRR and R_a are given in the tables6 and 7. From the response tables it is observed that the feed is the main effecting parameter on both MRR and R_a.

Table 6.*Response Table for Means of MRR*

Level	S	f	D
1	4.713	1.774	2.455
2	4.760	4.842	4.573
3	4.715	7.571	7.160
Delta	0.047	5.798	4.705
Rank	3	1	2

Table 7.*Response Table for Means of R_a*

Level	S	f	D
1	0.9322	1.2967	0.8144
2	0.9156	0.5900	0.8722
3	0.7367	0.6978	0.8978
Delta	0.1956	0.7067	0.0833
Rank	2	1	3

Main Effect Plots Analysis

Main effect plots for means of MRR and surface roughness (R_a) are drawn and shown in the figures 4 and 5.

The optimal condition for maximum volume of material removal rate (MRR) is found at
Speed: level2, 3000 rpm,
Feed: level3, 1350 mm/min
Depth of cut: level3, 1.5mm

The optimal condition for minimum surface roughness (R_a) is found at
Speed:level3, 4500 rpm
Feed: level2, 600 mm/min
Depth of cut: level1, 0.5 mm

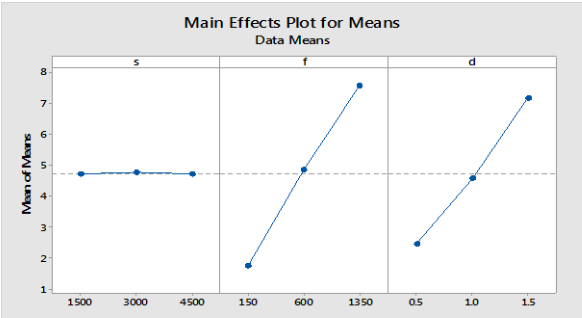

Fig 4.*Main Effect Plot for Means of MRR*

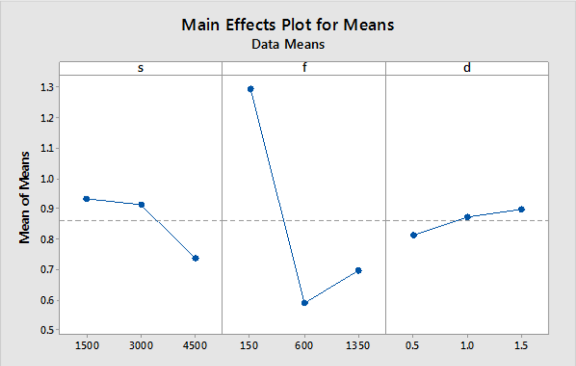

***Fig 5.**Main Effect Plot for Means of R_a*

ANOVA Results of MRR and R_a

Analysis of variance is employed to check the significance of the parameters at a confidence level of 95% i.e. 0.05 and the obtained results were given in the tables 8and 9. ANOVA results showed that the feed is the most influencing factor in effecting both MRR and surface roughness.

***Table 8.**ANOVA Results ofMRR*

Source	DF	Adj SS	Adj MS	F	P
S	2	0.013	0.0064	0.00	0.996
F	2	151.433	75.7165	43.59	0.000
D	2	99.946	49.9730	28.77	0.000
Error	20	34.742	1.7371		
Total	26	286.134			

***Table 9.**ANOVA results of R_a*

Source	DF	Adj SS	Adj MS	F	P
S	2	0.21156	0.10578	1.15	0.335
F	2	2.60899	1.30449	14.24	0.000
D	2	0.03281	0.01640	0.18	0.837
Error	20	1.83179	0.09159		
Total	26	4.68514			

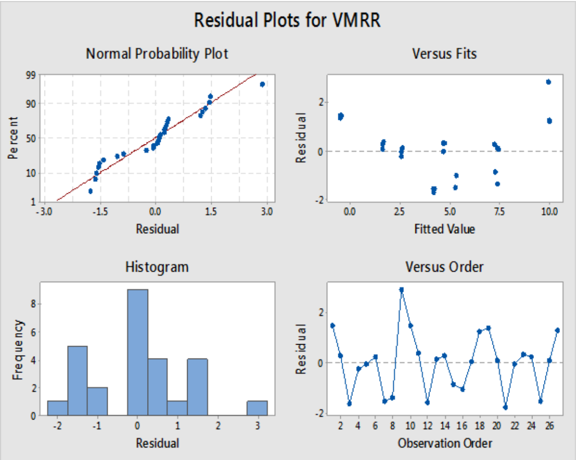

***Figure 6.**Residual Plots for MRR*

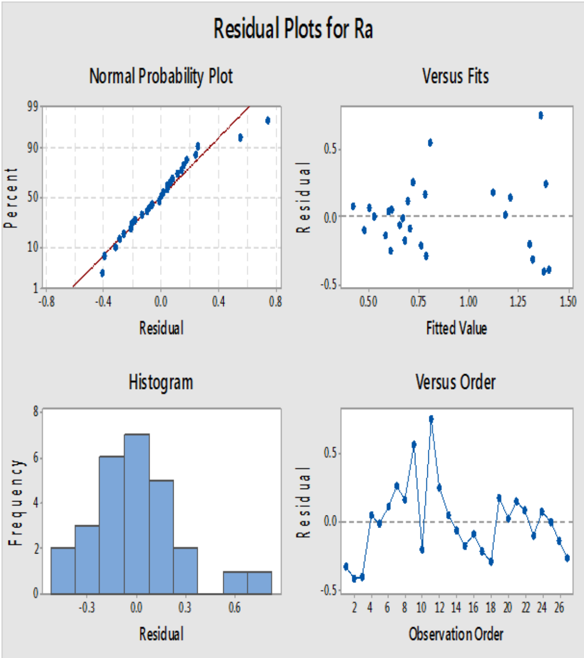

Figure 7.*Residual Plots for R_a*

Figures 6and 7 representing the residual plots for MRR and surface roughness. From the figures it is clear that the residuals are following the normal distribution and the constant variance assumptions of ANOVA as they are lying on the straight line and do not representing any of the regular patterns.

Prediction of Optimal Designs for MRR and R_a

Optimal design for MRR

For MRR the two most significant factors i.e. feed and depth of cut at their better levels are considered.

μ_{A3B3} = A3 + B3 – T

A3 = 7.571; B3 = 7.160; T = 4.73

μ_{A3B3} = 7.571 + 7.160 – 4.73 = 10.001

$$CI = \sqrt{\frac{(F_{95\%,1,doferror} * V_{error})}{(\eta_{efficiency})}}$$

Where, $\eta_{efficiency} = \frac{N}{(1+dof)}$ = 27/(1+2+2)

= 27/5 = 5.4

V_{error} = 1.7371

$F_{95\%,1,20}$ = 4.3512

$$CI = \sqrt{\frac{4.3512 * 1.7371}{5.4}} = 1.1830$$

The predicted optimal range of MRR at 95% of confidence level is obtained as

$\mu_{A3B3} - CI \leq \mu_{A3B3} \leq \mu_{A3B3} + CI$

$10.001 - 1.1830 \leq \mu_{A3B3} \leq 10.001 + 1.1830$

$8.818 \leq \mu_{A3B3} \leq 11.184$

Optimal design for R_a

For R_a the two most significant factors i.e. feed and speed at their better levels are considered.

μ_{A2B3} = A2 + B3 – T

A2 = 0.5900; B3 = 0.7367; T = 0.86

μ_{A3B3} = 0.5900 + 0.7367 – 0.86 = 0.4667

$$CI = \sqrt{\frac{(F_{95\%,1,doferror} * V_{error})}{(\eta_{efficiency})}}$$

Where, $\eta_{efficiency} = \frac{N}{(1+dof)}$ = 27/(1+2+2)

= 27/5 = 5.4

Verror = 0.09159

$F_{95\%,1,20}$ = 4.3512

$$CI = \sqrt{\frac{4.3512 * 0.09159}{5.4}} = 0.2716$$

The predicted optimal range of VMRR at 95% of confidence level is obtained as

$\mu_{A3B3} - CI \leq \mu_{A3B3} \leq \mu_{A3B3} + CI$

$0.4667 – 0.2716 \leq \mu_{A3B3} \leq 0.4667 + 0.2716$

$0.1951 \leq \mu_{A3B3} \leq 0.7383$

CONCLUSIONS

From the Taguchi and ANOVA results the following conclusions can be drawn

- The optimal condition for maximum volume of material removal rate (VMRR) is found to be at

Speed: level2, 3000 rpm,
Feed: level3, 1350 mm/min
Depth of cut: level3, 1.5mm.

- The optimal condition for minimum surface roughness (R_a) is found to be at

Speed: level3, 4500 rpm
Feed: level2, 600 mm/min
Depth of cut: level1, 0.5 mm.

- ANOVA results concluded that the feed is the most influencing factor in effecting both VMRR and surface roughness (R_a).
- The errors are following the normal distribution and the constant variance assumptions of ANOVA.
- The optimal design for VMRR and R_a are predicted from the estimated mean averages and they are accurate.

REFERENCES

1. D. Selvaraj and P. Chandarmohan, "Optimization of Surface Roughness of AISI304 Austenitic Stainless Steel in Dry Turning Operation Using Taguchi Design Method", Journal of Engineering Science and Technology, vol. 5, no. 3, (2010), pp. 293-301.
2. B. M. Gopalaswamy, B. Mondal and S. Ghosh, "Taguchi Method and ANOVA: An Approach for Process Parameters Optimization of Hard Machining While Machining Hardened Steel", Journal of Scientific and Industrial Research, vol. 68, (2009), pp. 686-695.
3. N. E. Edwin Paul, P. Marimuthu and R. VenkateshBabu, "Machining Parameter Setting for Facing EN 8 Steel with TNMG Insert", American International Journal of Research in Science and Technology, Engineering & Mathematics, vol. 3, no. 1, (2013), pp. 87-92.
4. S. Thamizhmanii, S. Saparudin and S. Hasan, "Analysis of Surface Roughness by Turning Process Using Taguchi Method", Journal of Achievements in Materials and Manufacturing, vol. 20, no. 1-2, (2007), pp. 503-506.
5. H. Kumar, M. Abbas, Aas Mohammad and H. ZakirJafri, "Optimization of Cutting Parameters in CNC turning", IJERA, ISSN: 2248-9622, vol. 3, no. 3, (2013), pp. 331-334.
6. M. Kumar Sorabh and N. Nirmal, "A Literature Review on Optimization of Machining Parameters in Wire EDM", International Journal of Latest Research in Science and Technology, vol. 2, no. 1, (2013), pp. 492.
7. V. Muthu Kumar, A. Suresh Babu, R. VenkataSwamy and M. Raajenthiren, "Optimization of the WEDM Parameters on Machining Incoloy 800 Super Alloy with Multiple Quality Characteristics", International Journal of Science and Technology, vol. 2, no. 6, (2010), pp. 1538.
8. I. Asilturk and H. Akkus, "Determining the Effect of Cutting Parameters on Surface Roughness in Hard Turning Using Taguchi Method", Measurement, vol. 44, (2011), pp. 1697-1704.
9. S. J. Raykar, D. M. Daddona and D. Kramar, "Analysis of Surface Topology in Dry Machining of EN-8 steel", Elsvier Journal, Procedia Material Science, vol. 6, (2014), pp. 931-938.
10. J. Varma, P. Agarwal and L. Bajpai, "Turning Parameter Optimization for Surface Roughness of ASTM A242 type-1 Alloy Steel by Taguchi Method", International Journal of Advances in Engineering & Technology, (2012) March.
11. K. Kanlayasiri and S. Boonmung, ‘‘Effects of Wire- EDM Machining Variables on Surface Roughness of Newly Developed DC 53 Die Steel:

Design of Experiments and Regression Model'', Journal of Materials Processing Technology, vol. 192-193, (2007), pp. 459-464.

12. V. Parashar, A. Rehman, J. L. Bhagoria and Y. M. Puri, "Investigation and Optimization of Surface Roughness for Wire Cut Electro Discharge Machining of SS 304", Using Taguchi Method, International Journal of Engineering, (2009), pp. 257-267.
13. H. Singh and P. Kumar, "Optimizing Feed Force for Turned Parts Through the Taguchi Technique", Sadana, vol. 31, no. 6, (2006), pp. 671-681.
14. A. Kumar Roy Vikas and K. Kumar, "Effect and Optimization of Machine Process Parameters on Material Removal Rate in EDM for EN41 Material Using Taguchi", International Journal of Mechanical Engineering and Computer Applications, vol. 1, no. 5, (2013), pp. 35-39.

