Optimization of CNC Turning Parameters on Aluminum 7015 Hybrid Metal Matrix Composite Using Taguchi Robust Design

SENTHIL KUMAR. M.P[*1] and RAJENDRAN. I[#2]
[*]PSV College of Engineering & Technology, Krishnagiri, Tamil Nadu, India.
[#]Dr. Mahalingham College of Engineering & Technology, Pollachi, Tamil Nadu, India
[1]*e- mail: s_kumarmp@yahoo.co.in*
[2]*e-mail: irus-rejendran@yahoo.co.in*

Abstract:-The Aluminum Hybrid Metal Matrix Composites (Al-HMMC) are finding numerous applications in many areas like Automobile, Piston and Cylinder and Aerospace, etc. Adding a third element into the metal matrix composite makes it hybrid. The Reinforcement of SiC and Graphite used in this Al-HMMC improves its strength. The present investigation is to find the optimum machining parameter of CNC turning centre on Al-HMMC. The main objective is to find the optimum cutting parameters to achieve low value of surface roughness and high Material Removal Rate (MRR). The cutting parameters considered in this experimental investigation are cutting speed, feed rate and depth of cut. Taguchi L_{27} orthogonal array was chosen to conduct the experiments. Signal to Noise ratio (S/N) and Analysis of Variance (ANOVA) were used to analyze the effect of cutting parameters on surface roughness and MRR. The contribution by each cutting parameter to surface roughness and MRR was also determined.

Keyword: Hybrid Metal Matrix Composite, Taguchi, Surface Roughness, MRR and ANOVA.

I. INTRODUCTION

Aluminum Hybrid Metal Matrix Composite (Al-HMMC) is one of the advanced materials with specific and special industrial applications. They are used widely in automobile industries such as bearing sleeves, piston, etc. One of the primary processes of manufacturing these components is by conventional machining. In modern manufacturing industries, CNC machines have been used to manufacture complicated shapes on advanced materials with high accuracy and precision. A suitable selection of machining parameters for the CNC turning mostly relies on the operator's experience and manufacturer guidelines. Machining parameters table offered by the manufacturer are more basic in nature and does not provide recent developed materials. Hence the parameters for newer materials need to be optimized. Numerous researchers have carried out studies on CNC turning of advanced materials. The following paragraphs summarize the outcome of those researchers. Sing and Kumar (2006) studied the effect of significant parameters on EN24 steel with TiC coated-tungsten carbide inserts. Important machining parameters namely speed, feed and depth of cut were considered for experimentation. Taguchi's optimization techniques were applied to optimize the machining parameters. They accomplished that the effect of depth of cut and variation of feed force were affected by the selected machining quality characteristics. Daniel et al (2006) used Taguchi Parameter Design for optimizing surface roughness generated by a CNC turning operation. Spindle speed, feed rate and depth of cut were considered for experimental studies. From the results they found that the feed rate had the highest effect and spindle speed had the moderate effect and depth of cut have the insignificant effect on machining process. Nalbant et al (2007) described an application of Taguchi method in the optimization of cutting parameters for surface roughness in turning. TiN coated tool and AISI 1030 steel as work piece were used. The experiment was designed using Taguchi method of experiment design and L_9 orthogonal array was used. Three parameters namely insert radius, feed rate and depth of cut were optimized. The results of the experiment suggest that the insert radius and feed rate are the main controllable parameters which affect the surface roughness more in turning AISI 1030 carbon steel. Thamizhmani et al (2007) optimized the surface roughness on SCM 440 alloy steel during turning operation using Taguchi method. They concluded that the results obtained from the experiments would be useful to the researchers and that the depth of cut was the significant parameter on surface roughness. Sundaramurthy and Rajendran (2010) optimized the surface roughness in end milling of Aluminium 6063 under minimum quantity lubrication. They concluded that the surface roughness is mainly affected by feed rate under MQL. Yanda et al (2010) optimized the MRR, surface roughness and tool life in conventional dry turning by FCD700. They concluded that the optimum MRR was obtained when the cutting speed and feed rate were at high. The optimum tool life was reached when the cutting speed and feed rate were less. The surface finish was low at high cutting speed and low feed rate. Sasimurugan and Palanikumar (2011) studied the surface roughness characteristics on hybrid Al-MMC. In this study, the feed rate, depth of cut and cutting speed were considered as input machining parameters. They concluded that the surface roughness becomes increased with increasing feed rate and decreased with increasing cutting speed. Sundaramurthy and Rajendran (2012) studied the surface roughness characteristics on Al6063-T6 during end milling. They concluded that the cutting speed was the significant parameter on surface roughness. Kamal Hassan et al (2012) investigated the machining parameters on MRR in turning of C34000. Taguchi L_{27} orthogonal array was used to conduct the experiments. The optimum results were verified through confirmation test runs. They concluded that the MRR is mainly affected by cutting speed and feed rate. With increase in cutting speed and feed rate the MRR gets increased. Durai et al (2012) studied the cutting parameters that ensure less power consumption in high tare CNC machines. The data acquisition system was used to measure the output characteristics. From the results, it was concluded that the feed rate and the depth of cut significantly influence the energy consumption. Neeraj et al (2012) applied the Taguchi technique through a case study in turning of mild steel bar using HSS tool for optimizing the process parameters. Influence of turning process parameters on surface roughness on mild steel has been studied. The results show that the cutting speed and depth of cut are the significant parameters to influence the surface roughness of mild steel. The surface roughness becomes decreased with increase in spindle speed and increased with increase in depth of cut**.** Krishnamurthy and Venkatesh (2013) determined the optimum cutting factors for surface roughness and MRR on TiB2 particles reinforced Al6063 metal matrix composites. From the experimental results it was found that feed is the most significant process parameter on surface roughness followed by cutting speed. The MRR results showed that the speed and the feed are the most significant parameters. Vishnu et al (2013) determined the optimum cutting parameters to achieve lower surface roughness and higher material removal rate using Taguchi methodology and Response Surface Methodology. The experimental results show that cutting speed and depth of cut are significant variables to the surface roughness of mild steel. Surface roughness gets decreased with increase in spindle speed and increased with increase in depth of cut. With the increase in feed rate the surface roughness gets increased and when the cutting speed is decreased the surface roughness becomes increased. The MRR gets increased with increase in cutting speed and when the feed rate is increased the MRR gets increased. Suresh et al (2013) developed a second-order quadratic model for surface roughness, Based on response surface methodology (RSM) technique, the relationship between the response and input variables influencing the surface roughness was determined. The optimum level of parameters setting in machining of Al-SiC-Gr composites for minimum surface roughness is at 113 m/min of cutting speed, 0.250 mm/rev of feed rate and 0.2 mm of depth of cut. Vikas et al (2013) optimized and evaluated the machining parameters on EN8 steel. The optimum parameters were found based on Taguchi and ANOVA. They concluded that minimum trust force on normal tool shape, moderate cutting speed, and lesser depth of cut and lowest feed are the optimum parameters.

The existing investigation shows that not much work have been carried out on Al-HMMC. Hence, the present investigation has been carried to find the optimum cutting parameters on Al-HMMC using Taguchi design methodology.

II. EXPERIMENTAL PLANNING

In the present study, CNC turning center was used for conducting the experiments, Al-HMMC was used as the work material and ceramic tool was used for machining the work material. Table 1 shows the chemical composition of the base material. Table 2 shows the composition and weight percentage of the work material. Table 3 shows the cutting parameter and their levels. Taguchi technique based L_{27} orthogonal array was chosen for conducting the experiments. Three important machining parameters namely cutting speed, feed rate and depth of cut were considered as machining input parameters and each parameter was assigned three levels such as minimum, medium and maximum. Table 4 shows the factors assigned to standard L_{27} orthogonal array. Surface roughness and MRR were considered as output parameters in this investigation. The surface roughness was measured using Surftest 211 Mitutoyo instrument. The MRR was calculated by analytical method. The S/N ratio was calculated to identify the optimum machining parameter. The significant parameters were found based on Taguchi design methodology by the ANOVA, which indicated the relationship between machining parameters and output performance characteristics.

TABLE 1
Chemical composition of Al7015

Al	91.3-93.9%	other each	<=0. 050%
Cr	<=0.15%	other total	<=0.15%
Cu	0.060-0.15%	Si	<=0.20%
Fe	<=0.30%	Ti	<=0.10%
Mg	1.3-2.10%	Zn	4.6%-5.20%
Mn	<=0.10%	Zr	0.10%-0.20%

TABLE 2
Weight percentage of reinforcement of Al7015

Al7015	SiC	Graphite
80%	17%	3%

TABLE 3
Cutting parameters and their levels

Sl. No	**Symbol**	**Machining Parameters**	**Levels**		
			1	**2**	**3**
1	A	Cutting speed (S)	100	125	150
2	B	Feed rate (F)	0.1	0.2	0.3
3	C	Depth of cut (DoC)	0.5	0.75	1.0

TABLE 4
Factors assigned to L_{27}orthogonal array

Exp. No.	**Cutting speed (S) m/min**	**Feed rate (F) mm/min**	**Depth of cut (DOC) mm**
1	100	0.1	0.5
2	100	0.1	0.75
3	100	0.1	1
4	100	0.2	0.5
5	100	0.2	0.75
6	100	0.2	1
7	100	0.3	0.5
8	100	0.3	0.75
9	100	0.3	1
10	125	0.1	0.5
11	125	0.1	0.75
12	125	0.1	1
13	125	0.2	0.5
14	125	0.2	0.75
15	125	0.2	1
16	125	0.3	0.5
17	125	0.3	0.75
18	125	0.3	1
19	150	0.1	0.5
20	150	0.1	0.75
21	150	0.1	1
22	150	0.2	0.5
23	150	0.2	0.75
24	150	0.2	1
25	150	0.3	0.5
26	150	0.3	0.75
27	150	0.3	1

III. RESULTS AND DISCUSSION

A. Analysis of S/N Ratio on Surface Roughness

To analyze the surface roughness the S/N ratio is used to identify the significant machining parameters through Analysis of Variance (ANOVA). In accordance with the Taguchi quality characteristics, the lower observed value indicates better surface roughness. It is known as “Lower is Better” (LB). Equation (1) was used to find out the S/N ratio. Table 5 shows the experimental results and their corresponding S/N ratios for lower surface roughness (Ra).

$$LB_{SR} = -10\log(1/r\sum yi^2) \qquad (1)$$

TABLE 5
Average surface roughness and S/N ratio for surface roughness

Exp. No.	Cutting speed (S) m/min	Feed rate (F) mm/min	Depth of cut (DOC) mm	Average Surface roughness	S/N Ratio
1	100	0.1	0.5	0.052	25.68
2	100	0.1	0.75	0.124	18.13
3	100	0.1	1	0.212	13.47
4	100	0.2	0.5	0.112	19.02
5	100	0.2	0.75	0.258	11.77
6	100	0.2	1	0.316	10.01
7	100	0.3	0.5	0.362	8.83
8	100	0.3	0.75	0.468	6.60
9	100	0.3	1	0.844	1.47
10	125	0.1	0.5	0.182	14.80
11	125	0.1	0.75	0.226	12.92
12	125	0.1	1	0.434	7.25
13	125	0.2	0.5	0.414	7.66
14	125	0.2	0.75	0.656	3.66
15	125	0.2	1	0.846	1.45
16	125	0.3	0.5	0.856	1.35
17	125	0.3	0.75	0.924	0.69
18	125	0.3	1	1.088	-0.73
19	150	0.1	0.5	0.224	13.00
20	150	0.1	0.75	0.24	12.40
21	150	0.1	1	0.44	7.13
22	150	0.2	0.5	0.514	5.78
23	150	0.2	0.75	0.778	2.18
24	150	0.2	1	0.976	0.21
25	150	0.3	0.5	1.182	-1.45
26	150	0.3	0.75	1.588	-4.02
27	150	0.3	1	1.984	-5.95

The experimental design helps to split the effect of each machining parameter at different levels. The mean S/N ratio for surface roughness is displayed graphically in Fig.1. The surface roughness for each factor's level indicates the relative effects of the various factors, A: spindle speed, B: feed rate and C: depth of cut on the machining performance characteristics such as surface roughness. From the S/N response graph Fig.1 for minimum surface roughness the optimal parametric combination is A3, B1, and C1. i.e. spindle speed at 150m/min, feed rate at 0.1 mm/rev and depth of cut at 0.5mm.

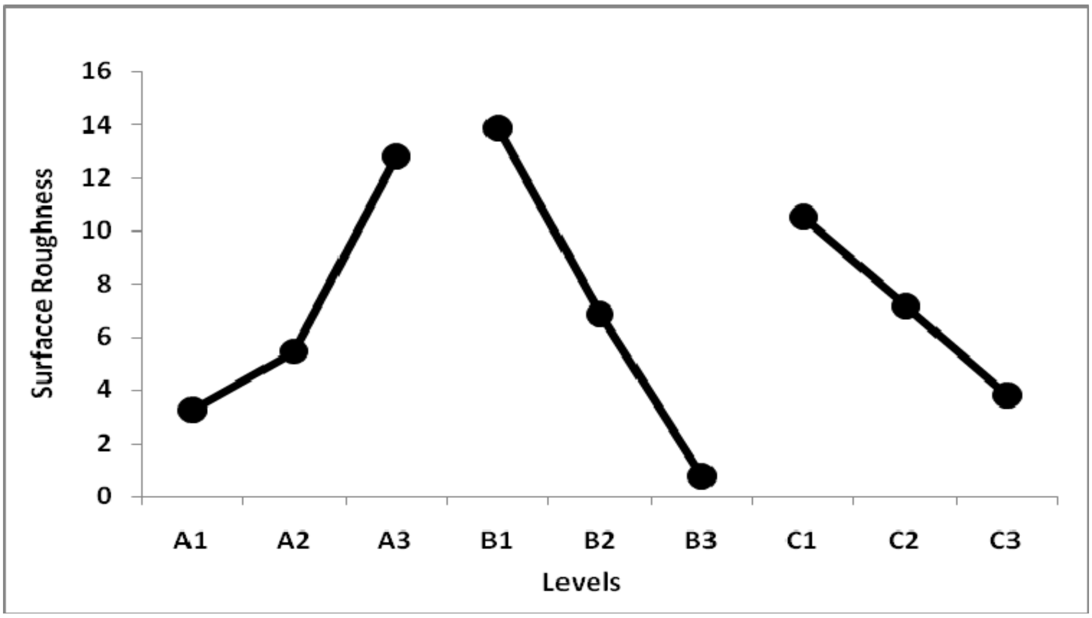

Fig. 1 Main effect plot for Surface Roughness

B. Analysis of Variance (ANOVA) for Surface Roughness

The purpose of using the ANOVA is to find the significant parameter that affects the surface roughness. Also this analysis helps to find the individual contribution on machining parameters. Table 6 shows the ANOVA with percentage contribution by each parameter while machining of Al-HMMC.

TABLE 6
ANOVA with percentage contribution for Surface Roughness

Control Factors	Sums of Squares	Degree of freedom	Variance	F ratio	% Contribution
Cutting speed (S)	447.42	2	223.71	12.66	25.17
Feed rate (F)	774.70	2	387.35	21.92	43.57
Depth of cut (DOC)	202.27	2	101.14	5.75	11.38
Error	353.46	20	17.67		19.88
Total	1777.85	26			100

The experiments were conducted based on the factors assigned as shown in Table 4. ANOVA was performed to find out the most influencing parameter that affects the machining performance parameter on selected output characteristics of surface roughness. The percentage contribution by each parameter shows the significant parameters that affect the surface roughness while machining of Al-HMMC. F-test was performed to find out the significant parameter at 95% of confident level. The tabulated value of F-test is 3.37. The calculated F-test value of cutting speed, feed rate and depth of cut is more than the tabulated value. It shows that the feed rate is the most significant parameter and cutting speed is the second significant parameter and the third significant parameter is the depth of cut on surface roughness. The ANOVA result is shown in Table 6. Fig. 2 shows the graphical representation of percentage contribution by various parameters on surface roughness when machining the aluminum composites.

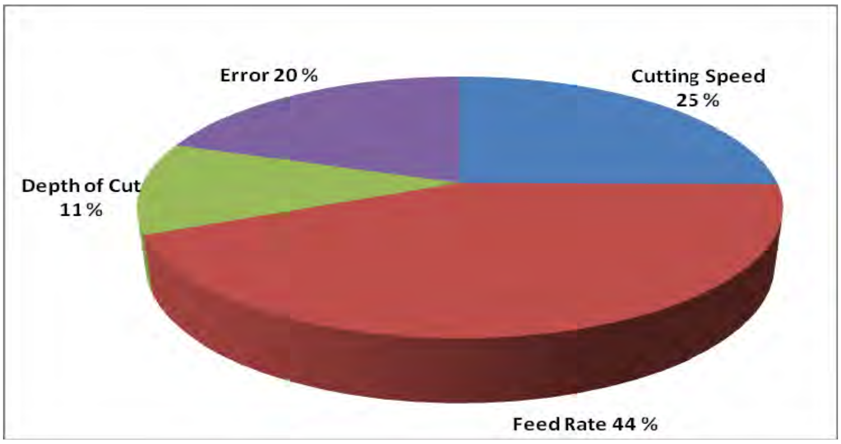

Fig. 2 Percentage contribution of surface roughness

C. Analysis of S/N Ratio on MRR

The S/N ratio is also used to analyze the MRR to identify the significant cutting parameters through ANOVA. In accordance with the Taguchi quality characteristics the higher observed value indicates higher MRR. It is known as "Higher is Better" (HB). Equation (2) is used to find out the S/N ratio. Table 7 shows the experimental results and their corresponding S/N ratios for higher MRR.

$$LB_{SR} = -10\log(1/r\sum 1/yi^2) \quad (2)$$

TABLE **7**
Experimental results and their corresponding S/N ratios

Exp. No.	**Cutting speed (S) m/min**	**Feed rate (F) mm/min**	**Depth of cut (DOC) Mm**	**Material Removal Rate (MRR) mm^3/min**	**S/N Ratio**
1	100	0.1	0.5	0.21	-13.56
2	100	0.1	0.75	0.45	-6.94
3	100	0.1	1	0.92	-0.72
4	100	0.2	0.5	0.52	-5.68
5	100	0.2	0.75	0.93	-0.63
6	100	0.2	1	2.53	8.06
7	100	0.3	0.5	0.82	-1.72
8	100	0.3	0.75	2.54	8.10
9	100	0.3	1	5.06	14.08
10	125	0.1	0.5	0.51	-5.85
11	125	0.1	0.75	0.82	-1.72
12	125	0.1	1	1.81	5.15
13	125	0.2	0.5	0.95	-0.45
14	125	0.2	0.75	1.97	5.89
15	125	0.2	1	3.88	11.78
16	125	0.3	0.5	1.48	3.41
17	125	0.3	0.75	3.89	11.80
18	125	0.3	1	6.87	16.74
19	150	0.1	0.5	1.07	0.59
20	150	0.1	0.75	2.49	7.92
21	150	0.1	1	3.98	12.00
22	150	0.2	0.5	2.66	8.50
23	150	0.2	0.75	4.95	13.89
24	150	0.2	1	7.98	18.04
25	150	0.3	0.5	4.88	13.77
26	150	0.3	0.75	7.99	18.05
27	150	0.3	1	10.97	20.80

The mean S/N ratio for MRR is displayed in Fig.3. The MRR for each factor's level shows the relative effects of the various factors such as A: spindle speed, B: feed rate and C: depth of cut on the selected machining output characteristics such as MRR. From the S/N response graph [Fig.3], for maximum MRR, the optimum parametric combination is A3, B3, and C3. i.e. spindle speed at 150m/min, feed rate at 0.3mm/rev and depth of cut at 1mm.

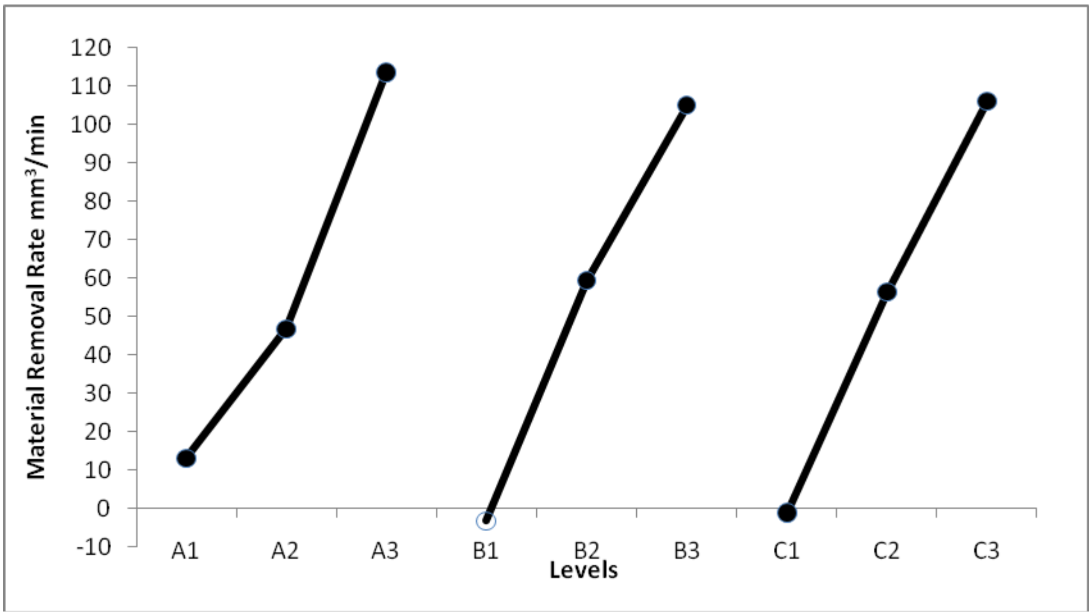

Fig. 3 Main effect plot for MRR

D. Analysis of Variance (ANOVA) on MRR

ANOVA is carried out to find the significant parameter that affects the MRR. Also it helps to find the contribution by each machining parameters. Table 8 shows the ANOVA with percentage contribution by each parameter. Fig.4 shows graphically the percentage contribution by each parameter on MRR.

TABLE 8
ANOVA with percentage contribution for MRR

Control Factors	Sums of Squares	Degree of freedom	Variance	F ratio	% Contribution
Cutting speed (S)	712.22	2	356.11	16.82	29.36
Feed rate (F)	655.07	2	327.53	15.52	27.00
Depth of cut(DOC)	636.31	2	318.15	15.07	26.23
Error	422.16	20	21.11		17.40
Total	2425.75	26			100

The percentage contribution by each parameter shows the significant parameters on MRR. F-test was performed to find out the significant parameter at 95% of confident level. The calculated F-test value of cutting speed, feed rate and depth of cut is more than the tabulated value of 3.37. From the Table 8 it is seen that the feed rate is the most significant parameter, cutting speed is the next significant parameter and the depth of cut is the third significant parameter on MRR. The ANOVA result is shown in Table 8. Also the Fig.4 shows the pictorial representation of percentage contribution by each parameter on MRR.

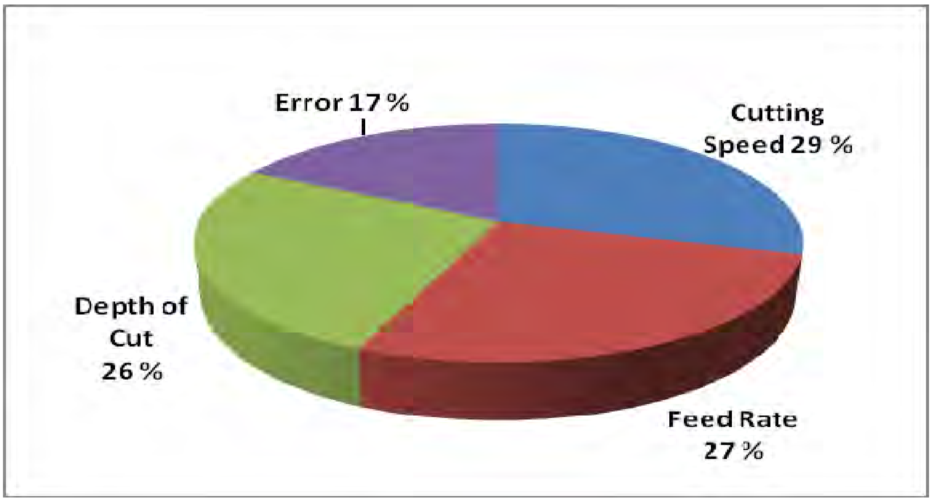

Fig.4 Percentage contributions of various parameters on MRR

IV. CONCLUSIONS

From the experimental results, calculated S/N ratio and ANOVA, the following conclusions are drawn for machining of Al-HMMC using CNC machine. To attain better surface finish the recommended parametric combination is A3, B1 and C1 which are represents spindle speed at 150m/min, feed rate at 0.1 mm/rev and depth of cut at 0.5mm respectively. From the ANOVA Table 6, it is found out that the feed rate is the most significant parameter, cutting speed is the second significant parameter and the depth of cut is the third significant parameter on surface roughness. For higher MRR the recommended parameter combination is A3, B3 and C3 which are represents spindle speed at 150m/min, feed rate at 0.3 mm/rev and depth of cut at 1 mm respectively. From the ANOVA Table 8, it is found out that the feed rate is the most significant parameter, cutting speed is the next significant parameter and the depth of cut is the third significant parameter on MRR.

REFERENCES

[1] Singh H. and Kumar P. (2006), “Optimizing Feed Force for Turned Parts through the Taguchi Technique”, Sadhana, Vol. 31, Number 6, pp. 671–681.
[2] Daniel Kirby. E. (2006), “A Parameter Design Study in a Turning Operation Using the Taguchi Method”, Industrial Technology Program, Department of Agricultural and Biosystems Engineering, The Technology Interface / Fall 2006, pp.1-14.
[3] Nalbant M., Gokkaya H., Sur G. (2007), “Application of Taguchi method in the optimization of cutting parameters for surface roughness in turning”, Materials and Design, Vol. 28, pp. 1379-1385.
[4] Thamizhmani S., Saparudin S. and Hasan S. (2007), “Analysis of Surface Roughness by Using Taguchi Method”, Achievements in Materials and Manufacturing Engineering, Vol. 20, Issue 1-2, pp. 503-505.
[5] Sundara Murthy. K and Rajendran. I. (2010), “A study on Optimization of Cutting Parameters and Prediction of Surface Roughness in End-Milling of Aluminium under MQL Machining”, International Journal of Machining and Machinability of Materials, vol. 7, No. 1-2, pp. 112-128.
[6] Yanda, J.A. Ghani, M.N.A.M. Rodzi, K. Othman and C.H.C. Haron. (2010),“Optimization of Material Removal Rate, Surface Roughness and Tool Life on Conventional Dry Turning of FCD700”, International Journal of Mechanical and Materials Engineering (IJMME), Vol.5, No.2, pp. 182-190.
[7] Sasimurugan.T and Palanikumar. K. (2011), “Analysis of the Machining Characteristics on Surface Roughness of a Hybrid Aluminium Metal Matrix Composite (Al6061-SiC-Al2O3)”, Journal of Minerals & Materials Characterization & Engineering, Vol. 10, No.13, pp.1213-1224.
[8] Sundara Murthy. K and Rajendran. I. (2012), “ Optimization of End-Milling Parameters under Minimum Quantity Lubrication using Principal Component Analysis and Grey Relational Analysis” Journal of the Brazilian society of Mechanical sciences and Engineering, Vol. 34, No. 3, pp. 253-261.
[9] Kamal Hassan, Anish Kumar, M.P.Garg. (2012), “Experimental investigation of Material Removal Rate in CNC turning using Taguchi method”, International Journal of Engineering Research and Applications, Vol. 2, Issue 2, pp.1581-1590
[10] DuraiMatinsureshBabu, Mouleeswaran Senthilkumar, and Jothiprakashvishnuu (2012),“Optimization of Cutting Parameters for CNC Turned parts using Taguchi’s Technique”, International Journal of Engineering, Vol. 3, pp.493-496.
[11] Neerajsharma and Renusharma, (2012), “Optimization of Process Parameters of Turning Parts: A Taguchi Approach” Journal of Engineering, Computers and Applied Sciences, Vol. 1, No.1, pp. 32-36.
[12] Krishna murthy. K and Venkatesh. J. (2013), “Assessment of Surface Roughness and Material Removal Rate on Machining of TiB2 Reinforced Aluminum 6063: A Taguchi’s Approach” International Journal of Scientific and Research Publications, Vol. 3, Issue 1, pp.1-6.
[13] Vishnu. D. Asal, Chintan. A. Prajapati, Pintu. K. Patel. (2013),“Optimization of Turning Process Using Design of Experiment: A Review”,Paripex - Indian Journal of Research, Vol.2,Issue 4, pp. 105-108.
[14] Suresh P., Marimuthu K., Ranganathan S. and Arunkumar G. (2013),“Evaluation of Parameters Influencing Surface Roughness on Turning of Al-SiC-Gr Hybrid Composites” International Journal of Advanced Engineering Applications, Vol.2, Issue.3, pp.38-43.
[15] Vikas B. Magdum and Vinayak R. Naik. (2013), “Evaluation and Optimization of Machining Parameter for Turning of EN 8 Steel”, International Journal of Engineering Trends and Technology, Vol. 4, Issue5, pp. 1564-1568.
[16] Phillip J. Ross. (1996), “Taguchi Techniques for Quality Engineering”, McGraw-Hill, New York.
[17] Montgomery, D.C.(2005), “Design and Analysis of Experiments”, 4th edition, John Wiley and Sons, New York.