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Optimization of Process Parameters in turning of Hybrid Metal Matrix Composite using Response surface Methodology

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Abstract: *Metal matrix composites consisting of two or more physically/chemically distinct phases are potential material for aerospace, automobile, defense, sport and research industries. Aluminium matrix composites reinforced with ceramic materials such as SiC, TiO_2, Al_2O_3 etc is attractive material for modern industrial sectors consequent to the increasing demand for new light weight materials having greater mechanical strength. Such materials are termed as hybrid aluminium matrix composites (HAMCs). 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. The mathematical models have been proposed for modeling analysis of the effect of turning parameter on the performance through response surface methodology (RSM). A central composite design involving three process parameters i.e speed, feed and depth of cut has been employed to establish a mathematical model between the process parameters and responses.*

Keywords: *Hybrid Metal Matrix Composite, Turning, Design of Experiments, Surface roughness, Material removal rate, Response surface methodology.*

1 INTRODUCTION

Hybrid composites are developing as an improvement over previously existing conventional composites. Hybridization is a process of incorporating two or more reinforcements in order to yield better stiffness, strength, high strength to weight ratio and other mechanical properties. Hybrid composites primairly consist of one matrix and two or more reinforcement. Hybrid Composite materials are formed by reinforcing two or more materials of varying properties with matrix phase.

Hybrid composites can have engineering combination of two or more forms of reinforcement like fibers, short fibers, particulates, whiskers and nanotubes. It can have different materials as reinforcement like (SiC, Al_2O_3), (Graphite, SiC) and (Graphite, Al_2O_3), etc. Hybrid metal matrix composites shows improved mechanical properties due to reduction in meniscus penetration defect and reduced formation of inter-metallic component at interfaces because of increased interfacial area. Hybrid composites are high tech and potential materials most sought in the fields of automotive application due to its high strength, stiffness, low cost and weight. Hybrid Composites have potential to substitute single reinforced composites due to improved properties.

Aluminium hybrid metal matrix composite (Al-HMMC) is one of the advanced materials with specific and special industrial applications. One of the primary processes of manufacturing these components is by conventional machining. In modern manufacturing industries, CNC machines have been used to cut complicated shapes on these 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.

2 LITERATURE REVIEW

K.Palanikumar et al. [2009], studied the optimization of process parameter of Al356-20%SiC metal matrix composite on CNC lathe machining using poly crystalline diamond inserts for surface quality. The parameters considered for the experiments were cutting speed, feed rate and depth of cut. Response surface methodology and analysis of variance were used in order to study the effects of machining parameters. For optimizing the machining parameters desirability function based approach is used with Design Expert software.

M.Seeman et al. [2010], attempted to model the machinability evaluation through the response surface methodology in machining of 20%SiC LM25 aluminium metal matrix composite. The combined effects of four machining parameters including cutting speed, feed rate, depth of cut and machining time on the basis of two performance characteristics of tool wear and surface roughness were investigated. Cutting speed and feed rate are found to be more significant than other parameters.

T.Rajmohan et al. [2012], presented an investigation on the optimization of machining parameters with multiple performance characteristics in drilling hybrid metal matrix Al356/SiC-mica composite. The drilling parameters namely spindle speed, feed rate, drill type and mass fraction of mica were optimized based on the multiple performance characteristics including thrust force, surface roughness, tool wear and burr height. Taguchi method with grey relational analysis was used for optimization.
N. Zeelan Basha et al. [2013], have performed experiment on CNC lathe with spindle speed, feed rate and depth of cut as parameter to be varied and optimization of surface roughness is carried out. Aluminium 6061 as work piece. A Second order mathematical model was developed using regression technique and optimization was carried out using Box-Behnken of response surface methodology. It was concluded that the change in feed rate has a significant effect on surface roughness at higher spindle speed and no effect at lower spindle speed.

Senthil Kumar et al. [2014], attempted to determine the optimum machining parameters in CNC turning of Al7015/SiC-graphite hybrid metal matrix composite. The cutting parameters considered in this experimental investigation are cutting speed, feed rate and depth of cut to achieve low value of surface roughness and high material removal rate. The experiments were conducted using Taguchi L27 orthogonal array. Signal to noise ratio and analysis of variance were used to analyze the effect of cutting parameters on surface roughness and MRR. It was found that the feed rate was the most significant parameter both on surface roughness and MRR.

Ravi Sekhar et al. [2015], have done detail study in turning of metal matrix composites. Mechanisms such as particle fracture, particle pullout, debonding, dislocation phenomena, thermal softening, wear modes, surface generation, cutting forces, chip formation, strains and stresses of metal matrix composites were addressed. Metal matrix composites promise to shape the technological advancements of the 21st century and they reviewed the research revelations of the mechanisms that make these materials so superior.

3 EXPERIMENTAL DETAILS

3.1 Selection of matrix material
Literature reveals that most of the researchers are using 2000, 6000 and 7000 aluminum matrix reinforced with SiCp for high strength properties whereas,5000 series aluminum matrix has used very rarely .The density of 5000 series aluminium is very low as compared to other series and its mechanical properties are also superior for industrial use especially in welding operations. So it is decided to take AA 5083 as a base matrix.

3.2 Reinforcement selection
Many materials can be used as reinforcements with Aluminum alloys which provide strength, low thermal conductivity, very high resistance to crack propagation, high fracture toughness to the design structure. So it is decided to take Silicon Carbide (SiC) and Titanium Dioxide (TiO_2) in powdered form as reinforcement for HMMC.

3.3 Fabrication by Stir casting
Stir casting process has been used to fabricate AA 5083/SiC-TiO_2 composite.

Table 1: HMMC's Fabrication Details for AA 5083/SiC-TiO_2

AA5083/SiC-TiO_2	Weight of AA 5083	Weight of SiC	Weight of TiO_2	Melting Temp. (AA5083) (60mins)	Stirrer Speed (RPM)
SiC 10% + TiO_2 3%	900 grams	90 grams	27 grams	650°C	350

Figure 1: Cast AA5083/SiC-TiO_2

3.4 CNC turning centre : Computer numerical controlled (CNC) lathes are rapidly replacing the older production lathes due to their ease of setting, operation, repeatability and accuracy.

Figure 2: MTAB CNC Flexturn Turning Centre

3.5 Surface Roughness tester

Surface roughness tester SRT-6210 has been used to measure the value of roughness in this experimental work.

Figure 3: Surface roughness tester

3.6 Material removal rate

The material removal is expressed as the ratio of the difference of weight of the work piece before and after machining to the machining time.

$$MRR = \frac{W_b - W_a}{t}$$

Where

W_b = Weight of work piece before machining in grams.

W_a = Weight of work piece after machining in grams.

t = time for machining in minutes.

4 DESIGN OF EXPERIMENTS

4.1 Response surface methodology (RSM)

Response Surface Methodology (RSM) is a collection of statistical and mathematical techniques useful for developing, improving and optimizing processes. RSM is useful for the modeling and analysis of experiments in which a response of interest is influenced by several variables and the objective is to optimize this response. Consider a process where the response variable (output) y depends on the controllable (input) variables $x_1, x_2, \ldots, x_k$. The relationship is:

$y = f(x_1, x_2, \ldots, x_k)$

The true form of the response variable y is seldom known for a process. In RSM, the true relationship between y and the independent variables is generally approximated by the lower
Order polynomial models such as:

$$y = \beta_0 + \beta_1 x_1 + \cdots + \beta_k x_k + \varepsilon$$

$$y = \beta_0 + \sum_{i=1}^{k} \beta_i x_i + \sum_{i=1}^{k} \beta_{ii} x_i^2 + \sum_{i<j} \beta_{ij} x_i x_j + \varepsilon$$

Where ε represents the statistical error term.Here, the βs are the unknown parameters. These parameters are estimated by first collecting data on the system and then performing statistical model building by using regression analysis. Response surface designs are special types of experimental designs which are commonly used for the data collection phase. Polynomial models are generally linear functions of the unknown βs. Hence linear regression is used for the model building phase. A linear regression model may be written in matrix notation as:

$$y = X\beta + \varepsilon$$

Where

$$y = (y_1, y_2, \cdots, y_n)^T, \quad X = \begin{pmatrix} 1 & x_{11} & \cdots & x_{1k} \\ \vdots & \vdots & \ddots & \vdots \\ 1 & x_{n1} & \cdots & x_{nk} \end{pmatrix}$$

$$\beta = (\beta_0, \beta_1, \cdots, \beta_k)^T, \quad \varepsilon = (\varepsilon_0, \varepsilon_1, \cdots, \varepsilon_n)^T$$

4.2 Central composite design (CCD)

The central composite design (CCD) is the most frequently used RSM design. A CCD can be broken down into three parts:

1. Two-level full or fractional designs (the core).
2. Axial points (outside the core).
3. Center points.

The central composite design (CCD) is one of the most popular classes of designs used for a second-order model.

The actual and coded values of various input parameters that were obtained by using face centered composite design (FCCD) in RSM along with their labeling. In this process total 20 experiments are given by the software at stipulated conditions. Experimental design matrix is shown in table 2.

Table 2: Experimental design matrix

Factor	Label	Levels		
Coded Values		**-1**	**0**	**+1**
Spindle Speed (rpm)	**A**	500	1000	1500
Feed (mm/rev)	**B**	0.01	0.02	0.03
Depth of Cut (mm)	**C**	0.1	0.3	0.5

5 RESULTS AND DISCUSSION

5.1 Analysis of Surface Roughness for AA 5083/SiC-TiO_2 composite

The results for AA 5083/SiC-TiO_2 composite after experimentation are obtained from design expert. Table 3 shows ANOVA table for surface roughness.

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	33.36599	9	3.707332	26.06768	< 0.0001	Significant
A-Speed	3.785941	1	3.785941	26.62041	0.0004	
B-Feed	26.32506	1	26.32506	185.1017	< 0.0001	
C-DoC	0.010824	1	0.010824	0.076108	0.7883	
AB	0.311261	1	0.311261	2.188593	0.1698	
AC	6.05E-05	1	6.05E-05	0.000425	0.9840	
BC	0.491041	1	0.491041	3.452696	0.0928	
A^2	0.002937	1	0.002937	0.020653	0.8886	
B^2	0.664815	1	0.664815	4.674573	0.0559	
C^2	0.179776	1	0.179776	1.264077	0.2871	
Residual	1.422195	10	0.142219			
Lack of Fit	0.958831	5	0.191766	2.069286	0.2219	not significant
Pure Error	0.463363	5	0.092673			
Cor Total	34.78818	19				

Table 3: ANOVA table of AA5083/SiC-TiO2 composite for Surface Roughness

The response ranges from 3.713 μ to 8.572 μ and the ratio of maximum to minimum is 6.1425. After eliminating the non-significant terms, the final response equation for surface roughness is given as follows

Final Equation in Terms of Actual Factors for AA 5083/SiC-TiO_2 composite

SR = 7.571616 - 0.00227 * Speed - 111.035 * Feed - 6.44973 * DoC + 0.03945 * Speed * Feed - 2.7E-05 * Speed * DoC + 123.875 * Feed * DoC + 1.31E-07 * Speed^2 + 4916.818 * Feed^2 + 6.392045 * DoC^2

5.2 Analysis of Material Removal Rate for AA 5083/SiC-TiO_2 composite

The results for AA 5083/SiC-TiO_2 composite after experimentation are obtained from design expert. Table 4 shows ANOVA table for material removal rate.

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	1.632664	9	0.181407	113.4439	< 0.0001	Significant
A-Speed	0.16641	1	0.16641	104.0654	< 0.0001	
B-Feed	0.00036	1	0.00036	0.225128	0.6454	
C-DoC	0.44521	1	0.44521	278.4144	< 0.0001	
AB	0.0032	1	0.0032	2.001137	0.1876	
AC	0.0722	1	0.0722	45.15065	< 0.0001	
BC	0.06845	1	0.06845	42.80557	< 0.0001	
A^2	0.072009	1	0.072009	45.03127	< 0.0001	
B^2	0.258878	1	0.258878	161.8906	< 0.0001	
C^2	0.000184	1	0.000184	0.115122	0.7414	
Residual	0.015991	10	0.001599			
Lack of Fit	0.011241	5	0.002248	2.366507	0.1831	not significant
Pure Error	0.00475	5	0.00095			
Cor Total	1.648655	19				

Table 4: ANOVA table of AA5083/SiC-TiO_2 composite for MRR

Final Equation in Terms of Actual Factors for AA 5083/SiC-TiO_2 composite

MRR = 1.949409 - 0.0014 * Speed - 113.452 * Feed + 1.152727 * DoC + 0.004 * Speed * Feed + 0.00095 * Speed * DoC - 46.25 * Feed * DoC + 6.47E-07 * Speed^2 + 3068.182 * Feed^2 - 0.20455 * DoC^2

5.3 Multi-objective optimization

In this study, two responses have been considered, i.e. surface roughness and MRR for AA5083/SiC-TiO_2 composite. The best combination of cutting parameters during the turning operation should produce minimum surface roughness and the maximum MRR. The Two responses surface roughness and MRR have been optimized simultaneously using developed models. This has been done on the basis of composite desirability optimization technique.

Name	Goal	Lower Limit	Upper Limit	Lower Weight	Upper Weight	Importance
Speed	is in range	500	1500	1	1	3
Feed	is in range	0.01	0.03	1	1	3
DoC	is in range	0.1	0.5	1	1	3
SR	minimize	3.713	8.572	1	1	3
MRR	maximize	0.41	1.54	1	1	3

Table 5: Constraints of input parameters and responses

Cutting parameters	Multi-objective optimization values
Spindle speed(rpm)	1500 rpm
Feed (mm/rev)	0.01 mm/rev
Depth of cut (mm)	0.5 mm

Table 6: Optimal process parameter

Table 6 gives the optimal input cutting parameter setting for multi objective optimization. Optimal turning can be achieved at a Spindle speed of 1500 rpm, depth of cut of 0.5 m, and feed rate of 0.01 mm/rev.

5.4 Confirmation experiments for AA5083/SiC-TiO_2 composite

Once the optimal level of the cutting parameters is selected, the final step is to predict and verify the improvement of the performance characteristics using the optimal level of the cutting parameters. Conformation Experiments have been carried out. The final values of surface roughness and MRR are 1.54µ and 3.713gm respectively. These values are compared with optimal response values. The percentage of error for optimum experimental and validation values is shown in table 7.

Responses	Predicted	Actual	Error(%)
MRR (gm)	1.46735	1.54	4.95
Surface roughness(µ)	3.531	3.713	5.15

Table 7: Error percentage

6 CONCLUSIONS

The Hybrid MMC have been fabricated by stir casting process. The following conclusion can be drawn based on the experimental work conducted.

1. A Hybrid metal Matrix Composite with AA 5083 with 10% SiC and 3% TiO_2 have been successfully fabricated using the stir casting method.
2. The effect of input parameters i.e. Spindle speed, Feed, Depth of cut on Surface roughness and Material Removal Rate has been investigated.
3. The analysis of variance revealed that the factor Spindle speed, feed and depth of cut are most influential parameters on MRR and SR.
4. The most optimal process parameter settings are spindle speed of 1500 rpm, feed of 0.01 mm/rev and depth of cut of 0.5 mm.
5. The error between experimental and predicted for MRR and SR lie with 4.95% and 5.15 % respectively. Obviously, this confirms excellent reproducibility of the experimental conclusion.

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