International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 3 Issue 9, September- 2014

Modeling of Process Parameters on Surface Roughness in Milling of Aluminum Metal Matrix Composite (Al-7075 & Sic) using RSM

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Abstract— **Present days, Greater attention is given to surface roughness as surface finish influences mechanical properties. Roughness is a measure of the texture of a surface. It is quantified by the vertical deviations of a real surface from its ideal form. Analysis of surface roughness involves large number of parameters including cutting parameters, tool geometry, work material, chatter and cutting fluids. Milling machines are the principal machine tool used in milling to assess the machining performance.**

In present study, an attempt has been made to manufacture AMC through liquid metallurgical route and two different work materials are considered in HAAS CNC milling VF2 machine under the same set of machining conditions such as cutting speed, feed rate, depth of cut and cutting diameter.

The surface finish prediction strategy has been developed for correlating the machining parameters with surface roughness using multiple regression technique and optimization of machining parameters using Response surface methodology.

Keywords—Milling, Metal Matrix Composites

I. INTRODUCTION

Milling and End milling are the most important milling operations in variety of manufacturing industries including aerospace and automotive sector due to its capability of producing complex geometric surfaces, ability to remove material faster with reasonable accuracy and surface finish [1]. In modern industries CNC milling machine is very useful for its flexibility and versatility that allows manufacture of products in short time at low cost with high quality and good finish. Greater attention is given to surface roughness as surface finish influences mechanical properties fatigue behavior, wear, corrosion, lubrication and electrical conductivity [2].

Considerable research taken place on surface finish resulting from turning operations, where as that of machining process using multi point cutters requires attention by researchers. With multi point cutting tools used in milling, processing time is very low as compared to some of the conventional machining process [3]. The inter dependence and correlation among quality and productivity is very complex and difficult to understand. It depends on tool – work material. Very little attention has been devoted to the effect of work piece material in milling operations [4].

The material selected were aluminum Alloy and Metal matrix Composite of Aluminum. The process selected for manufacturing aluminum metal matrix composite is stir casting process [5]. The test specimen is cast into174x15x15mm sizes, to accommodate 16 samples machining in each piece. Specimen are rough machined all faces to get flat surface. The thickness is maintained 15 mm to ensure rigidity of mounted piece on the machine vice. The specimen is machined on one face with different depth of cuts adjacent to each other. Aluminum Alloy is selected for study due to its extensive use in ordinance industries because of its superior strength. AMC is selected for study due to less research [6-10] has been conducted on this material.

TABLE I. Mechanical Properties of Aluminum Alloy

Properties	Value
Density	2730kg/m^3
Poisson's Ratio	0.33
Elastic Modulus (GPa)	70
Tensile Strength (Mpa)	276
Yield Strength (Mpa)	145
Elongation (%)	9-10
Shear Strength (MPa)	170
Fatigue Strength (MPa)	195

II. EXPERIMENTATION

The machine used in this experiment was a CNC Vertical milling machine because of its flexibility and versatility in operation, manufacture by HAAS CNC milling VF2 with 20 HP vector dual drives, 10000 RPM, 1000 IPM.

The tools employed in this study were general purpose HSS end mills to determine a feasible range of cutting conditions based on work piece and tool material a total of 16 pilot tests were conducted. The number of samples is based on Taguchi L_{16} (4^4) Orthogonal Array with 4 factors with 4 levels design. The pilot study resulted in a feasible range of 76-100m/min for Cutting speed, 320-545mm/min for Feed rate, 0.2-0.8 mm for Depth of cut, 6-12 mm for cutter diameter. The tests were conducted using 3 cutters of same diameter of 8mm and 2, 3, 4 numbers of cutting edges. The experiments were conducted with cutting fluid. The 4 independent variables were cutting speed, feed rate, depth of cut, cutter diameter. Details pertaining to the selection of these variables are Cutting Speed, depth of cut, feed rates, cutter diameter.

TABLE II. Cutting tools use

Cutter Diameter, mm	Number of Cutting Edges/Lips
8	2
8	3
8	4

Fig. 1 HAAS VF-2 CNC machining center

Fig. 2 End mill cutters

TABLE II. Experimental Design

1	Cutting speed (m/min)	76	84	92	100
2	Feed rate (mm/min)	320	395	470	545
3	Depth of cut (mm)	0.2	0.4	0.6	0.8
4	Cutter Diameter (mm)	6	8	10	12

Given the above conditions, all other conditions were maintained fixed and constant during the experiment. Three different cutters with 4 levels of cutting speed, 4 levels of feed rate, 4 levels of depth of cut, 4 levels of cutter diameter were considered. The dependent variable was surface roughness. A total of 16 observations were taken for each of the work material Aluminum Alloy and Metal Matrix Composite of Aluminum. Taguchi L_{16} (4^4) orthogonal array was used for number of trials for 4 factor, 4 level design.

The test specimen was mounted in a vice clamped on the milling machine work table. Rough machining is performed and work is set ready for trial. The required cutting speed, feed rate and depth of cut were incorporated in CNC part programming to perform the first cut. The end mill was placed in the tool holder which has previously mounted in the milling head. The specimen was set to the starting position. After each trial specimen machining spindle was stopped and the next set of conditions was programmed. Each sample was marked with corresponding trial number to identify the conditions used. The steps were repeated until the whole experiment was complete.

The instrument used for measuring surface finish was tale surf. The device consists of a tracer head and an amplifier. The head housed a diamond stylus. Any movement of stylus is converted into electric fluctuations by tracer head. These signals are magnified by the amplifier and registered on the digital display. The readings shown on the digital display indicates the average height of the surface roughness. R_a values were repeated at least 3 times and then the average of these values were recorded.

The experimental data for two materials was analyzed statistically using analysis of variance (ANOVA) procedure to determine the effect of the independent variables of cutting speed, feed rate, and depth of cut and cutter diameter on surface roughness. In addition to the statistical analysis interaction plots of independent variables were constructed to illustrate the effect of variables on surface roughness. Optimization of machining parameters using Response surface methodology is carried out.

III. RESULTS

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Finally, complete content and organizational editing before formatting. Please take note of the following items when proofreading spelling and grammar:

A. Experimental Tests

TABLE IV. The L_{16} (4^4) Orthogonal Array

Exp. No.	A	B	C	D
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	1	4	4	4
5	2	1	2	3
6	2	2	1	4
7	2	3	4	1
8	2	4	3	2
9	3	1	3	4
10	3	3	1	2
11	3	3	1	2
12	3	4	2	1
13	4	1	4	2
14	4	2	3	1
15	4	3	2	4
16	4	4	1	3

Response surface methodology is a collection of mathematical and statistical techniques useful for modeling in which a response of interest is influenced by several variables and the objective is to optimize this response.

After conducting the 16 cutting experiments the surface roughness readings are used to find the parameters appearing in multiple regression models with the aid of MINITAB. The following table (table-5) gives the constant terms used in the following regression equation; it has been used for calculation of surface roughness values and are tabulated as follows.

Ra = -16.4+1.54 X1+0.134 X2+7.63 X3+0.0159 X4-0.021 X1*X1+0.00054 X2*X2 +5.20 X3*X3-0.00884 X1*X2+0.004 X1*X3 -0.00036 X1*X4-0.145 X2*X3- 0.000174 X2*X4

TABLE V. Surface roughness values of Aluminum Alloy 7075 with 5% Sic

S. No	Cutter dia(d) mm	Cutting speed (Cs) m/mm	Depth of cut (D) mm	Feed (F) mm/min	Average Ra - exp	Calcu-lated Ra
1	6	76	0.2	320	1.142	1.676
2	6	84	0.4	395	1.35525	1.78975
3	6	92	0.6	470	1.40675	1.9049
4	6	100	0.8	545	1.4995	2.2005
5	8	76	0.8	395	3.09475	2.45655
6	8	84	0.6	320	2.3144	2.4854
7	8	92	0.4	545	2.1736	2.33725
8	8	100	0.2	470	3.0375	2.3661
9	10	76	0.4	470	2.35075	2.8015
10	10	84	0.2	545	2.4525	2.74185
11	10	92	0.8	320	3.47125	3.2088
12	10	100	0.6	395	2.5015	3.14915
13	12	76	0.6	545	3.45125	3.40865
14	12	84	0.8	470	3.26475	3.6123
15	12	92	0.2	395	3.535	3.46635
16	12	100	0.4	320	3.4485	3.67

The obtained experimental values of surface roughness are plotted and below figure (Fig.3) shows the variation of roughness values obtained from experiments with calculated values using regression technique.

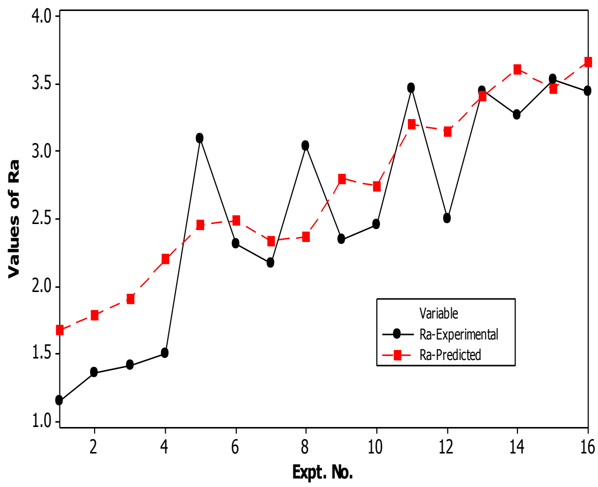

Fig. 3 Roughness values of Aluminium Alloy Experimental Vs Calculated

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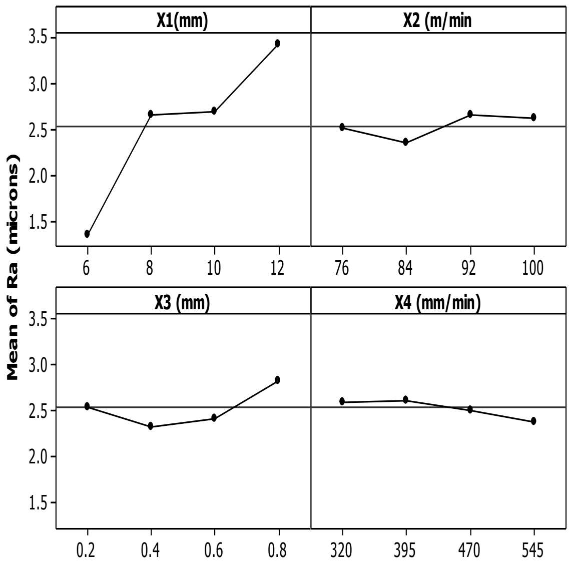

Fig. 4 Interaction plot for surface roughness of Aluminum Alloy

With reference to the above figure the following discussions are made.

The surface roughness increases with the increase in cutting diameter up to certain value, then further increases at high cutting diameter.

The surface roughness decreases with increase in cutting speed and further increases as the cutting speed increases.

The surface roughness decreases up to a certain value and then increases with increase in depth of cut.

The surface roughness value decreases with increase in feed rate.

TABLE VI. Summary of RSM with regression analysis for Alloy

S value	R-Sq (%)	R-Sq(adj)
02913	98.4	87.9

IV. CONCLUSIONS

A. Aluminum Alloy

The surface roughness values for Alloy are varying between 0.27 to 1.02 microns for the trial specimen. Roughness value is more at 0.8 mm depth of cut at cutting speed of 88 m/min and feed rate of 450 mm/min and roughness value is less at 0.5 mm depth of cut at cutting speed of 88 m/min and federate of 300 mm/min.

B. Metal Matrix Composite of Aluminum

The surface roughness values for MMC of aluminum are 1.108420 microns for the specimen. Roughness value is less at 0.4mm depth of cut with 6mm cutter diameter at cutting speed of 76 m/min and feed rate of 545mm/min.

Surface roughness value is increasing with the increase in the reinforcement of SiC.

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