Indian J.Sci.Res. 17(2): 82-86, 2017 ISSN: 0976-2876 (Print)
ISSN: 2250-0138(Online)

APPLICATION OF BOX-BEHNKEN DESIGN FOR OPTIMIZATION OFDRILLING PARAMETERS OF ALUMINIUM METAL MATRIX COMPOSITES

[1]Ajith Arul Daniel S, [2]Sakthivel M, [3]Sudhagar S
[1,2,3]Department of Mechanical Engineering, Anna University Regional Campus Coimbatore

Abstract - Aluminium matrix composites are used for a wide range of applications such as automobile, aerospace, and marine industries. Because of the abrasive reinforcements present in it, Aluminium matrix composites were joined to the group of difficult to machine metals. In this study, response surface methodology (RSM) and Box-Behnken design (BBD) are applied for modelling, optimization, and an analysis of the effect of important machining parameters on thrust force and surface roughness in the drilling of aluminium metal matrix composites produced through stir casting method. Experiments are carried out using Al 6061-aluminum alloy reinforced with fly ash of varying percentage. Drilling test is carried out using carbide drill of 10 mm diameter on a vertical machining center. The design of experiment concept has been used to optimize the experimental conditions. Three factor three level Box-Behnken experimental design is used to provide data for modelling and the variables of model are spindle speed, feed rate and percentage of reinforcement. The multiple regression analysis using RSM is used for establishing an input-output relationship of the process. The developed mathematical models are tested using analysis of variance. The effect of drilling parameters on thrust force and surface roughness are evaluated and optimum drilling condition is determined by using desirability function method. The optimized drilling process parameters have been obtained are feed rate of 50 mm/min, spindle speed of 2997 rpm, and 5.46 % of fly ash, which could result in minimum thrust force of 975.68 N and surface roughness of 1.87µm.

Keywords - Drilling, Fly ash, Aluminium alloy, Box-Behnken design,RSM

I. Introduction

Aluminium based metal matrix composites has been widely used as a substitute material in

automobile, aerospace and defence applications because of their high strength to weight ratio and wear resistance[1]. Aluminium is the most commonly used material for making metal matrix

composites. Aluminium alloys are quite attractive because of their low density, good corrosion resistance and high thermal and electrical conductivities. Aluminium alloys are usually reinforced by Al_2O_3, SiC, B_4C and BN. The addition of reinforcing elements increases the mechanical properties of the composites [2]. Dunia [3] found that there is an increase in hardness of the composite material with the increase in the weight percentage of reinforcements. Nowadays consumer products such as bicycle frames and tennis racquets are also made with metal matrix composites.

Fly ash is an industrial waste obtained as a bi-product of combustion of coal. Its constituents are SiO_2, Al_2O_3 and Fe_2O_3 , with varying amounts of carbon, magnesium, calcium and sulfur. Hari and Ahmed observed that the contents of the fly ash vary with the sources from which it is obtained [4]. Also fly ash behaves like abrasives such as Al_2O_3, SiC, B_4C etc. It is found that the hardness of the composite materials increases with the increase in weight percentage of fly ash.

Pillai& Geetha [5] observed that the separation of fly ash particle and dispersion are more effective in stir casting method than in all other processes due to the shearing of fly ash particles. Distribution of fly ash particles in the centre portion of the casting reveals a uniform one. There is a good interfacial bonding between the matrix and fly ash particles. Hashim et al [6] studied Metal matrix composite has been relatively high cost due to their expensive processing techniques. Here low cost stir casting technique is evaluated for use.

Drilling is an important secondary operation which is affected by various factors such as feed, speed, tool material and workpiece material [7]. Because of the abrasive reinforcement particles the machining properties such as tool wear, drilling force and burr formation of the metal matrix composites are poor. So it is mandatory to optimize drilling parameters.

Drilling experiments carried out on graphite / bismaleimide (Gr/Bi) titanium (Ti) stacks shows that thrust force and feed rate have an effect on damage distance and exit burr height [8]. Three different tools, namely high-speed steel (HSS), high- speed cobalt (HSS-Co), and carbide tools are used and it is found that carbide tools, produced the smallest cutting force magnitudes, the smallest burrs and the best quality of hole.

Drilling experiment are conducted on two composite materials Al 2219 / 15 SiCp and Al 2219 / 15 SiCp - 3Gr

[1]Corresponding Author

to study the effect of spindle speed and feed rate on thrust force, surface finish and burr height using solid carbide multi facet drills of 5 mm diameter[9]. The Taguchi design of experiments and analysis of variance is applied to analyze the drilling characteristics of these composites.Taguchi full factorial L27 orthogonal array is used for the drilling experiments on A356/20/SiCp metal matrix composites[10]. Basavarajappa et al [11] conducted drilling experiment on two composite materials Al 2219 / 15 SiCp and Al 2219 / 15 SiCp - 3Gr to study the effect of spindle speed , feed rate on thrust force, surface finish and burr height using solid carbide multi facet drills of 5 mm diameter. The Taguchi design of experiments and analysis of variance is applied to analyze the drilling characteristics of these composites. The result shows that the dependent variables are greatly influenced by feed rate rather than spindle speed.It is found that the feed rate is the main factor influencing surface finish and thrust force. Central composite design is used for the study of drilling characteristics of Al356/ 5SiC-3 mica, Al356/ $10SiC_3$ mica and Al356/ 15SiC-3 mica with varying spindle speed and feed rate using a 6 mm diameter uncoated carbide drill [12].

Box-Behnken is an important design of experimental method in analytical chemistry [13]. Box-Behnken design was used for optimization of the sorption process of verofix red using a biopolymer [14]. Box-Behnken design can be applied to the manufacturing engineering field for optimizing machining Parameters [15].

The review of literatures, which has been presented above, provides the scope for the researchers to study the multiple performance optimizations of machining parameters on the thrust force and surface roughness in the drilling of hybrid Al 6061/ fly ash composites. From the previous work available for the machining of composites, adequate investigations have not been carried out to study the effect of cutting parameters on responses during machining of aluminium metal matrix composites simultaneously.

The present work deals with the optimization of parameters in the drilling of aluminium metal matrix composites (Al 6061 + Fly ash) by solid carbide drill considering surface roughness and thrust force. Multiple performance optimizations of these responses are carried out using desirability analysis. The experiments are conducted using Box-Behnken design (BBD). The study presents the results of a detailed experimental investigation to determine the effect of the cutting parameters in the drilling of metal matrix composites.

II. Experimental Details

A. Materials used

Aluminum alloy Al 6061 is used as a matrix material. Fly ash is used as the reinforcement material. The composites are fabricated with 3–9 wt% of the fly ash in steps of the 3 wt%.

The composites are fabricated by stir casting method as it ensures uniform distribution of the reinforcements [16].The Al 6061 alloy, which is in the form of rod, has been cut into small pieces to accommodate into the Silica Crucible. Al 6061 is at first melted in an electric furnace. Next, fly ash preheated to a temperature of about 300° C to remove moisture, are added to the molten metal at 700 ° C and stirred continuously. Then Magnesium is added in small amounts during stirring to increase the wetting. Finally, the melt was casted in a permanent die.

B. Experimental design

The experiments are conducted based on the Box-Behnken design in the Experimental Design Scheme. From the literature and the previous work done by the authors in the field, the most important drilling parameters, which influences the drilling process is identified and are spindle

speed, feed rate and percentage of fly ash.

Three level experiments are conducted based on Box-Behnken experimental design. The factors considered to be spindle speed, feed rate and percentage of fly ash. The factors and their levels

are shown in the table 1.

Table 1

Machining parameter and level

		Level		
Control parameters	Unit	-1	0	1
Spindle speed	Rpm	1000	2000	3000
Feed rate	Mm/min	50	100	150
Wt of fly ash	%	3	6	9

Numerical optimization technique has been used to optimize the machining parameters. Analysis of variance (ANOVA) is used to evaluate the significance of input parameters. Design-Expert 9.0 statistical software is used to establish the design matrix, to analyse the experimental data and to fit the experiential data to a second-order polynomial. Sequential F test, lack-of-fit test, and other adequacy measures are used to check the model"s performance.

C. Experimental procedure

The drilling experiments are carried out in the Computer Numerical Control (CNC) Vertical Machining Centre (BMV 40 T 20) manufactured by Bharat Fritz Werner Limited (BFW). The experimental setup is shown in the Fig.2 . The machining samples are prepared in the form of 100 mm x 50 mm x 10 mm blocks for each material. The drilling test has been conducted for a depth of 10 mm (through hole) and it is the machining length for each trial. Solid carbide drill bit of diameter 10 mm point angle of 118 and a helix angle of 30.The Kistler dynamometer (Type 9129A) with Kistler charge amplifier Type 5070A and DynoWare software Type 2825D1-2 v2.63 is used to record the thrust force in the drilling of aluminium metal matrix composites. The dynamometer is connected to a 4-channel charge amplifier type through a connecting cable, which in turn is connected to the PC by a 37-pin cable from the A/D board.

III. Box-Behnken experimental design

Box-Behnken design is the one of the commonly used experimental design methods in response surface methodology (RSM). BBD is a class of rotatable or nearly rotatable second-order design based on three-level incomplete factorial designs. RSM uses linear or no-linear regression equations to represent the response functions in terms of independent variables. Response surface methodology consists of a group of statistical and mathematical techniques used in the development of an adequate functional relationship between a response of interest „y" and a number of associated control variables denoted by, [17].

In the present work, Mathematical models have been developed for performances, namely thrust force and surface roughness using RSM. A Three-level second-order Box-Behnken design has been adapted to study linear, quadratic, and two-factor (2FI) interaction effects. In the present study, three parameters, namely, spindle speed, feed rate and wt% fly ash are identified and the ranges of the parameters are selected based on the preliminary experiments. Table 2 shows 15 sets of coded conditions used to form the design matrix of Box-Behnken design. In BBD, for a three factorial experiment the lower, middle and upper values are notated by1, 0, and -1 respectively.

Table 2Box-Benkhen design matrix, with coded and actual variables

		Actual variables		
Exp. no	Run order	Spindle speed, rpm	Feed rate, mm/min	Wt of Fly ash, %
1	11	1000	50	6
2	4	3000	50	6
3	15	1000	150	6
4	3	3000	150	6
5	5	1000	100	3
6	9	3000	100	3
7	12	1000	100	9
8	2	3000	100	9
9	13	2000	50	3
10	6	2000	150	3
11	14	2000	50	9
12	1	2000	150	9
13	8	2000	100	6
14	10	2000	100	6
15	7	2000	100	6

IV. Optimization Results and discussion

The results of the machining parameters are measured according to the Box-Behnken design matrix of 15 experiments with coded and actual independent process variables. The measured responses are listed in Table 3. The measured responses are analyzed by the Design Expert 9.0 software and the fit summary output suggests the quadratic model for further analysis.

Table 3 Experimental Results

Exp. No.	Run order	Surface Roughness (μm)
1	11	2.9
2	4	1.8
3	15	7.3
4	3	3.69
5	5	8.1
6	9	2.77
7	12	2.41
8	2	4.8
9	13	2.3
10	6	4.05
11	14	2.16
12	1	3.86
13	11	2.65
14	4	2.68
15	15	2.75

A. Analysis of variance

Analysis of variance (ANOVA) essentially consists of partitioning the total variation in an experiment into components ascribable to the controlled factors and error. The adequacies of the developed models are tested at 95% confidence interval using ANOVA technique and were shown in the Table 4 and 5. Lack of fit test, test for significance of regression equation and the test for significance of individual model coefficients are performed using the same software Design Expert 9.

ANOVA for thrust force shows the Model F-value is 5.30, implies that the model is significant. The values of "Prob>F" less than 0.0500 indicates model terms are significant. In this case A (Spindle speed), B (Feed rate), C (Wt of Fly ash) are significant model terms. The "Lack of Fit F-value" is 6.02, which implies the lack of fit is not significant. Not significant lack of fit is good. The Model F-value of 10.39 for surface roughness implies that the model is significant. In this case A B, C, AC and A^2 are significant model terms. From the above analysis, it is clear that the developed models are well within the limits and can be used for the prediction of response.

Table 4ANOVA for surface roughness

Source	Sum of Squares	df	Mean square	F value	P value Prob>F
Model	26.53	9	2.95	10.39	0.0095
A-Spindle speed					
(rpm)	2.94	1	2.94	10.37	0.0235
B-Feed rate (mm/min)	9.33	1	9.33	32.90	0.0023
C-Wt of Fly ash (rpm)	0.66	1	0.66	2.31	0.0356
AB	0.50	1	0.50	1.75	0.0828
AC	9.06	1	9.06	31.95	0.0024
BC	6.250E-004	1	6.250 E-004	2.20E-003	0.0738
A^2	3.53	1	3.53	12.46	0.0167
B^2	2.156E-003	1	2.156 E-003	7.60E-003	0.0938
C^2	0.66	1	0.66	2.33	0.1253
Residual	1.42	5	0.28		
:Lack of fit	1.41	3	0.47	178.82	0.0056
Pure error	5.267E-003	2	2.63E-003		
Cor total	27.94	14			

V. Conclusion

In this paper, mathematical models based on response surface methodology are developed using Box-Behnken design. For developing the model three input factors such as spindle speed, feed rate and wt% of fly ash and responses such as thrust force and spindle speed are considered. ANOVA techniques are used to test the developed RSM model. The following conclusions were drawn after conducting the experiments and analyzing the resulting data:

- BBD can be used for developing a mathematical model for predicting thrust force and surface roughness.
- ANOVA clearly shows that the main factor affecting the thrust force and surface roughness is feed rate, followed by spindle speed and reinforcement.
- The optimal combinations of process parameters for minimizing thrust force and surface roughness are spindle speed of 2997 rpm, feed rate of 50 mm/min and 5.46 % of reinforcement, which could result in minimum thrust force of 975.68 N and surface roughness of 1.87µm.
- The Built Up Edge formation on drill is observed and this may be affect the response of the experiment.
- The burr formation around the drill indicates the burr height also an important response parameter.

References

[1] R. Prasad, R. Asthna, "Aluminium metal matrix composites for automotive applications: Tribologicalconsiderations", Tribol. Lett, vol 17(3), pp. 445-453, 2006.

[2] K.K. Chowla, ", Composite Materials: Science and Engineering",Springer.

[3] D. A. Saheb, "Aluminium SiC and alumina

graphite particulate composite", ARPN journal of engineering and applied scince.

[4] M. Hrairi, M. Ahmed, Y. Nimir, "Compaction of fly ash–aluminum alloy composites and evaluation of their mechanical and acoustic properties", Advanced Powder Technology, Vol. 20(6), pp. 548-553, 2009.

[5] Pillai, R.M., GeethaRamani,Characterization of Stir Cast Al–12Si-X fly ash Composite ,Aluminum in India, 2006, 5 (4), pp: 15 -24

[6] Hashim J, Looney L, Hashmi M.S.J 1999 „Metal Matrix Composites: Production by the Stir casting method‟, Material Processing Technology, Vol.92, pp. 1 – 7.

[7] Davim, J. Paulo, " Study of drilling metal matrix composites based on the Taguchi techniques", Material processing technology, vol. 132, pp. 250-254, 2003.

[8] M. Ramulu,M.P. Raob,H. Kao, "Drilling of (Al2O3)p/6061 metal matrix composites", Journal of Materials Processing Technology,2002.

[9] S. Basavarajappa, G. Chandramohan, J.P Davim, "Some studies on drilling of hybrid metal matrix composites based on Taguchi techniques",Journal of material processing technology, vol. 196, pp. 332-338,2008.

[10] J.P. Davim, J. Silva, A.M. Baptista, "Experimental cutting model of metal matrix composites", Journal of Materials Processing Technology, Vol. 183, Issues 2–3,pp. 358-362,2007.

[11] Basavarajappa, J, Chandramohan, G.& Paulo 2008, DJ „Some studies on drilling of hybrid metal matrix composites based on Taguchi techniques‟,Journal of Material processing technology.

[12] T. Rajmohan, K. Palanikumar, "Application of central composite design in optimization of machining parameters in drilling hybrid metal matrix composites", Measurements, vol. 46, pp. 1470-1480, 2013.

[13] Toh K. and Isa N. (2010), „Noise adaptive fuzzy switching median filter for salt-and-pepper noise reduction‟ IEEE Signal Processing Letters, Vol. 17, No. 3, pp. 281–284.

[14] G. Annadurai, R. Y. Sheeja, Bioprocess Engineering, vol. 18, pp. 463-469, 2000.

[15] L. Gu, L. Li, W. Zhao, K.P. Rajurkar, "Electrical discharge machining of Ti6Al4V with a bundled electrode", International Journal of Machine Tools and Manufacture, Vol. 53, Issue 1, pp. 100-106, 2012.

[16] T. Rajmohan. K. Palanikumar, Optimization of machining parameters for surface roughness and burr height in drilling hybrid composites, J. Mater. Manuf. Process

[17] A.I. Khuri, S. Mukhopadhyay, Response surface methodology, WIREs Comput. Stat. 2 (2010) 128–14.

[19] K. Palanikumar, "Application of Taguchi and response surface methodologies for surface roughness in machining glass fiber reinforced plastics by PCD tooling", Int. J. Adv. Manuf. Technol. 36 (1) (2008) 19–27.