Modeling and optimization of burr height in drilling of Al-Fly ash composite using Taguchi method

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Abstract: -

This investigation presents the use of Taguchi method for minimizing the burr height in drilling of Al- Fly ash composite. The Taguchi method, a powerful tool to design optimization for quality, is used to find optimal cutting parameters. The methodology is useful for modeling and analyzing engineering problems. The purpose of this study is to investigate the influence of cutting parameters, such as cutting speed and feed rate, and point angle on burr height produced when drilling of Al-Fly ash composite. A plan of experiments, based on L_{27}Taguchi design method, was performed drilling with cutting parameters in Al-Fly ash composite. All tests were run without coolant at cutting speeds of 20, 40, and 60 m/min and feed rates of 0.035, 0.07, and 0.14 mm/rev and point angle of 80°, 100°, and 135°. The orthogonal array, signal-to-noise ratio, and analysis of variance (ANOVA) were employed to investigate the optimal drilling parameters of Al-Fly ash composite. From the analysis of means and ANOVA, the optimal combination levels and the significant drilling parameters on burr height were obtained. The optimization results showed that the combination of low cutting speed, medium feed rate, and low point angle is necessary to minimize burr height. The predicted values and measured values are quite close to each other; therefore, this result indicates that the developed models can be effectively used to predict the burr height on drilling of Al-Fly ash composite.

Keywords: Taguchi method, Drilling. Mathematical modeling equations. Burr formation.

1. Introduction: A composite material is a heterogeneous solid consists of two or more different materials that are mechanically or metallurgically bonded together. Each of its components retains its identity in the composite and maintains its characteristic structure and property. The composite material, however generally possesses characteristics properties, such as stiffness, strength, high temperature performance, corrosion resistance, hardness or conductivity that are not possible with the individual components by them. Analysis of these properties shows that they depend on (1) the property of individual components;(2) the relative amount of components;(3) the size, shape and distribution of the discontinuous components;(4) the degree of bonding between them; and (5) the orientation of the various components [1]. In general all composites having two phase, the reinforcing and matrix phases.

Fly ash-reinforced MMCs is a type of MMCs in which a metal alloy is the matrix and fly ash the particulate reinforcement. Fly ash has recently been combined with aluminium alloys to produce a class of MMCs called fly ash-reinforced aluminium MMCs or Ash alloys [2]. The use of fly ash in aluminium MMCs offer the advantages of reducing its disposal volumes for the electric utility industry, while providing a high value- added use of fly ash. They also provide improved material properties at a reduced cost. Since the production of aluminium is energy-intensive, the replacement of part of aluminium by fly ash promises significant energy savings [3].

The Investigation presents the use of Taguchi method for minimizing the burr height in drilling Al-Fly ash composite. Al-fly ash composite is extensively used as a main engineering material in various industries such as aircraft, aerospace, and automotive industries where weight is probably the most important factor. These materials are considered as easy to machining and possess superior machinability [4] .Drilling is one of the most commonly used machining processes in the shaping of Al-Fly ash composite. It has considerable economical importance because it is usually among the finishing steps in the fabrication of industrial mechanical parts. The drilling process produces burrs on exit surface of a work piece. The exit burr is the material extending off the exit surface of the work piece [5] .Their effect on products is important because they may cause some critical problems such as the deterioration of surface quality, thus reducing the product durability and precision .Burr formation affects work piece accuracy and quality in several ways: dimensional distortion on part edge, challenges to assembly and handling caused by burrs in sensitive locations on the work piece, and damage done to the work subsurface from the deformation associated with burr formation [6-8].

Nihat Tosun[9] Use The grey relational analysis for optimizing the drilling process parameters for the workpiece surface roughness and the burr height is introduced. Various drilling parameters, such as feed rate, cutting speed, drill and point angles of drill were considered. An orthogonal array was used for the experimental design. Optimal machining parameters were determined by the grey relational grade obtained from the grey relational analysis for multi-performance characteristics (the surface roughness and the burr height). Experimental results have shown that the surface roughness and the burr height in the drilling process can be improved effectively through the new approach.

Stein and Dornfeld [10] presented a study on the burr height, thickness, and geometry observed in the drilling of 0.91-mm diameter through holes in stainless steel 304L. They presented a proposal for using the drilling burr data as part of a process planning methodology for burr control. To minimize the burr formed during drilling, Ko and Lee [11] investigated the effect of drill geometry on burr formation. They showed that a larger point angle of drill reduced the burr size. Sakurai et al. [12] have also tried to change the cutting conditions and determined high feed rate drilling of aluminum alloy. The researchers examined cutting forces, drill wear, heat generated, chip shape, hole finish, etc. Gillespie and Blotter [13] studied experimentally the effects of drill geometry, process conditions, and material properties. They have classified the machining burrs into four types: Poisson burr, rollover burr, tear burr, and cut-off burr. Valuable review about burr in machining operation provided important information [14].Erol Kilickap [15] Modeling and optimization of burr height in drilling of Al-7075 using Taguchi method and response surface methodology. This investigation presents the use of Taguchi and response surface methodologies for minimizing the burr height and the surface roughness in drilling Al-7075. The optimization results showed that the combination of low cutting speed,
low feed rate, and high point angle is necessary to minimize the burr height

The study shows that the Taguchi method is suitable to solve the stated within minimum number of trials as compared with a full factorial design.
The main objective of this study was to demonstrate a systematic procedure of using Taguchi design method in process control of drilling process and to find a combination of drilling parameters to achieve low burr height and surface roughness.
Experiments were designed using Taguchi method so that effect of all the parameters could be studied with minimum possible number of experiments. Using Taguchi method, Appropriate Orthogonal Array has been chosen and experiments have been performed as per the set of experiments designed in the orthogonal array. Signal to Noise ratios are also calculated to analyze the effect of parameters more accurately.

Results of the experimentation were analyzed analytically as well as graphically using ANOVA. ANOVA has determined the percentage contribution of all factors upon each response individually.

2. Taguchi method

Traditional experimental design methods are very complicated and difficult to use. Additionally, these methods require a large number of experiments when the number of process parameters increases [16]. In order to minimize the number of tests required, Taguchi experimental design method, a powerful tool for designing high-quality system, was developed by Taguchi. This method uses a special design of orthogonal arrays to study the entire parameter space with small number of experiments only.

Taguchi recommends analyzing the mean response for each run in the inner array, and he also suggests analyzing variation using an appropriately chosen signal-to-noise ratio (S/N).

There are 3 Signal-to-Noise ratios of common interest for optimization of Static Problems;

(I) SMALLER-THE-BETTER:

$$n = -10 \text{ Log } \left(\frac{1}{n}\sum_{i=0}^{n}\frac{1}{\text{y2}}\right)$$

(II) LARGER-THE-BETTER:

$$n = -10\ Log_{10}\ [\text{mean of sum squares of reciprocal of measured data}]$$

(III) NOMINAL-THE-BEST:

$$n = 10\ Log_{10}\ \frac{\text{Square of means}}{\text{variance}}$$

Lower is better for minimum burr height and surface roughness so,

Lower is better = $\frac{S}{N}$ = -10 Log.$(\frac{1}{n}\sum_{i=0}^{n}\frac{1}{y2})$

Where n is no of observation, y is observed data.

Regardless of category of the performance characteristics, the lower S/N ratio corresponds to a better performance. Therefore, the optimal level of the process parameters is the level with the lowest S/N value. The statistical analysis of the data was performed by analysis of variance (ANOVA) to study the contribution of the factor and interactions and to explore the effects of each process on the observed value.

3. Design of experiment

In this study, three machining parameters were selected as control factors, and each parameter was designed to have three levels, denoted 1, 2, and 3 (Table 1). The experimental design was according to an L27(3^13) array based on Taguchi method, while using the Taguchi orthogonal array would markedly reduce the number of experiments.
A set of experiments designed using the Taguchi method was conducted to investigate the relation between the process parameters and delamination factor. DESIGN EXPERT @ 16 minitab software was used for regression and graphical analysis of the obtained data.

Table 1 Drilling parameters and Levels

Symbol	Drilling Parameters	Level 1	Level 2	Level 3
A	**Cutting speed, v (m/min)**	20	40	60
B	**Feed rate, f (rev/min)**	0.035	0.070	0.140
C	**Point angle, θ (°)**	80	100	135

4. Experimental details

Mild Steel plates of 150×150×25 mm were used for the drilling experiments in the present study. The chemical composition and mechanical and physical properties of Al-Fly ash composite can be seen in Tables 2 and 3, respectively. The drilling tests were carried out to determine the bur height and surface roughness under various drilling parameters. HSS drills (10-mm diameter) were used for experimental investigations.

The burr height was measured using a height master and can measure a Value up to 100mm.

Table 2 Chemical composition of Al-Fly ash composite

Elements	Maximum weight %
Al	80.312
Sn	0.11

Si	8.59
Fe	1.27
Cu	2.03
Pb	0.40
Mg	0.10
Zn	6.65
Mn	0.13

Table 3 Mechanical and physical properties of Al- Fly ash composite

parameters	Value
Density 10^3 kg m^{-3}	2.532
Impact Strength (J)	10

5. Results and discussion

5.1 Experiment results and Taguchi analysis

In machining operation, minimizing the burr height (H) is an important criterion. The burr formation in drilling primarily depends upon the tool geometry, cutting parameters, and workpiece materials. When the material has moderate ductility, the material tends to elongate to some extent during burr formation, resulting in a large burr height and burr volume. However, if the material is quite brittle, catastrophic fracture occurs as the feed rate and cutting speeds increase, resulting in regular burrs having several large chunks, lobes, or petals [4].

A series of drilling tests was conducted to assess the influence of drilling parameters on burr height in drilling Al- Fly ash composite. Experimental results of the burr height for drilling of Al- Fly ash composite with various drilling parameters are shown in Table 4. Table 4 also gives S/N ratio for burr height. The S/N ratios for each experiment of L27 (3^13) was calculated. The objective of using the S/N ratio as a performance measurement is to develop products and process insensitive to noise factor. Table 5 shows average effect response table. Thus, by utilizing experiment results and computed values of the S/N ratios (Table 5), average effect response value and average S/N response ratios were calculated for burr height.

Table 4 EXPERIMENTAL RESULT AND CORRESPONDING S/N RATIO

S.No.	Levels of factor			Experimental Result	S/N Ratio
	v	f	θ	H (mm)	H
1	20	0.035	80	0.02	-33.98
2	20	0.035	100	0.20	-13.98
3	20	0.035	135	0.36	-8.874
4	20	0.070	80	0.12	-18.42
5	20	0.070	100	0.05	-26.02
6	20	0.070	135	0.20	-13.98
7	20	0.140	80	0.03	-30.46
8	20	0.140	100	0.18	-14.89
9	20	0.140	135	0.42	-7.535
10	40	0.035	80	0.04	-27.96
11	40	0.035	100	0.04	-27.96
12	40	0.035	135	0.41	-7.744
13	40	0.070	80	0.12	-18.42
14	40	0.070	100	0.31	-10.03
15	40	0.070	135	0.31	-10.17

16	40	0.140	80	0.09	-20.42
17	40	0.140	100	0.30	-10.46
18	40	0.140	135	0.36	-8.754
19	60	0.035	80	0.15	-16.48
20	60	0.035	100	0.30	-10.46
21	60	0.035	135	0.30	-10.46
22	60	0.070	80	0.12	-18.42
23	60	0.070	100	0.13	-17.72
24	60	0.070	135	0.13	-17.72
25	60	0.140	80	0.05	-26.02
26	60	0.140	100	0.08	-21.94
27	60	0.140	135	0.14	-17.08

Table 5 ANOVA table for Burr Height

Source	SS	DOF	Variance	F test	C%
Cutting speed(A)	0.020319	2	0.0101595	1.69	4.91
Feed rate (B)	0.005869	2	0.002934	0.488	1.42
Point angle (C)	0.200135	2	0.1000675	16.67	48.42
A×B	0.064015	4	0.01600375	2.66	15.40
B×C	0.033465	4	0.008366	1.393	8.09
C×A	0.41481	4	0.01037025	1.72	10.03
error	0.048019	8	0.0060023		11.61
Total	0.413302	26			

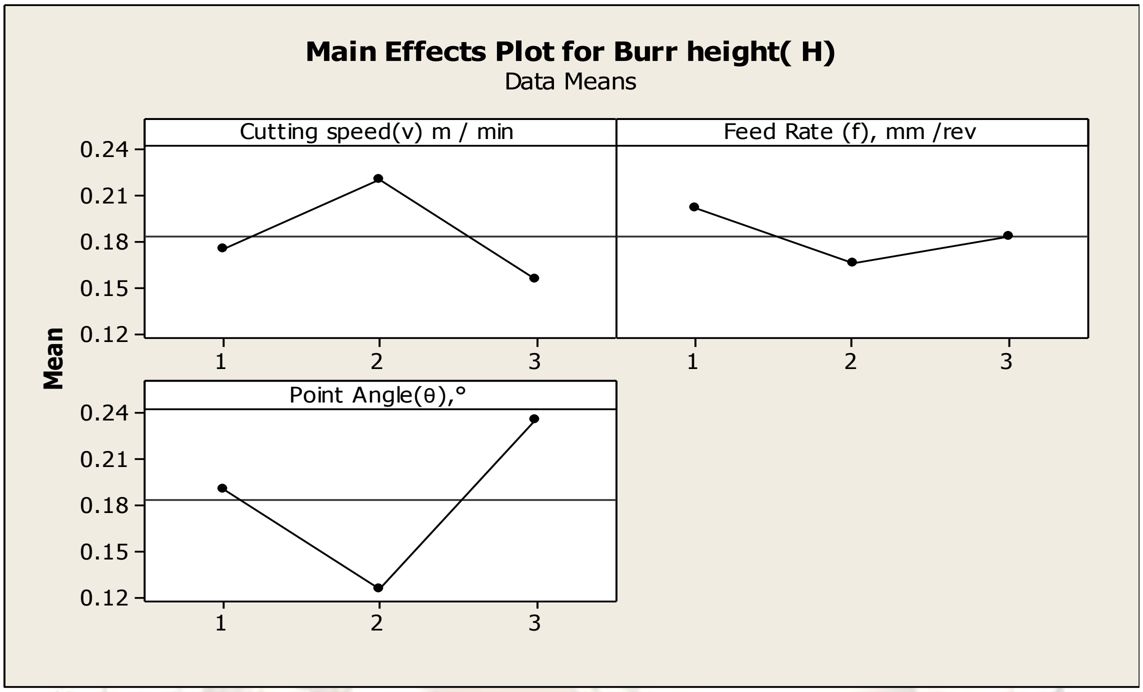

Fig 1 Effect of drilling parameters on Burr Height

From the ANOVA table it is clear that maximum contribution factor is angle having percentage contribution up to 48.42%.After that second main Contribution is of interaction A*B which means the combined effect of cutting speed and feed rate. Hence the individual ranking of these three parameters on the average value of means of Burr height:-

Table 6 Mean values of process parameters for burr height

Level	Speed (A)	Feed (B)	Angle (C)
1	0.17556	0.20222	0.17722
2	0.22111	0.16611	0.08222
3	0.15556	0.18389	0.29278
Delta	0.06556	0.03611	0.21056
Rank	2	3	1

From above response table of means it is clear that optimal working condition for drilling are A3, B2 and C2.From the ranking shown in above table it is evident that the main factor is angle.

Table 7 Optimum Levels of Process Parameters

Process Parameters	**Parameter Designation**	**Optimum Level**

cutting speed (V)	A3	60
Feed (F)	B2	0.070
Point angle (degree)	C2	100

5.2 Results

The effect of parameters i.e Cutting speed, feed rate and point angle and some of their interactions were evaluated using ANOVA analysis with the help of MINITAB 16 @ software. The purpose of the ANOVA was to identify the important parameters in prediction of Burr Height & Surface Roughness. Some results consolidated from ANOVA and plots are given below:

5.2.1 Burr Height

Point angle is found to be the most significant factor (F-value 16.67) & its contribution to burr height is 48.42 %. The interaction between cutting speed and feed rate (F-value 2.66) is found to be significant which contributes 15.40% and the interaction between point angle and cutting speed (F-value 1.72) is found to be significant which contributes 10.03%.The best results for Burr height (lower is better) would be achieved when Al-Fly ash composite workpiece is machined at cutting speed of 60 m/min, point angle of 100^0, feed rate of 0.070 mm/rev. With 99% confidence interval, the point angle effects the burr height most significantly.

6. Conclusion

The present study was carried out to study the effect of input parameters on the burr height. The following conclusions have been drawn from the study:

1. The Burr height is mainly affected by cutting speed and point angle. With the increase in cutting speed the burr height is increases & as the feed rate increases the burr height is decreases. But it is also observed that with the point angle, Burr height tends to decreases with increase in point angle up to some extent.
2. From ANOVA analysis, parameters making significant effect on burr height point angle, and interaction between point angle & cutting speed were found to be significant to Burr height for reducing the variation.
3. The parameters considered in the experiments are optimized to attain minimum burr height and surface roughness using response graph, fit summary test and analysis of variance (ANOVA) technique. The best setting of input process parameters for defect free drilling (minimum burr height) within the selected range is as follows:
    i) Low cutting speed i.e. 60m/min.
    ii) High feed rate i.e. 0.07mm/rev.
    iii) Point angle should be 100^0.

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