Yashvir Singh*, Amneesh Singla and Ajay Kumar

Statistical Analysis of Process Parameters in Drilling of Al/Al_2O_{3p} Metal Matrix Composites

Abstract: This paper presents a statistical analysis of process parameters for surface roughness in drilling of Al/Al_2O_3p metal matrix composite. The experimental studies were conducted under varying spindle speed, feed rate, point angle of drill. The settings of drilling parameters were determined by using Taguchi experimental design method. The level of importance of the drilling parameters is determined by using analysis of variance. The optimum drilling parameter combination was obtained by using the analysis of signal-to-noise ratio. Through statistical analysis of response variables and signal-to-noise ratios, the determined significant factors are depth of cut and drill point angle with the contributions of 87% and 12% respectively, whereas the cutting speed is insignificant contributing by 1% only. Confirmation tests verified that the selected optimal combination of process parameter through Taguchi design was able to achieve desired surface roughness.

Keywords: drilling, Al-Al_2O_3 MMC, Taguchi method, surface finish, tool wear, material removal rate, regression analysis, S/N ratio, ANOVA

DOI 10.1515/jmsp-2014-0012
Received March 31, 2014; accepted September 20, 2014.

1 Introduction

Metal matrix composites (MMC) are materials which combine tough metallic matrix as a binder and a hard ceramic as reinforcement with superior properties like high strength to wear ratio, high modulus, superior wear resistance and corrosion resistance. Metal matrix composites are widely used in various fields like aerospace, automotive, electronics and metallic industries and are very difficult to machine material due to the presence of hard ceramic particle [1–5]. Amongst traditional machining processes, drilling is one of the most important metal cutting operations. Although modern metal cutting methods have tremendously improved in the manufacturing industry, conventional drilling process still remains one of the most common processes [7]. The large part of money spent on any one class of cutting tools is spent on drills. Therefore, from the viewpoint of cost and productivity, modeling and optimization of drilling processes are at most important for the manufacturing industry [6]. Most of the researches on the machining of Al/SiC MMC have focused on turning and facing while drilling has received less attention. Davim [1] investigated the study of drilling metal matrix composites of type A356/20% SiC-T6 based on the Taguchi technique with the objective of establishing the correlations between cutting velocity, feed rate and cutting time with the evaluation of tool wear, the specific cutting pressure and the hole surface roughness using PCD drill. Tosun et al. [2, 3] investigated the effect of the various cutting parameters on the surface quality and microstructure on drilling of Al/17% SiC particulate MMC by using various drills. They have suggested that TiN coated HSS drills can be used for drilling Al/SiC-MMC rather than solid carbide tools. Davim [3] presented a study on the influence of cutting parameters such as cutting velocity, feed rate, cutting time on drilling metal – matrix composites and concluded that interaction of cutting speed/feed is the most important factor contributing towards surface roughness of drilled holes. Tsao [8] performed an experimental work with an objective to establish a correlation between feed rate, spindle speed and drill diameter with the induced delamination in a CFRP laminate. Mohan et al. [9] used taguchi method to study the influence of process parameters such as speed, feed rate, and drill size, specimen thickness on cutting force and torque during drilling of glass fiber polyester reinforced composites. Basavarajappa et al. [10] discussed the influence of speed and feed on drilling of hybrid metal matrix composites based on taguchi techniques. Mustafa et al. [12] performed an experimental investigation in the optimization of cutting parameters for surface roughness

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in dry drilling process using taguchi method. Haq et al. [13] used Taguchi method for Multi response optimization of machining parameters of drilling Al/SiC metal matrix composite using grey relational analysis. The objective of taguchi robust design is to determine the optimal parameter settings and making the process performance insensitive to various sources of variations. Taguchi technique allows the process optimization with minimum number of experiments without need for process model development. Thus, by this method, it is possible to reduce the time and cost for experimental investigations.

It is observed from literature survey that there exists a need to study on the effects of various parameters on drilling of Al-Al_2O_3 MMC since number of works are reported on drilling of laminates, tool steel, Al-Sic composite materials, and very rarely on drilling of Al-Al_2O_3 MMC. In the present work, Taguchi method of parameter design has been employed for optimizing surface roughness, for drilling of Al-Al_2O_3 MMC.

2 Experimental works

In this study, aluminum reinforced with Al_2O_3 of particle of size 25 μm with 10% volume fractions manufactured through stir casting process is used as MMC for experimental work. The drilling tests are performed on radial drilling machine under dry condition. In order to perform the experiments, the metal matrix composite is cut into block of 100 × 40 × 20 mm. In order to get flat surface block was faced in a lathe. The standard HSS twist drills of 10 mm diameter with various cutting point angles (99, 119 and 139 degrees), coated by TiN are used in this experimental work.

2.1 Plan of experiment

Three factors and three levels considered in this study are mentioned in Table 1. The experiments are performed using L_9 orthogonal array in order to reduce time and cost. The response values obtained are shown in Table 2. Regression analysis is employed to analyze the effect of the drilling parameters on surface roughness. The settings of drilling parameters were determined by using taguchi design method on the basis of L_9 orthogonal array.

Table 1: Process parameter and their levels

Parameter	Level 1	Level 2	Level 3
Speed	184	465	746
DOC	15	20	25
Angle	99	119	139

Table 2: L_9 orthogonal array and the desired parameter values

Serial no.	Speed (rpm)	DOC (mm)	Angle (θ)	Ra (μm)
1	184	15	99	2.233
2	184	20	119	3.003
3	184	25	139	3.454
4	465	15	119	2.321
5	465	20	139	3.080
6	465	25	99	3.340
7	746	15	139	2.780
8	746	20	99	2.531
9	746	25	119	3.790

3 Design and analysis of cutting parameters

The results of the experiments were studied using the S/N ratio and ANOVA analyses. Based on the results of the S/N ratio and ANOVA analyses, optimal cutting parameters for surface roughness were obtained.

3.1 Analysis of the signal-to-noise (S/N) ratio

In the Taguchi approach, the term 'signal' represents the desired value (mean) for the output characteristics and the term 'noise' represents the undesirable value (S.D) for the output characteristics. Therefore, the S/N ratio is the ratio of the mean to the S.D. Taguchi used the S/N ratio to measure the quality characteristics deriving from the desired value [11]. The S/N ratio η is defined as given in Eq. (1).

$$\eta = -10 \times \log_{10}(\mathrm{MSD}) \quad (1)$$

Smaller-the-better

It is used when the occurrences of some undesirable product characteristics is to be minimized. It is given by Eq. (2).

$$\eta = -10 \times \log_{10}\left[\frac{\sum y_i^2}{N}\right] \quad (2)$$

Here, η is the resultant S/N ratio, N is the number of observations on the particular product, and y is the surface roughness. The factor 10 ensures that this ratio measures

Table 3: S/N response table for surface roughness mean S/N ratio (dB)

Symbol	Cutting parameters	Level 1	Level 2	Level 3	Max. Min.
A	Speed	2.89	2.91	3.03	0.13
B	Depth of cut	2.44	2.87	3.52	1.08
C	Angle	2.70	3.03	3.10	0.40

the inverse of bad quality; the more flaws in the paint, the greater is the sum of the sum of squared number of flaws, and the smaller (i.e., more negative) the S/N ratio. Thus, maximizing this ratio will increase quality. It is better suitable for quantity like surface roughness [11]. Table 3 shows the drilling parameter considered, its symbol and its level.

3.2 Analysis of the variance

Analysis of variance (ANOVA) is done to determine the parameter which is most affecting the result of experiments i.e. which parameter significantly affects the surface roughness. This is achieved by separating total variability of the S/N ratio, which is measured by the sum of squared deviation (SS_T) from total mean S/N ratio into contribution by each design parameters and the error [11].

First the total sum of squares (SS_T) is calculated by using Eq. (3).

$$SS_T = \sum_{i=1}^{n} (n_i - m)^2 \tag{3}$$

where n is the number of experiments in the orthogonal array and n_i is the mean S/N ratio for the i-th experiments.

The SS_j and SS_e are calculated using Eqs. (4) and (5).

$$SS_j = \sum_{j=1}^{l} (n_j - m)^2 \tag{4}$$

$$SS_T = \sum_{j=1}^{n_p} SS_j + SS_e \tag{5}$$

Total sum of squares (SS_T) is decomposed into two sources: the sum of squared deviation SS_j due to each design parameters, and sum of squared error SS_e. Percentage contribution (p_j) and F-value of each of the parameter are calculated using Eq. (6).

$$p_j = \frac{SS_j}{SS_e} \tag{6}$$

$$F_j = \frac{MS_j}{MS_e} \tag{7}$$

F-test is used to identify the parameter that has significant effect on quality characteristic. The F-value of each design parameter is a ratio of mean squared deviations to the mean squared error. If the value of F is more than 4, then it means change of design parameters has a significant effect on quality characteristics.

From ANOVA table for surface roughness, it is observed that depth of cut and drill point angle are the significant parameters for affecting the surface roughness. The optimal cutting parameters for surface roughness are: cutting speed at level 3, depth of cut at level 3 and drill point angle 3.

4 Result and discussion

4.1 Main effects plots

Figures 1 and 2 display the main effect plots for surface roughness. It can be seen that the speed, depth of cut and drill point angle are significant parameters affecting

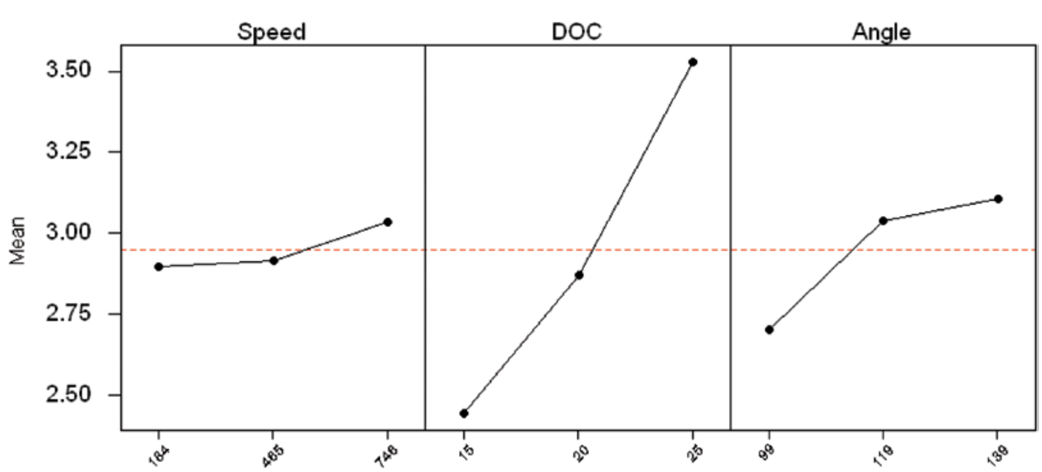

Fig. 1: Effect of process parameter on surface roughness

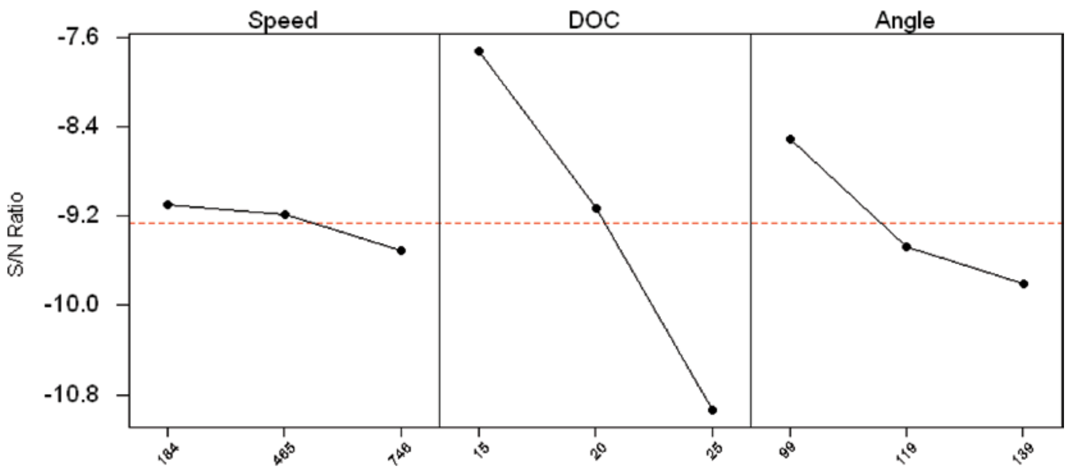

Fig. 2: Effect of signal-to-noise ratio on surface roughness

surface roughness. It has been observed that surface roughness increases with increase in speed. This is due to fact that at higher cutting speeds, cutting forces and tendency towards built-up edge formation weakens due to increase in temperature and consequent decrease of frictional stress at the rake. The surface roughness increases with increase in the depth of cut. This is because the height of the peaks and the depth of the valleys are proportional to the depth of cut. The surface roughness has been found to be increased with increasing the drill point angle reaches maximum value then decreases.

4.2 Modeling of surface roughness

The cutting speed, depth of cut and drill point angle are considered in the development of mathematical models for surface roughness. Model has been obtained by analyzing the data presented in Table 2 and is given below as Eq. (8). The correlations between the considered drilling parameters for drilling conditions on Al-Al_2O_3 are obtained by linear regression. The linear polynomial models are developed using commercially available Minitab 13 software for various drilling parameters. The improved model after neglecting the terms, which have insignificant effect on the surfaces roughness, is obtained as

$$\begin{aligned} \text{Ra} = &-0.532 + 0.000244\ \text{speed} \\ &+ 0.108\ \text{DOC} + 0.0101\ \text{angle} \end{aligned} \tag{8}$$

ANOVA for the response surface given by Eq. (8) is presented in Table 4. It is clear from the F-test that the model is adequate at 99% confidence level as the F-value of model is higher than the tabulated F-value. Figure 3 shows

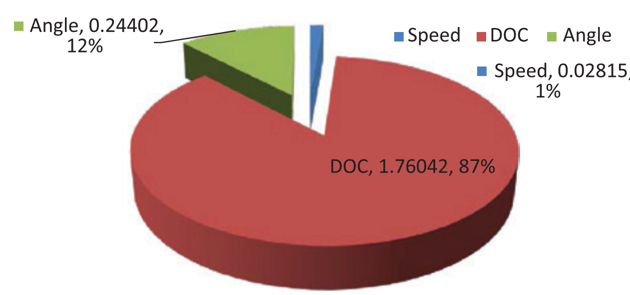

Fig. 3: Percentage contributions of factors

Table 4: Results of the analysis of variance for surface roughness

Symbol	Cutting parameter	DOF	Sum of squares	Mean square	F	P	Contribution (%)
A	Speed	2	0.03346	0.01673	0.23	0.81	1
B	Depth of cut	2	1.78687	0.89343	12.3	0.07	87
C	Angle	2	0.28047	0.14023	1.94	0.34	12
Error		2	0.14479	0.07239			
Total		8	2.24558				

the percentage contribution of various factors. The two significant main effects of factors affecting the surface roughness are depth of cut and drill point angle with the contributions of 87% and 12% respectively, whereas the cutting speed is insignificant contributing by 1% only.

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