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Multi-objective optimization of end milling process parameter for stir casted alumina reinforced aluminium metal matrix composite using RSM

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Abstract. Modern manufacturing firms aim to attain quality, dimensional precision, increased production rate, minimal tool wear, economy and mainly surface roughness. Milling is becoming an essential material removal technique can be used for optimizing surface roughness of the composites for micro level and economic performance. Alumina reinforced Aluminium Metal Matrix Composites (AAMMC) developed by the stir casting method gives good mechanical properties and which is also used in many automotive, aerospace and industrial applications. This work focuses on the effect of end milling machining process parameters such ascutting speed, feed rate, depth of cut on machining of stir casted AAMMC. Alumina content of 10wt% is reinforced with Aluminium matrix is used for this research work, it was found that AAMMCs provide higher strength to weight ratio, wear resistance and hardness properties. Optimal levels and important end milling machining parameters were obtained using ANOVA and response surface methodology. The optimal values of surface roughness and the machining time were obtained at Cutting Speed of 1750 rev/min with a feed rate of 0.3 mm/rev and depth of cut 0.2mm. The predicted and measured values were interrelated with each other. This results determined that the model obtained using response surface methodology is utilized to analyse the Surface Roughness S.R and the Machining Time M.T of milling machining of AAMMC.

Keywords: Metal Matrix Composites, Response surface methodology, Surface roughness, machining time

1. Introduction

Aluminium alloy metal matrix composite with higher specific strength has a widely used in various industrial application such as automobile and aerospace. By using stir casting processes, experiments were done with selected parameters such as stirring speed, size, holding temperature, and position of the impeller. Further, the metal matrix composites with good uniform particle distribution, low porosity and good wettability were fabricated by stir casting method [1]. The Aluminium which is utilized in aerospace and marine field required improved properties such as high durability and wear resistance. The Al6061 is combined with alumina by varying the content from 6 to 12% wt with increment of 3% wt fraction at 200℃.The tensile, wear and hardness properties are improved by the addition of alumina particulates [2]. Bharath et al. indicated that aluminium MMC is reinforced with alumina to give good physical and mechanical properties. This composites were utilized in various applications such as defence, sports, biomedical, electronics, etc. Alumina in the form of nano with 40 mm size is added with Aluminium by different ratios at 60℃. It is identified that better mechanical properties are obtained when 2% of alumina is added and also wear resistance properties are increased and friction coefficient values are decreased [3]. Dinesh et al. studied the various properties of $Al\text{-}Al_2O_3$ Composites which is Processed by Casting and powder metallurgy Routes. The tensile strength, yield strength, and hardness increased with the increasing percentage of alumina content. However, the fracture toughness of the composite is decreased when increasing in alumina [4]. Aluminium and alumina are mixed with various proposition to form high wear rate composites. The high wear rate is obtained in 6061 AL alloy compared with other composites [5]. The mechanical properties of aluminium alloy reinforced with graphite and Al2O3 by stir casting technique was investigated by Mandeep et al. [6]. In this, LM25 aluminium alloy is formed by 10% addition of alumina for the making of the composite by stir casting. It is the low-cost manufacturing method and Alumina reinforced MMC has less porosity. End milling experiment was conducted on composite by using solid coated carbide in EN24 grade material tool steel. The experiment was optimized by using response surface methodology (RSM). The parameters such as feed rate, cutting speed and depth of cut were selected for end milling process of composites. The output parameters are surface roughness and material removal rate (MRR). The optimized parameters with a high grade of accuracy was obtained by using Response surface methodology and Genetic algorithm [7]. Ankit et al. analyzed the various parameters in CNC milling machine Using Composite Material as a Cutting Tool. The Experimental results demonstrate that cutting force and cutting speed influences the surface roughness and also the tool life of end mill cutters of a CNC milling machine [8].Aseer et al. studied a correlation between feed rate, cutting speed and drill tool with the induced hole diameter error in a Bahunia racemosa/glass fiber composites using RSM method. The experimental results showed that the higher cutting speed, lower feed rates and HSS brass coated tool are essential parameter to minimize the hole diameter error [9].

The main objective of this work is to find an optimized combination of end milling process parameters to reduce surface roughness and machining time. It also presents an approach to identify the suitable mathematical model for surface roughness and machining time in end milling of Alumina reinforced aluminium matrix composites by response surface methodology.

2. Materials and Methods

Aluminium rods and alumina powder purchased from Arihant aluminium industries and VB ceramics Chennai, Tamilnadu respectively. Initially, aluminium rods were kept in a crucible furnace.

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Aluminium rods were heated at the temperature of 850℃ and melted for an hour continuously. The temperature of furnace was raised at 700℃ which is above the liquid state and then temperature was reduced below the liquid state to keep it in semi-solid state. Then, alumina particles were mixed to the molten metal at the furnace with the temperature of 750℃ and is stirred manually for 6-7 minutes. Further, aluminium and alumina content in the molten state was poured into a rectangular plate mould to get the alumina reinforced aluminium metal matrix composites (AAMMC). The end milling process parameters were selected for machining AAMMC in PMT Automatic Multi-Purpose Milling Machine-PMT - S1, HABU industries, Trichy Figure 1. the machined Alumina reinforced aluminium matrix composite (AAMMC) is shown in Figure 2.

The end milling parameters with various levels are given in Table 1. The response surface methodology is used to optimize the surface roughness and machining time. BoxBehnken method is chosen to identify the effect of end milling process parameters such as the cutting speed, feed rate and depth of cut on surface roughness and machining time of Alumina reinforced aluminium metal matrix composites. The surface roughness was measured using Mitutoyo surface roughness tester in Saranathan Engineering College, Trichy and also machining time was taken from digital stopwatch for 17 experimental runs.

Figure 1. PMT Automatic milling machine setup

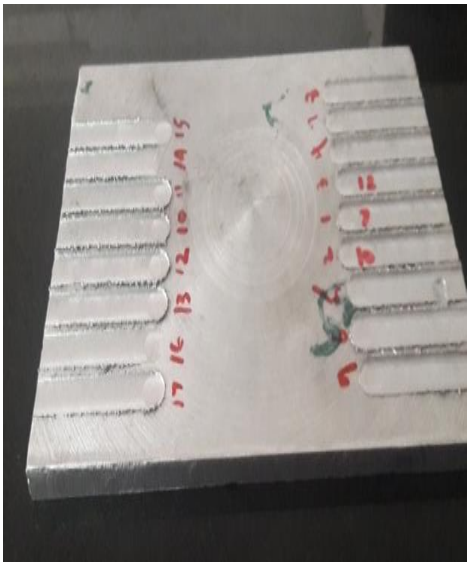

Figure 2. Machined Aluminium-Alumina MMC plate

Table 1 End milling Machining process parameters and levels

Symbol	Variables	Units	Experimental Levels		
			Low (-1)	Mid (0)	High (1)
A	Cutting speed	rev/min	660	1205	1750
B	Feed rate	mm/rev	0.2	0.3	0.4
C	Depth of cut	mm	0.2	0.35	0.5

3. Results and Discussion

3.1 Experimental results

The selected variables and levels for this work along with the observed output responses are given in Table 2.

Table 2 Process design layout using Box–Behnken method and Test results

Runs	Cutting speed rev/min	Feed rate mm/rev	Depth of cut mm	S.R micron	M.T Sec
1	660	0.2	0.35	4.413	23.2
2	1205	0.3	0.35	3.541	21.6
3	1750	0.2	0.35	2.244	20.2
4	1205	0.2	0.5	3.918	20.8
5	1205	0.3	0.35	3.24	20.3
6	1205	0.3	0.35	3.39	20.5
7	1205	0.4	0.5	3.92	22.1
8	660	0.4	0.35	4.325	26.9
9	1750	0.4	0.35	2.462	17.8
10	660	0.3	0.2	4.288	26
11	1750	0.3	0.2	1.426	18.3
12	1205	0.2	0.2	3.429	20.6
13	1205	0.3	0.35	3.12	22.1
14	1750	0.3	0.5	2.563	19.1
15	660	0.3	0.5	4.193	25
16	1205	0.3	0.35	3.58	21.3
17	1205	0.4	0.2	3.514	22.4

3.2 Response Surface methods

The response surface methods has be used in various fields[10,11] to analysis and optimize various process parameters which affects the final characteristics [12] From the ANOVA Table3, among the various process parameters such as cutting speed feed rate and depth of cut, the cutting speed influence the surface roughness. The response surface plot of cutting speed vs feed rate is shown in Figure 3. The surface roughness increases with increase in the cutting speed and the feed rate do not influence surface roughness. Also, the cutting speed versus depth of cut plot shown that increase in speed and decrease in depth of cut provides better surface roughness [13].

From an ANOVA Table 3, it is identified that cutting speed is an influencing machining time. The surface response plot of cutting speed versus feed rate for machining time is given Figure 4. Minimum machining time is obtained with a maximum cutting speed of 1750 rev / mm, higher feed rate of 0.4 mm/rev and less depth of cut 0.2 mm. The minimum machining time is found to be 18.49 seconds.

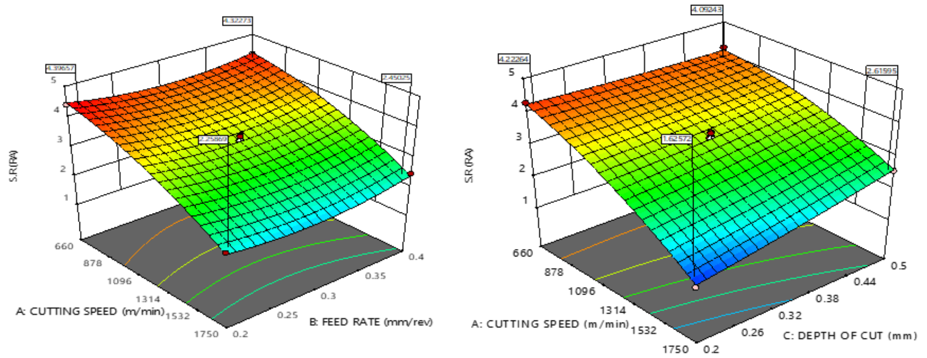

Figure 3 Contour plot of cutting speed vs feed rate and cutting speed vs depth of cut for Time

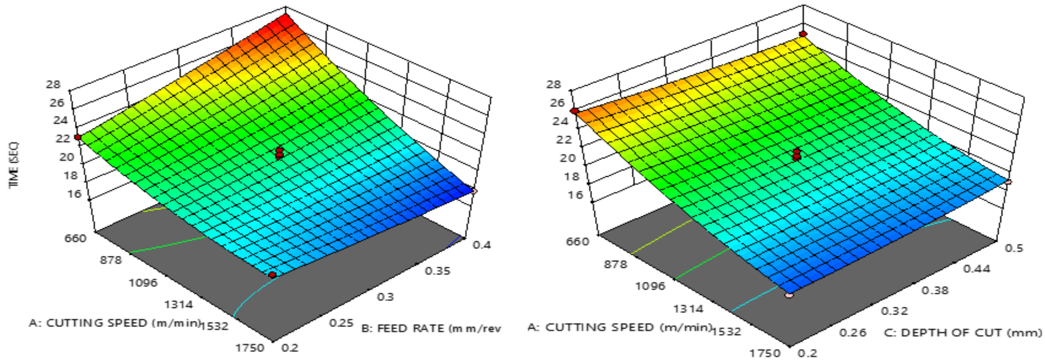

Figure 4 Contour plot of cutting speed vs feed rate and cutting speed vs depth of cut for Time

3.3 ANOVA for surface Roughness and Machining Time

From the Table 3 it is observed that the Model F-value of 45.34 for surface roughness and 25.72 for time implies that the model is significant. And also 0.01% chance "Model F-value" this huge can happen is due to the presence of noise for surface roughness and time. Further, the values of "Prob> F" is less than 0.0500 indicate that the model terms are significant for both[14]. Further from the Table 3, the cutting speed and depth of cut influence the surface roughness and also cutting speed and feed rate influence machining time. The Predicted R^2 of 0.8557 for surface roughness and 0.9344 for machining time is in reasonable agreement with the Adjusted R^2 of 0.9329for surface roughness and0.9615for machining time. Further more, Adeq Precision value 24.0193 for surface roughness and 18.996 for machining time, which gives the signal to noise ratio which is greater than 4 indicates a sufficient signal. The Lack of Fit is also found to be insignificant for the model from ANOVA. The correlation in terms of coded factors and actual factors for surface roughness and machining time is given by Equation. (1), (2), (3) and (4) respectively.

$$S.R = +3.37 - 1.07 \times A + 0.0271 \times B + 0.2421 \times C + 0.0765 \times AB + 0.3080 \times AC - 0.0208 \times BC - 0.2955 \times A^2 + 0.2823 \times B^2 + 0.0388 \times C^2 \quad (1)$$

$$S.R = +8.34199 - 0.0012 \times CUTTING\ SPEED - 17.8725 \times FEED\ RATE - 3.7171\ DEPTH\ OF\ CUT + 0.0014\ CUTTING\ SPEED \times FEED\ RATE + 0.0037\ CUTTING\ SPEED \times DEPTH\ OF\ CUT - 1.3833\ FEED\ RATE \times DEPTH\ OF\ CUT - 9.9478E - 07\ CUTTING\ SPEED^2 + 28.2275\ FEED\ RATE^2 + 1.7233 \times DEPTH\ OF\ CUT^2 \quad (2)$$

$$M.T = 21.16 - 3.2125 \times A\, 0.55 \times B - 0.0375 - 1.525 \times AB\, 0.45 \times AC - 0.125 \times BC\, 0.745 \times A^2\, 0.12 \times B^2\, 0.195 \times C^2 \quad (3)$$

$$M.T = 23.8152 - 0.0054 \times CUTTING\ SPEED\ 34.9345 \times FEED\ RATE - 10.4496\ DEPTH\ OF\ CUT - 0.0279 \times CUTTING\ SPEED \times FEED\ RATE\ 0.0055 \times CUTTING\ SPEED \times DEPTH\ OF\ CUT - 8.3333 \times FEED\ RATE \times DEPTH\ OF\ CUT\ 2.5082\,e - 06 \times CUTTING\ SPEED^2 \times 12\ FEED\ RATE^2\ 8.6666 \times DEPTH\ OF\ CUT^2 \quad (4)$$

3.4 Validation of Results:

For the Optimization, cutting speed of range 660 to 1750, feed rate 0.2 to 0.4, depth of cut of 0.2 to 0.5 is fixed. Surface roughness and the machining time is kept for minimum value as the goal and the optimization is carried out are given in Table 4. From the Optimization, it is found that cutting speed of 1750rev/min, the feed rate of 0.308 mm/rev and depth of cut 0.2 mm as the optimal process parameters. And the expected response for surface roughness is 1.15 micron and 18.4 seconds for machining time respectively with an good desirability of 0.95.

Table 3 ANOVA for Surface Roughness and Time

Source	S.R Sum of Squares	M.T Sum of Squares	S.R df	M.T Df	S.R Mean Square	M.T Mean Square	S.R F-value	M.T F-value	S.R p-value	M.T p-value
Model	10.64	97.86	9	9	1.18	10.87	45.34	25.72	< 0.0001	0.0001
A-Cutting Speed	9.08	82.56	1	1	9.08	82.56	348.49	195.28	< 0.0001	< 0.0001
B-Feed Rate	0.0059	2.42	1	1	0.0059	2.42	0.2258	5.72	0.6491	0.048
C-Depth of Cut	0.469	0.0113	1	1	0.469	0.0113	18	0.0266	0.0038	0.875
AB	0.0234	9.3	1	1	0.0234	9.3	0.8982	22	0.3748	0.0022
AC	0.3795	0.81	1	1	0.3795	0.81	14.56	1.92	0.0066	0.2088
BC	0.0017	0.0625	1	1	0.0017	0.0625	0.0661	0.1478	0.8045	0.712
A^2	0.3676	2.34	1	1	0.3676	2.34	14.1	5.53	0.0071	0.051
B^2	0.3355	0.0606	1	1	0.3355	0.0606	12.87	0.1434	0.0089	0.7161
C^2	0.0063	0.1601	1	1	0.0063	0.1601	0.2429	0.3787	0.6372	0.5578
Residual	0.1824	2.96	7	7	0.0261	0.4228				
Lack of Fit	0.0294	0.6875	3	3	0.0098	0.2292	0.256	0.4035	0.854	0.7591
Pure Error	0.1531	2.27	4	4	0.0383	0.568				
Cor Total	10.82	100.82	16	16						
S.R	Std. Dev. 0.1614 Mean3.39 C.V. % 4.77 R^2 0.9831 Adjusted $R^2$0.9615 Predicted R^2 0.9344 Adeq Precision24.0193									
M.T	Std. Dev.0.6502Mean 21.66 C.V. % 3.00 R^2 0.9706 Adjusted R^2 0.9329 Predicted R^2 0.8557 Adeq Precision 18.9996									

A confirmation Run for the optimized values was conducted and the obtained results matched with the predicted values as given in the Table 4 [15]. Cutting Speed of 1750rev/min with a feed rate of 0.3mm/rev and depth of cut 0.2 mm was used to study the confirmation of the predicted results. The surface response and the machining time had a small error percentage of less than 10 were shown in Table 5 [16].

Table 4 Constraints and Limits for Surface Roughness and Time

Name	Goal	Lower Limit	Upper Limit	Lower Weight	Upper Weight	Importance
A: Cutting Speed	is in range	660	1750	1	1	5
B:Feed Rate	is in range	0.2	0.4	1	1	4
C:Depth of Cut	is in range	0.2	0.5	1	1	5
Surface Roughness	minimize	1.426	4.413	1	1	5
TIME	minimize	17.8	26.9	1	1	3

Table 5 Comparison of confirmation experiments with the results

Exp. No	Surface Roughness (microns)			Machining Time (sec)		
	Obtained	Predicated	Error	Obtained	Predicated	Error
1	1.562	1.514	3.17 %	19.42	18.407	5.50 %
2	1.584	1.514	4.62 %	19.55	18.407	6.20 %
3	1.593	1.514	5.21 %	19.57	18.407	6.31 %

4 Conclusion:

Aluminium-alumina metal matrix composites (AAMMC) were prepared by using stir casting method. Box-Behnken design was adopted for conducting various experimental runs by using Design Expert V.11. Further, end milling process was carried out in an automatic milling machine. surface roughness and machining time were calculated. ANOVA tables has shown surface roughness and machining time models were significant. Minimum surface roughness and machining were achieved at maximum cutting speed and feed rate but minimum depth of cut. The optimized parameter of this end milling process were cutting speed at 1750 rev/min, feed rate at 0.4 mm/rev and depth of cut at 0.2 mm respectively. The optimized value of surface roughness and machining time was1.514micron and18.406 sec respectively.

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