Prediction and Optimization of End Milling Process Parameters of LM25 Al Alloy Based MMC

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***Abstract*— One of the most perceptions of quality in mechanical product is its physical look. One among the foremost necessary factors in physical look is that the surface roughness. This analysis focuses on study and analysis of surface quality improvement in end milling operation of LM25 AL alloy/B4C metal matrix composite. Aluminium matrix composites (AMCs) are emerging as advance engineering materials due to their ductility, strength and toughness. The present study investigate the effect of spindle speed, feed rate, depth of cut and varied percentage (% wt.) of B4C on surface roughness in end milling of LM25 Al alloy. LM 25 Al alloy is reinforced with varied composition (weight %) of Boron carbide using Stir casting method. Stir casting method is used to prepare the specimen due to better and even spread of reinforcement material. Experiments is conducted on a CNC milling machine according design of experiments methodology. A prophetic response surface model for surface roughness is developed using Response Surface Methodology. The result obtained using RSM gives a good prediction of surface roughness when compared to actual surface roughness. The experimental results was analysed statistically to examine the influence of process parameters on surface roughness.**

***Index Terms*— Metal matrix composites, Response surface Methodology (RSM), Surface roughness (R_a).**

I. Introduction

Metal-matrix composites have been increasingly used in industries because of their improved properties over those of non-reinforced alloys. The reinforcement material such as silicon carbide, boron carbide, aluminium oxide or alumina etc., can be added to aluminium to enhance its properties. Among the various types of MMCs, aluminum based composites have been found in various engineering applications such as the aerospace and automobile industries.

GOPAL KRISHNA [1] found that addition of Boron Carbide particles in the matrix induces more strength to matrix alloy by offering more resistance to tensile strength. Increase in strength is due to the increase in hardness of the composite AROKIADASS et al [2] developed a model to predict the tool wear while machining of LM25 Al alloy reinforced with SiC_p particles using the process parameters of spindle speed, feed rate, depth of cut and % of SiC_p. The experiments were conducted on a vertical milling machine for the machining of LM25 Al/SiCp. The tool used for the machining operation is a carbide tool. The response surface roughness was studied.

BASHEER et al [3] developed a model to predict the surface roughness in precise machining of metal matrix composites considering the size and volume of reinforcement, tool nose radius, feed rate, and the depth of cut.

CHAPMAN [4] found that through test conducted on a wide variety of Aluminium-Boron Carbide atainable by process design variations, conditions which yielded materials with potential success in applications as automotive brake friction materials were identified.

MOHANTYA [5] founded that with increase in percentage of Boron carbide addition to Aluminium 1100, there was a transition from Al-B-C formation to formation of Boron rich Al-B at grain boundaries. The result reveals that the modulus of composite depends mainly on weight percentage of reinforcement rather than interfacial wetting.

SASIMURUGAN [6] conducted experiments to study the influence of cutting parameters on surface roughness in machining of hybrid metal matrix composites.

PALANIKUMAR [7] developed a model for surface roughness through response surface method (RSM) while machining GFRP composites. Four factors five level central composite rotatable design matrix was employed to carry out the experimental investigation. Analysis of variance (ANOVA) was used to check the validity of the model.

II. MATERIALS AND METHODS

Experimental work

In this experiment LM25 Aluminium alloy with various %wt. of B_4C are used. Stir casting method is used for experimentation. The test sample dimensions are 120mm × 120mm × 10mm. 5 work pieces (LM25 AL reinforced with 3% 6% 9% 12% and 15% weight of B_4C) are prepared in total. The tool used is Nano coated carbide tool having 5mm diameter. The machining is carried out in CNC milling machine. The chemical composition of LM25 Al alloy is shown in Table-I. According to the central composite design (CCD), 31 experiments were carried out using MINITAB-17 software.

Table I: Chemical composition of LM 25 Aluminium alloy

Chemical composition	**%**
Copper	0.1 Max
Magnesium	0.20-0.60

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Silicon	6.5-7.5
Iron	0.5 Max
Manganese	0.3 Max
Nickel	0.1 Max
Lead	0.1 Max
Tin	0.05 Max
Titanium	0.2 Max
Aluminium	Remainder

III. RESPONSE SURFACE METHOD

The second order polynomial response surface mathematical model, that analyses the parametric influences on the various response criteria is shown in equation (1).

Table II: Levels of parameters

PARAMETERS	UNITS	SYMLBOS	LEVELS				
			-2	-1	0	1	2
Spindle speed(A)	Rpm	N	2000	2500	3000	3500	4000
Feed rate(B)	mm/rev	F	0.02	0.03	0.04	0.05	0.06
Depth of cut(C)	Mm	D	0.5	1	1.5	2	2.5
Boron carbide(D)	%wt.	W	3	6	9	12	15

Response surface modelling was considered to establish the mathematical relationship between the response (Yu) and the various process parameters.

The second order polynomial response surface mathematical model, that analyses the parametric influences on the various response criteria, are portrayed as follows:

$Y_u = b_0 + \sum_{i=1}^{k} b_i x_i + \sum_{i=1}^{k} b_{ii} x_i^2 + \sum_{j>1}^{k} b_{ij} x_i x_j$ (1)

where, Xi (1, 2, k) are coded level of k quantitative variables. The coefficient b_0 is the free term, the coefficients bi are the linear terms, the coefficients b_{ii} are the quadratic terms, and the coefficients b_{ij} are the interaction terms.

Applying the least square technique, the values of these coefficients can be estimated by using the observations collected (Y_1, Y_2, Y_n) through the design points (n).

To establish the initial model and refined model, a software package MiniTab was used to determine the coefficients of mathematical modelling based on the response surface regression model. The level of parameters which are selected for the experiments were given in the Table-II.

In Table-III the experimental design matrix and results were given. Here in this experiment, the process parameters are spindle speed (A), feed rate (B), depth of cut (C), and %wt. of B_4C (D) respectively. It shows various regression equation value for 31 experiments respectively. The error between the surface roughness value and the regression equation value is also shown in table-III. The error obtained is within the acceptable range respectively.

Table III: Experimental design matrix and results

EX NO	COADED VALUE				SURFACE ROUGHNESS (R_A)(μm)	REGRESSION EQUATION VALUE	ERROR
	A	B	C	D			
1	-1	-1	-1	-1	0.86	0.863335	-0.003335
2	1	-1	-1	-1	0.8	0.795001	0.004999
3	-1	1	-1	-1	0.92	0.913335	0.006665
4	1	1	-1	-1	0.87	0.875001	-0.005001
5	-1	-1	1	-1	0.85	0.843335	0.006665
6	1	-1	1	-1	0.76	0.760001	-0.000001
7	-1	1	1	-1	0.91	0.918335	-0.008335
8	1	1	1	-1	0.87	0.865001	0.004999
9	-1	-1	-1	1	0.86	0.858335	0.001665
10	1	-1	-1	1	0.84	0.835001	0.004999
11	-1	1	-1	1	0.9	0.903335	-0.003335
12	1	1	-1	1	0.91	0.910001	-0.000001

13	-1	-1	1	1	0.88	0.878335	0.001665
14	1	-1	1	1	0.84	0.840001	-0.000001
15	1	1	1	1	0.95	0.948335	0.001665
16	1	1	1	1	0.94	0.940001	-0.000001
17	-2	0	0	0	0.92	0.920002	-0.000002
18	2	0	0	0	0.84	0.843334	-0.003334
19	0	-2	0	0	0.78	0.786668	-0.006668
20	0	2	0	0	0.94	0.936668	0.003332
21	0	0	-2	0	0.85	0.851668	-0.001668
22	0	0	2	0	0.86	0.861668	-0.001668
23	0	0	0	-2	0.85	0.851668	-0.001668
24	0	0	0	2	0.92	0.921668	-0.001668
25	0	0	0	0	0.87	0.87	0
26	0	0	0	0	0.87	0.87	0
27	0	0	0	0	0.87	0.87	0
28	0	0	0	0	0.87	0.87	0
29	0	0	0	0	0.87	0.87	0
30	0	0	0	0	0.87	0.87	0
31	0	0	0	0	0.87	0.87	0

IV. RESULTS AND DISCUSSION

Modelling and statistical analysis:

The data which is presented in Table-III is analysed by using MiniTab software. Table-IV is the initial model and includes all the linear, interaction and square terms.

The regression equation for predicting the surface roughness (R_a) is as follows:

Surface roughness (R_a) = 0.8000 – (0.019167A) + (0.037500B) + (0.002500C) + (0.017500D) + ($0.002917A^2$) – ($0.002083B^2$) – ($0.003333C^2$) + ($0.004167D^2$) + (0.00750A*B) – (0.00375A*C) +

(0.01125A*D) + (0.00625B*C) – (0.00125B*D) + (0.01000C*D) (2)

Table IV: Statistical Analysis of all linear, square and interaction terms

Estimated coefficient for R_a					
Predictor		Coefficient		p value	
Constant		0.87		<0.000	
A		-0.019167		<0.000	
B		0.0375		<0.000	
C		0.0025		<0.021	
D		0.0175		<0.000	
A*A		0.002917		<0.005	
B*B		-0.002083		<0.033	
C*C		-0.003333		<0.002	
D*D		0.004167		<0.000	
A*B		0.0075		<0.000	
A*C		-0.00375		<0.006	
A*D		0.01125		<0.000	
B*C		0.00625		<0.000	
B*D		-0.00125		0.312	
C*D		0.01		<0.000	
S = 0.0047871 R-sq = 99.36% R-sq (adj) = 98.80%					
Analysis of Variance					
Source	**DF**	**Adj SS**	**Adj MS**	**F**	**P**

Regression	14	0.056782	0.004056	176.98	0
Linear	4	0.050067	0.012517	546.18	0
Square	4	0.001315	0.000329	14.35	0
Interaction	6	0.0054	0.0009	39.27	0
Residual Error	16	0.000367	0.000023		
Total	30				

ANOVA is shown at the end of Table-IV. It shows that the value of $p < 0.05$ for all square, linear and interaction terms. This shows that all these effects are significant on the surface roughness.

The insignificant square and interaction terms can be removed from the above initial model to generate a more precise model.

Improved modelling and statistical analysis:

Factors that are influencing the surface roughness are only shown in Table-V. Based on 5 % confidence interval, that is the value of $p < 0.05$, in linear terms spindle speed, feed rate, depth of cut and %wt. of Boron carbide; in square terms spindle speed, feed rate, Depth of cut and %wt. of Boron carbide; in interaction terms spindle speed-feed rate, spindle speed-Depth of cut, spindle speed-%wt. of Boron carbide, feed rate-Depth of cut and Depth od cut-%wt. of Boron carbide plays an important role in affecting surface roughness. R-sq (adj) is 98.79% indicating that our model can predict within 98.79% accuracy. The regression equation for surface roughness (R_a) is as follows:

Table V: Statistical analysis of improved model

Estimated coefficient for R_a					
Predictor		Coefficient		p value	
Constant		0.87		<0.000	
A		-0.019167		<0.000	
B		0.0375		<0.000	
C		0.0025		<0.021	
D		0.0175		<0.000	
A*A		0.002917		<0.005	
B*B		-0.002083		<0.033	
C*C		-0.003333		<0.002	
D*D		0.004167		<0.000	
A*B		0.0075		<0.000	
A*C		-0.00375		<0.006	
A*D		0.01125		<0.000	
B*C		0.00625		<0.000	
C*D		0.01		<0.000	
S = 0.0047999 R-sq = 99.31% R-sq (adj) = 98.79%					
Analysis of Variance					
Source	**DF**	**Adj SS**	**Adj MS**	**F**	**P**
Regression	13	0.056757	0.004366	189.5	0
Linear	4	0.050067	0.012517	543.28	0
Square	4	0.001315	0.000329	14.27	0
Interaction	5	0.005375	0.001075	46.66	0
Residual Error	17	0.000392	0.000023		
Total	30				

The data obtained was further analysed to study the interaction among process parameters and the interaction plot and main effect plots were generated and shown in Figures 2 and 1 respectively. It shows that the feed rate, spindle speed and %wt. of B_4C plays an important role in enhancing the surface finish. In end milling of LM25 Aluminium alloy/Boron carbide MMC, Depth of cut has less influence on surface roughness.

Main Effects Plot for Surface roughness (R_a)

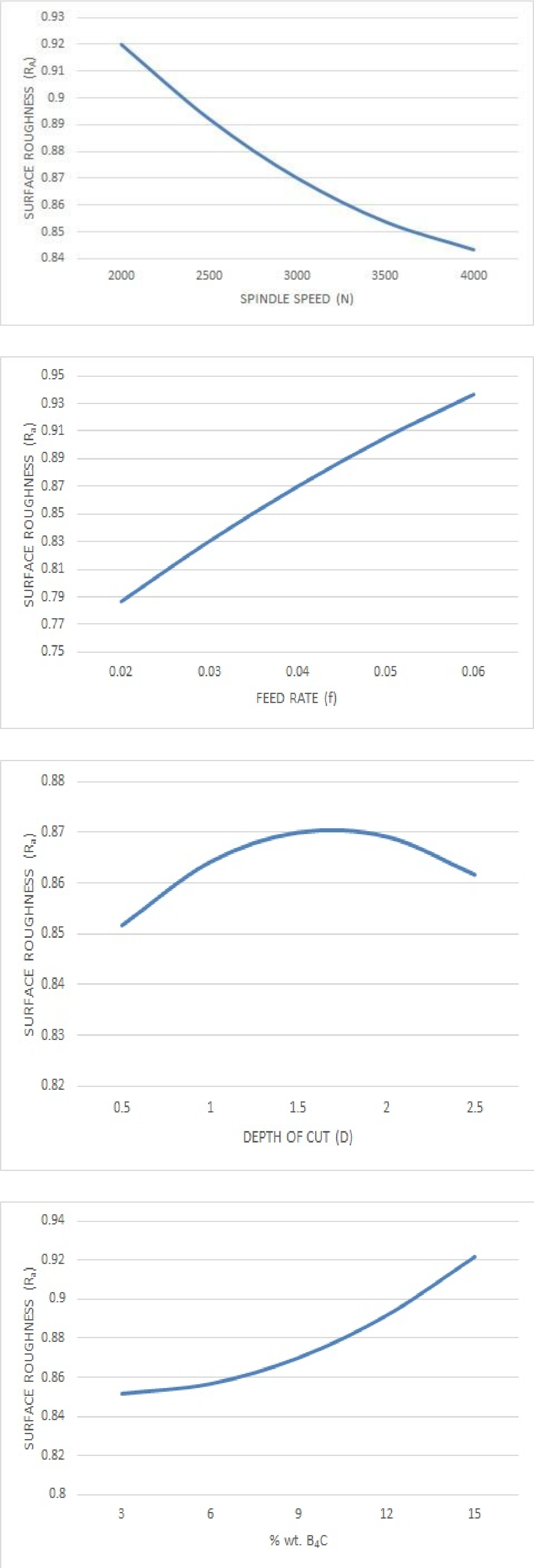

Fig 1: Main effects plot for surface roughness

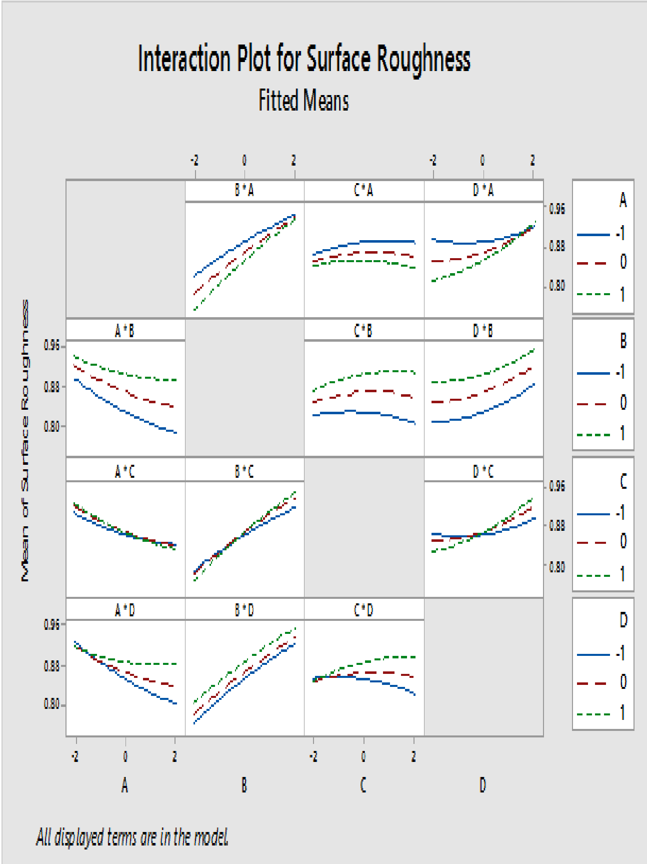

Fig 2: Interaction plot for surface roughness

Main Effects Plot for Surface roughness (R_a)

From the above figure 1 we can conclude that:

Speed: An increase in speed in speed will considerably decrease the surface roughness. Unstable larger Built up edge (BUE) is formed and chip fracture occurs producing low rough surface at low cutting speed. The BUE vanishes, chip fracture decreases due to which the roughness decreases at high cutting speed.

Feed: An increase in feed will considerably increase surface roughness. The chatter and heat generation increases due to increase in feed rate which increases the surface roughness.

Depth of cut (DOC): There is slight increase in surface roughness while increasing depth of cut.

%wt. of B_4C: The surface roughness increases with increase in %wt. of B_4C.

Interaction Plot for Surface roughness (R_a)

From the above figure 2 we can conclude that:

Spindle speed-Feed rate: An increase in feed will considerably increase surface roughness. The chatter and heat generation increases due to increase in feed rate which increases the surface roughness. At low cutting speed (s), the unstable larger BUE is formed and also the chips fracture readily producing the rough surface. As the cutting speed (s) increases, the BUE vanishes, chip fracture decreases, and, hence, the roughness decreases. The best surface finish was achieved at the lowest feed rate and highest cutting speed combination. This conclusion may be very useful as for mass production, optimal values for spindle speed and feed rate can be set hence reduce the manufacturing time without losing surface finish.

Feed rate-Depth of cut: From experience we know that feed rate and %wt. of Boron carbide interaction effects the surface roughness. Increasing the feed rate will increase the surface roughness. Also increasing the %wt. of Boron carbide will increase the surface roughness. The reason being, addition of reinforcing materials which are normally harder and stiffer than the matrix, machining becomes significantly more difficult than in the case for conventional materials. The best surface finish is achieved at the lowest feed rate and lowest %wt. Boron carbide combination.

V. CONCLUSION:

The experiments were done on a CNC milling machine for the machining of LM25 Aluminium alloy/Boron carbide. Nano coated carbide tool is used for machining operation. The response surface roughness R_a was studied.

1) Using response surface methodology (RSM), the second order polynomial models were created to predict the surface roughness respectively.
2) The main effect plot shows that the feed rate was the most dominant parameter on surface roughness followed by spindle speed and %wt. of B_4C.
3) Depth of cut has less influence on surface roughness.
4) The interactions plots for surface roughness was studied.
5) The surface roughness model developed can be used in enhancing the surface quality of a product and can give better surface finish.

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