Effect of Cutting Factors on Surface Roughness and MRR during End Milling of Aluminum Alloy Al6063-T6

Makkena Veeranjaneyulu.[1], Dr. Anay Jain.[2], Dr. B Raghu Kumar.[3]

[1]Research Scholar, Dept. of Mechanical Engg, OPJS University, Churu, Rajasthan.

[2]Associate professor, Dept. of mechanical Engg, OPJS University, Churu, Rajasthan.

[3]Professor & HOD, Dept. of Mechanical Engg., PVP Sidhardha College of Engg., Vijayawada

Abstract: ***In this investigation an experimental setup for effects of cutting factors on surface roughness and MRR during end milling of aluminum alloy Al6063-T6 was carried out. Spindle speed (N), feed rate (f), radial depth of cut (rdoc) and axial depth of cut (adoc) has been selected as input parameters to investigate the quality of surface roughness and MRR. The experiment was conducted using Taguchi L9 orthogonal array design. Response Surface Methodology (RSM) was employed to analyze the effect of these cutting factors. The results concluded that the optimal cutting factors combination for good surface finish is with high cutting speed, low feed rate, low axial depth of cut and high radial depth of cut and for maximum MRR with high cutting speed, low feed rate, low axial depth of cut and high radial depth of cut.***

Keywords: *MRR, surface roughness, Taguchi, orthogonal array, Response Surface Methodology.*

1. INTRODUCTION

To produce the necessary part for resulting required geometrical shapes and dimensional tolerances, it is important the machining parameters. Traditional machining process such as turning, drilling, milling and abrasive cutting are frequently used for producing complex shapes of parts by removing unwanted material in form of chip formation. The shape and size of chip, material removal rate, dimensional accuracy and surface finish are directly related to the cutting tool, work piece and machining parameters. Milling operation is used as a corrective machining process in parts manufacturing to achieve good and quality surfaces. The type of material used has greater influence in selection of cutting tool and machining parameters. At present work input parameters are cutting speed, feed rate, radial depth of cut and axial depth of cut and surface roughness, material removal rate selected as output variables. The series of experiments are conducted according to Taguchi L9 orthogonal array design. The required data was collected and analyzed using the statistical models of RSM. Surface regression model and ANOVA are used to find significant factors which affect the surface roughness and material removal rate. Surface plots are drawn to see the area of parameters where the surface roughness is low and material removal rate maximum. Response optimization results surface roughness is minimum with the combination of low radial depth of cut, axial depth of cut, feed rate and high cutting speed, material removal rate is maximum with the combination of high radial depth of cut, axial depth of cut, feed rate and low cutting speed.

2. REVIEW OF PAST WORK

Balinder singh et al., (2014) the study evaluates the machining performance of EN24 steel using CNC milling machine which employed carbide End Mill cutting tool. Surface roughness and MRR as response variables and the control parameters for this operation include: feed, cutting speed and doc. All the experiment trials, planning and analysis were executed using Taguchi design of experiments. It concludes that the feed rate contributed 87.79%, cutting speed contributed only 1.58% and doc contributed 0.0035 for surface roughness. For MRR the most significant factor is feed rate and then followed by doc and speed. The contribution of feed rate, cutting speed and doc was 57.17%, 29.85% and 0.03% respectively for MRR.

Okokpujie Imhade P et al., (2015) the work is on effects of cutting parameters (spindle speed, feed rate, axial doc and radial doc) on surface roughness during end milling of aluminium 6061 under minimum quality lubrication (MQL) condition was carried out. The experiment was designed by using central composite design (CCD) and a mathematical model developed by using least square method shows accuracy of 89.5% which is reasonably reliable for surface roughness prediction. Speed is the most significant effect on the surface roughness, followed by feed rate. However radial doc has little effect on the surface roughness and axial doc has no significant effect.

M Nurhaniza et al., (2016) The research aims to study the effect of cutting parameters (feed, speed and depth of cut) on surface feature of CFRP Aluminium in milling operation using PCD tool. L9 Taguchi orthogonal array, signal-to-noise (S/N) ratio, and ANOVA are used to analyze the data. It indicates that, for good surface finish the parameter combination is high speed, low feed rate, and low depth of cut.

Niraj Kumar et al., (2016) in this work, Mild steel specimens are machined on a vertical milling machine with different values of parameters (feed, cutting speed and depth of cut) with response parameter as Ra. The Ra value is found to increase as increasing feed and depth of cut, whereas, a decrease is observed with increasing spindle speed.

Akhilesh Chaudhary et al., (2017) the aim of the work is to predict the cutting parameters (speed, feed and depth of cut) in regulate surface roughness of Al6082 aluminium alloy in dry end milling operation. The conduct experiments using L_{27} orthogonal array design. The data was analyzed using Minitab software and results that Speed occupies rank 1, feed occupies rank 2 and depth of cut occupies rank 3. It means that the surface roughness is maximum affected by the speed followed by feed and doc. The surface roughness decreases as increasing spindle speed and increases as increasing feed.

3. EXPERIMENTAL SETUP

The setup is for conducting experiments on milling machine (work piece material is AL6063T6) using L9 orthogonal array.

The selected machine for the experiment is Universal Milling Machine (END MILL, Make: SURAJ), the machine is featured with the working surface of table 1050x250mm, table travel longitudinal 600mm, table travel vertical 450mm, table travel cross 225mm, arbor diameter 25.4mm and spindle speeds are 65, 100, 140, 240, 360 and 525rpm.

FIGURE 3.1: Universal Vertical Milling Machine & work-pieces

An Uncoated General Purpose Solid Carbide 4 Flute End Mill was used for cutting the work-piece. Three different cutter diameters of 8mm, 10mm and 12mm were used with specifications as GP SC End Mill 4FL 8x8x28x75, GP SC End Mill 4FL 10x10x22x72 and GP SC End Mill 4FL 12x12x25x75 used as one of the control factor in the process. Surface roughness measurement is using Surf-test SJ-210-Series 178-Portable Surface Roughness Tester. It provides a 2.4 inch color graphic LCD screen, excellent readability, easy to negotiate and operate, up to 10 measurement conditions and one measured profile can be stored in the internal memory. An optional memory card can be used as an extended memory to store large quantities of measured profiles and conditions. The display interface supports 16 languages, which can be freely switched and it also featured with an alarm warns you when the cumulative measurement distance exceeds a preset limit.

FIGURE 3.2: End mill cutters, surface roughness measuring

Selected input parameters and their level are as follows.

S. no.	Independent Variables	Notation	Units	Limits		
				Level1	**Level2**	**Level3**
1	Spindle Speed	N	rpm	100	240	360
2	Feed Rate	f	m/min	0.06	0.12	0.18
3	Radial Depth of cut	rdoc	m	8	10	12
4	Axial Depth of cut	adoc	m	0.5	1.0	1.5

Table 3.1: Selected Input parameters and Their Levels

4. RESPONSE SURFACE METHODOLOGY

Experimental data collected and tabulated in Table4.1 as follows and data analysis was carried out.

S.no. E	A	B	C	D	N (rpm)	f (m/min)	rdoc (mm)	adoc (mm)	Ra (μm)	MRR (mm^3/min)
E1	1	1	1	1	100	0.06	8	0.5	2.149	240
E2	1	2	2	2	100	0.12	10	1	2.900	1200
E3	1	3	3	3	100	0.18	12	1.5	3.480	3240
E4	2	1	2	3	240	0.06	10	1.5	1.607	900
E5	2	2	3	1	240	0.12	12	0.5	2.212	720
E6	2	3	1	2	240	0.18	8	1	2.435	1440
E7	3	1	3	2	360	0.06	12	1	1.439	720
E8	3	2	1	3	360	0.12	8	1.5	1.785	1440
E9	3	3	2	1	360	0.18	10	0.5	2.202	900

Table 4.1: Experimental data with factors and matrix design

I. Response Surface Regression

Source	DF	Adj SS	Adj MS	F-Value	P-Value	% C
Model	4	3.17479	0.79370	33.43	0.002	97.10
Linear	4	3.17479	0.79370	33.43	0.002	97.10
Speed(rpm)	1	1.64038	1.64038	69.10	0.001	50.17
Feed(m/min)	1	1.42198	1.42198	59.90	0.002	43.49
rdoc(mm)	1	0.09653	0.09653	4.07	0.114	2.95
adoc(mm)	1	0.01590	0.01590	0.67	0.459	0.47
Error	4	0.09496	0.02374			2.90
Total	8	3.26975	**Model R-sq value = 97.10%**			

Table4.2: ANOVA for Surface Roughness vs. Input parameters

According to Normal Plot of Standardized Effects and ANOVA speed and feed are the most significant factors which affect the surface roughness and then followed by radial depth of cut and axial depth of cut are the significant. The percentage of contribution occupied by the parameters as 50.17% of speed, 43.49% of feed, 2.95% of radial depth of cut and 0.47% of axial depth of cut.

Regression Equation for surface roughness is

Ra(μm) = 1.472 - 0.004018*N + 8.11*f + 0.0634*rdoc + 0.103*adoc

Source	DF	Adj SS	Adj MS	F-Value	P-Value	%C
Model	4	5477613	1369403	15.15	0.011	93.81
Linear	4	5477613	1369403	15.15	0.011	93.81
Speed(rpm)	1	459213	459213	5.08	0.087	7.86
Feed(m/min)	1	2306400	2306400	25.51	0.007	39.50
rdoc(mm)	1	405600	405600	4.49	0.102	6.95
adoc(mm)	1	2306400	2306400	25.51	0.007	39.50

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Error	4	361587	90397			6.19
Total	8	5839200	Model R-sq Value = 93.81%			

Table4.3: ANOVA for Material Removal Rate vs., input parameters

According to Normal Plot of Standardized Effects and ANOVA feed and axial depth of cut are the most significant factors which affect the material removal rate and then followed by speed radial depth of cut are the significant. The percentage of contribution occupied by the parameters as 39.50% of feed, 39.50% of axial depth of cut, 7.86% of speed and 6.95% of radial depth of cut.

Regression Equation for material removal rate is

MRR(mm3/min) = -2084 - 2.126*N + 10333*f + 130.0*rdoc + 1240*adoc

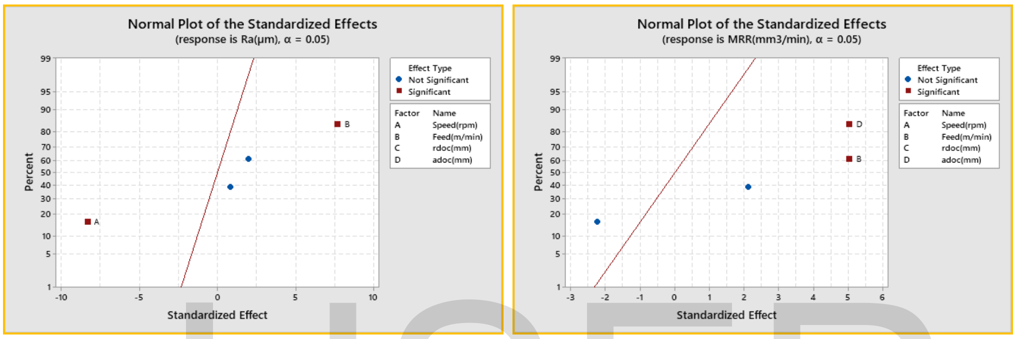

Figure 4.1: Normal Plot of the Standardized Effects for Surface Roughness MRR

II. Surface Plots

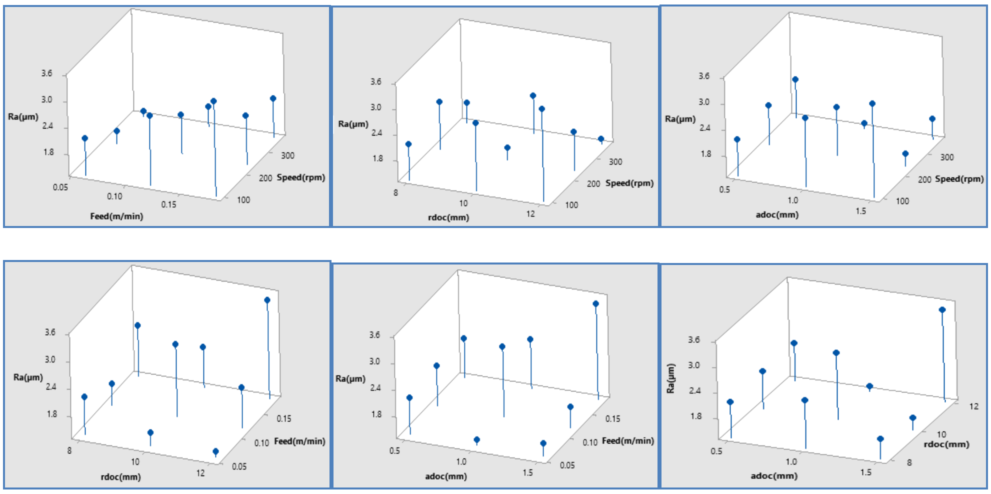

Figure4.2: Surface Plots of Surface Roughness vs. Input Parameters

Surface plots shows that surface roughness is minimum by the combination of low feed, high speed, high radial depth of cut and middle of axial depth of cut.

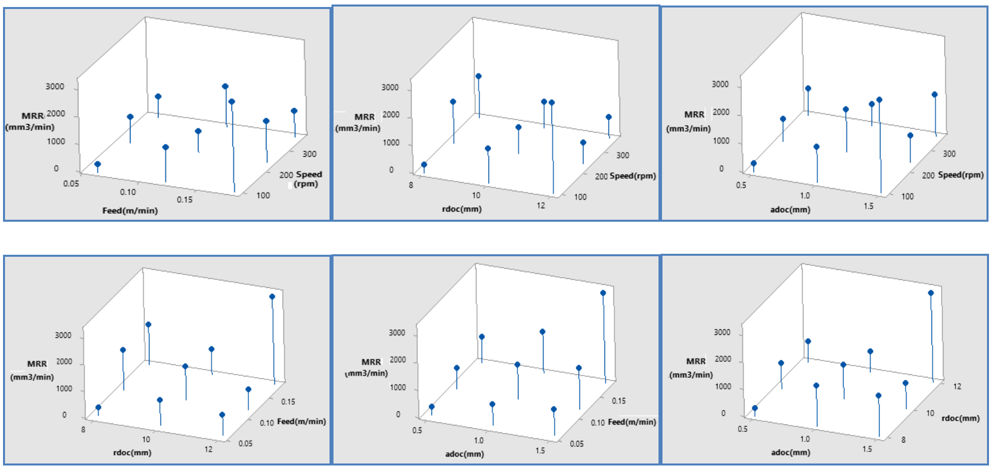

Figure 4.3: Surface Plots for Material Removal rate vs. Input Parameters

Surface plots shows that material removal rate is maximum by the combination of high feed, low speed, high radial depth of cut and high axial depth of cut.

III. Response Optimization

Surface roughness optimization	Material Removal rate optimization
Goal: Minimum **Parameter Setting:** Speed=360rpm, feed=0.06m/min, rdoc=8mm and adoc=0.5mm **Estimated Response:** Surface roughness = 1.07126 µm **Composite desirability:** 1	**Goal:** Maximum **Parameter Setting:** Speed=100rpm, feed=0.18m/min, rdoc=12mm and adoc=1.5mm **Estimated Response:** Material Removal Rate = 2984 mm^3/min **Composite desirability:** 0.915

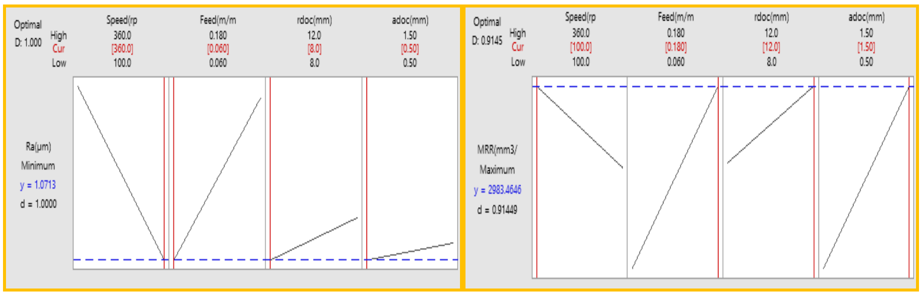

Figure 4.4: Optimization of Surface Roughness and Material removal Rate

5. CONCLUSIONS

The cutting factors radial depth of cut, axial doc, speed and feed are selected as input parameters and Ra (surface roughness), MRR (material removal rate are selected as response output parameters. The effect of these input parameters on responses as follows.

Significant factors:

- ✓ According to Pareto Chart of the Standardized Effects and ANOVA analysis, it shows that: all the factors radial doc, axial doc, speed and feed are the most significant factor for the response surface roughness; axial doc, feed and radial doc are the major significant parameters for the response MRR and speed is not significant

Effect of factors:

- ✓ As increasing feed rate surface roughness, MRR increases.
- ✓ As increasing spindle speed surface roughness, MRR decreases.
- ✓ As increases radial depth of cut, all the responses surface roughness, MRR also increases.
- ✓ As increasing axial depth of cut surface roughness, MRR increases

Optimization:

- ✓ All the responses are optimized individually and it results; **Ra** is better with the combination of low radial depth of cut, low axial depth of cut, high speed and low feed rate; **MRR** is maximum with the combination of high radial depth of cut, high axial doc, low speed & high feed rate

Verification:

- ✓ Comparison graphs of responses (experimental values with estimated values) in verification results; **Ra** values are closely matched, MRR values are fairly matched.

6. REFERENCES

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