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Multi response Characteristics of Machining Parameters During Drilling of Alluminium 6061 alloy by Desirability Function Analysis using Taguchi Technique

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Abstract

This paper presents a new approach for optimizing the machining parameters on drilling of alluminium 6061 alloy. Optimization of machining parameters was done by an analysis called desirability function analysis (DFA), which is a useful tool for optimizing multi-response problems. In this work, based on Taguchi's L_{27} orthogonal array, drilling experiments were conducted over a wide a range of cutting conditions such as spindle speed varied in the range 600 rpm to 1000 rpm in 3steps, feed rate varied from 0.3 to 0.6mm /rev in 3 steps, high-speed steel (HSS) drills of 3 different diameters (8mm, 10mm and 12mm) and different point angles have been used for drilling of 27 through holes on 10mm depth with variable combination of soluble oil mixing with pure water on Aluminum 6061 alloy. A drill tool dynamo meter was used to record the thrust force and torque. A composite desirability value is obtained for the multi-responses using individual desirability values, based upon that value, the optimum levels of parameters have been identified and significant contribution of parameters were determined by analysis of variance (ANOVA). Confirmation test was conducted to validate the test result, which shows that the multi-responses in the machining process are improved through this approach. Thus, the application of desirability function analysis in Taguchi technique proves to be an effective tool for optimizing multi response characteristics of machining parameters during of drilling of alluminium 6061 alloy.

Keywords: Al 6061, Drilling, Thrust force, Torque, Orthogonal Array (OA), Desirability Function Analysis (DFA)

Introduction

Most of manufacturing industries perform a huge number of drilling operations in machine shops. The drilling technology has been studied to improve the cutting performance with optimizing the cutting parameters and the tool geometry. However, burrs are sometimes formed when the drill exits the work piece and the exit burrs have to be removed in the deburring process. The control of burr formation, therefore, has been strongly required to reduce the post process of the drilling operation. Many researchers have been made on burr formation so far. The earlier works associated the burr shape with the cutting parameters experimentally. Some mathematical models based on the experiments were presented to determine the cutting conditions. A statistical analysis was presented to estimate the burr height in the drilling process. Some of researches tried to associate the drill geometries with burr formations. From the point of view of the cutting force, the thrust at the end of the cut promotes burr formation in drilling of the plates. When the cutting chip flows upward, a large burr is left at the edge of the hole. Therefore, the thrust and torque should be controlled to reduce burr formation. The study of drilling has often presented some difficulties which are linked to the complex geometry of the twist drill. In practice, generally empirical equations are used to calculate thrust force and torque. These equations are very approximate, because they do not take all the cutting parameters into account. They often use only the feed speed and the diameter of the drill.

Williams recognized the significance of the feed on the resultant velocity and on altering the cutting geometry. In making predictions of torque and thrust, Williams argued that a portion of the drill acted as an orthogonal cutting edge because the cutting velocity is assumed to be perpendicular to the cutting edge. In 1972 Armarego and Cheng proposed an approach to predict thrust and torque during drilling for a conventional drill and a modified drill in order to simplify the calculations. The method of calculation used the orthogonal cutting model and the oblique cutting model, and was also used in 1979 by Wiriyacosol and Armarego. Basically, this method consists of dividing the cutting edges into a limited number of cutting elements. These elements were assumed to be oblique cutting edges on the cutting lip and orthogonal cutting edges on the chisel edge. The calculation used empirical equations established from orthogonal cutting tests. In most of the methods mentioned above, the major problem was to choose the number of cutting elements, and to determine the empirical equations for some cutting parameters. Watson initially used practically the same method, with a different geometry and developed a model for the chisel edge and the lip from the orthogonal cutting model and the oblique cutting model, respectively. The author initially used the same principle which consisted of dividing drill edges into a number of elementary cutting edges. Watson recognized that the chips front the lips and the chisel edges are continuous across their width and that continuity imposes a restriction on the possible variation of the chip flow angle across those edges. Elhachimi et al. assumed that the chisel edge model results are very small compared with where the cutting process takes places and they found that the thrust force is not sensitive to the variation of the spindle rotational speed. However, the effect of the spindle speed cannot be neglected on the torque. The power and the torque are proportional to the rotational speed. Moreover, thrust force, torque and power increase with the feed. Chandrasekharan et al. developed a theoretical method to predict the torque and thrust along the lip and chisel edge. A mechanistic force model can be used to develop models for cutting force system and a calibration algorithm to extract the cutting model coefficients. A statistical analysis of hole quality was performed by Furness et al. They found that feed and speed have a relatively small effect on the measured hole quality features. With the expectation of hole location error, the hole quality is not predictably or significantly affected by the cutting conditions. Although the authors did not expect these results, they have the important positive implication that production rates may be increased without sacrificing hole quality. Rincon and Ulsoy showed that the changes in the relative motion of the drill do affect the variations of the forces. An increase in the ranges of drill motion results in an increase in the ranges of torque and thrust. They suggested that drill vibrations can have an effect on drilling performance because increasing vibration during entry can cause poor hole location accuracy and burr formulation. The 6061 composition of aluminum is an extensively used material for the construction of a wide variety of materials. Bicycles, airplane parts, automotive parts and aluminum cans are all constructed utilizing 6061 aluminum. In many cases, the foil interior wrapper on food containers is also made with 6061 aluminum alloy. Due to its good mechanical properties such as machinability and low density, Aluminum is commonly used in a wide range of industries and constitutes about 40% of all metal-cutting operations.

Based on the literature survey performed, venture into this work was amply motivated by the fact that a little research has been conducted to obtain the optimal levels of process parameters that yield the thrust force and torque of Al6061 during drilling apart from burr size. Majority of the works are concentrating only on influence of volume fraction of Al6061in the fabrication of metal matrix composites. More over no study has been performed in drilling using desirability function analysis integrated with taguchi technique to optimize multiple performance considerations namely thrust force and torque.

Experimental Procedure

The standard high- speed steel twist drills of 8mm, 10mm and 12mm with different point angles(118^{o},126^{o} and 136^{o}) ,variable cutting fluid mixture ratio[(120ml of soluble oil + 880ml of water), (180ml of soluble oil + 820ml of water), (240ml of soluble oil + 760ml of water)]was used with variable speeds and feed rates for the present investigation. Drilling operation was carried out on a Universal Milling Machine with vertical head attachment, Sutlej make, Ludhiana, Punjab, India. Sensing signaled (thrust force (0-5000N) and torque (0-500Nm) were measured using drill tool dynamometer (IEIOS Bangalore make, Model: 651). Drilling of exercises was carried out for each experimental condition to drill 10mm depth blind holes on the Aluminum 6061alloy having the composition of 0.63% Si, o.466% Fe, 0.096% Cu, 0.179% Mn, 0.53% Mg,0.091% Zn, 0.028% Cr,0.028% Ti and remaining aluminum and for each experimental condition five holes were drilled.

Fig. 1: Experimental Setup

Design of Experiments using Taguchi's orthogonal array technique:

Taguchi method has been widely employed in several industrial fields, and research works. By applying the Taguchi technique, the time required for experimental investigations can be significantly reduced, as it is effective in the investigation of the effects of multiple factors on performance as well as to study the influence of individual factors to determine which factor has more influence, which one less. The factor level combinations selected for the design of experiments table1.An L27 OA lay out was selected to satisfy the minimum number of experiments condition. Factors and Levels of the Experiment and results are shown in table1&2.

Table 1: Factors and Levels of the Experiment

Levels of factors	Cutting Speed (rpm) A	Feed rate (mm/rev) B	Drill diameter (mm) C	Point angle (æ%) D	Cutting fluid mixing ratio (%)E
1	350	0.3	8	118	12
2	550	0.5	10	126	18
3	750	0.6	12	136	24

Table 2: Experimental results as per L27 orthogonal array

Exp	A	B	C	D	E	Measured Responses	
						F_t (Kg-f)	T(Kg-m)
1.	1	1	1	1	1	108.36	272
2.	1	1	1	1	2	119.21	352
3.	1	1	1	1	3	127.00	380
4.	1	2	2	2	1	124.00	456
5.	1	2	2	2	2	223.00	482
6.	1	2	2	2	3	241.00	431
7.	1	3	3	3	1	328.00	340
8.	1	3	3	3	2	127.00	276
9.	1	3	3	3	3	225.00	232
10.	2	1	2	3	1	329.68	308
11.	2	1	2	3	2	331.00	420
12.	2	1	2	3	3	226.42	341
13.	2	2	3	1	1	218.52	367
14.	2	2	3	1	2	293.00	448
15.	2	2	3	1	3	303.46	268
16.	2	3	1	2	1	367.00	403
17.	2	3	1	2	2	315.00	246
18.	2	3	1	2	3	296.00	372
19.	3	1	3	2	1	125.81	384
20.	3	1	3	2	2	127.80	364
21.	3	1	3	2	3	224.00	388
22.	3	2	1	3	1	122.00	454
23.	3	2	1	3	2	302.00	374
24.	3	2	1	3	3	268.74	358
25.	3	3	2	1	1	217.32	207
26.	3	3	2	1	2	340.00	282
27.	3	3	2	1	3	233.00	278

Desirability Function Analysis (DFA)

One useful approach to optimization of multiple responses is to use the simultaneous optimization technique popularized by Derringer and Suich (1980). Their procedure introduces the concept of desirability functions. The method makes use of an objective function, *D*(*X*), called the desirability function and transforms an estimated response into a scale free value (*di*) called desirability. The desirable ranges are from zero to one (least to most desirable, respectively). The factor settings with maximum total desirability are considered to be the optimal parameter conditions.

Optimization steps using desirability function analysis:

Step 1: Calculate the individual desirability index (di) for the corresponding responses using the formula proposed by Derringer and Suich. There are three forms of the desirability functions according to the response characteristics.

In this study, the smaller-the-better characteristic is applied to determine the individual desirability values for thrust force and torque since both are to be minimized.

Step 2: For smaller-the-better, the value of ω_j is expected to be the smaller the better. When ω_j is less than a particular criteria value, the desirability value equals to 1; if the ω_j exceeds a particular criteria value, the desirability value equals to 0. The desirability function of the smaller-the-better can be written as given in Eq.1

$$d_i = \begin{cases} 1 \\ \left[\dfrac{\omega_j - \omega_{\max}}{\omega_{\min} - \omega_{\max}} \right]^r, \omega_{\min} \le \omega \le \omega_{\max}, r \ge 0 \\ 0 \end{cases} \tag{1}$$

Where $\omega_{\max}$ and $\omega_{\min}$ represent the upper and lower tolerance limits of and r represent the weights. Compute the composite desirability (d_G). The individual desirability index of all the responses can be combined to form a single value called composite desirability (d_G) by the following Eq.2

$$d_G = \left[d1^{n1} X d2^{n2} X d3^{n3} X .... dm^{nm} \right]^{1/n} \tag{2}$$

Where di is the individual desirability of the property, m_i is the weight of the property “” in the composite desirability and m is the sum of the individual weights.

Step 3: Determine the optimal parameter and its level combination. The higher the composite desirability value implies better product quality. Therefore, on the basis of the composite desirability (d_G), the parameter effect and the optimum level for each controllable parameter are estimated.

Step 4: Perform ANOVA for identifying the significant parameters. ANOVA establishes the relative significance of parameters. The calculated total sum of square value is used to measure the relative influence of the parameters.

Step 5: Calculate the predicted optimum condition. Once the optimal level of the design parameters has been selected, the final step is to predict and verify the quality characteristics using the optimal level of the design parameters.

Table 3 shows the evaluated individual desirability and composite desirability for each experiment using L_{27} orthogonal array. The higher composite desirability value represents that the corresponding experimental result is closer to the ideally normalized value. Since the experimental design is orthogonal, it is then possible to separate out the effect of each machining parameter on the composite desirability value at different levels. The response mean of the composite desirability for each level of the machining parameter is summarized in Table 4. In addition, the total mean of the composite desirability for the 27 experiments is also calculated and listed in Table 4. Figure 3 shows the factor effects (response graph) for the composite desirability value for the levels of the machining parameters. Basically, the larger the composite desirability, the better is the multiple performance characteristics. However, relative importance among the machining parameters for the multiple performance characteristics is still needs to be known so that the optimal combinations of the machining parameter levels can be determined more accurately.

Table 3: Evaluated individual desirability and composite desirability

Si. No	Individual desirability(d_i)		Composite Desirability(d_G)
	F_t	T	
1.	1.0000	0.7636	0.8738
2.	0.9580	0.4727	0.6729
3	0.9279	0.7345	0.8255
4.	0.9395	0.0945	0.2979
5.	0.5567	0.0000	0.0000
6.	0.4871	0.1854	0.3005
7.	0.1507	0.5163	0.2789
8	0.9279	0.7490	0.8336
9.	0.5490	0.9090	0.7064
10.	0.1443	0.6327	0.3021
11.	0.1392	0.2254	0.1771
12.	0.5435	0.5127	0.5278
13.	0.5740	0.4182	0.4899
14.	0.2861	0.1236	0.1880
15.	0.2456	0.7782	0.4372
16.	0.0000	0.2872	0.0000
17.	0.2010	0.8582	0.4153
18.	0.2745	0.4000	0.3313
19	0.9325	0.3563	0.5764
20.	0.9248	0.4291	0.6299
21.	0.5528	0.3418	0.4346
22.	0.9472	0.1018	0.3105
23.	0.2513	0.3927	0.3141
24.	0.3799	0.4509	0.4138
25.	0.5787	1.0000	0.7607
26.	0.1044	0.7272	0.2755
27.	0.5181	0.7418	0.6199

Table 4: Response mean of the composite desirability

	Average Composite Desirability			
Machining Parameter	Level 1	Level 2	Level 3	Max - Min
Cutting Speed (A)	0.5322	0.3187	0.4817	0.2135
Feed Rate(B)	0.5577	0.3057	0.4691	0.2520
Drill Diameter (C)	0.4619	0.3624	0.5083	0.1459
Point angle (D)	0.4797	0.3317	0.4293	0.1480
Cutting fluid mixing ratio(E)	0.4322	0.3896	0.5107	0.1211

Total mean of Composite desirability=0.4381

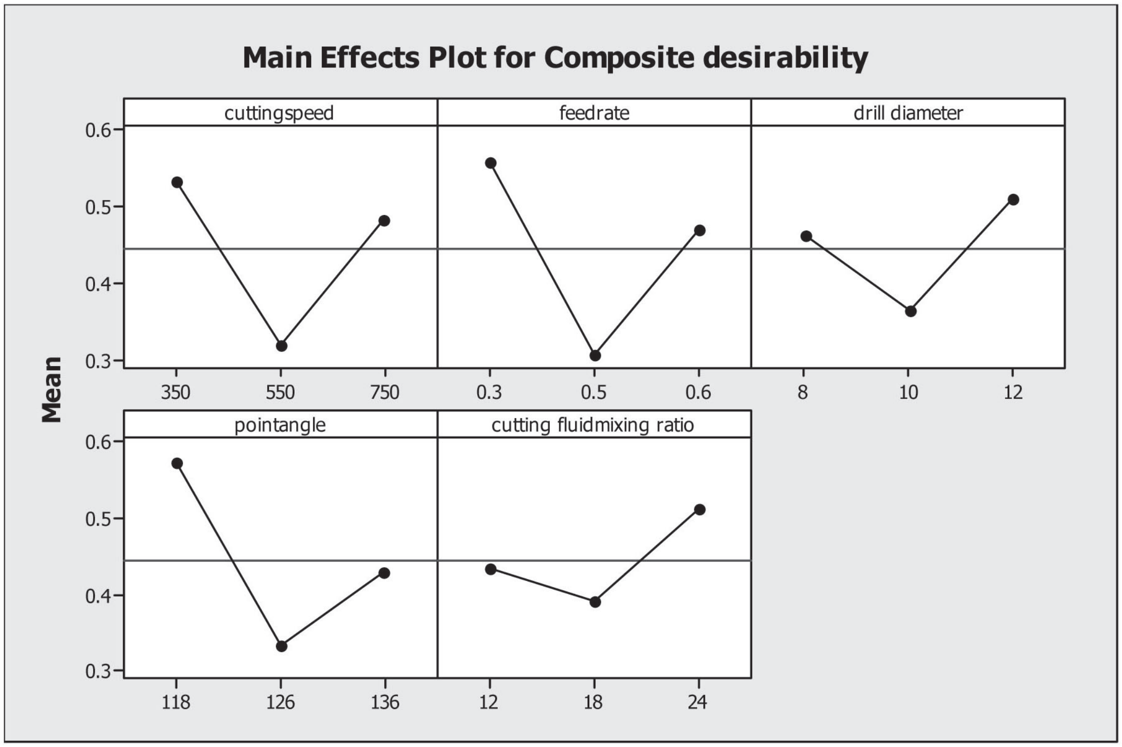

Fig. 2: Response graph for the composite desirability value

Analysis of Variance

Analysis of Variance (ANOVA) is a method of apportioning variability of an output to various inputs. Table 5 shows the results of ANOVA analysis. The purpose of the analysis of variance is to investigate which machining parameters significantly affect the performance characteristics. This is accomplished by separating the total variability of the composite desirability value, which is measured by the sum of the squared deviations from the total mean of the composite desirability value, into contributions by each machining parameter and the error. First, the total sum of the squared deviations SS_T from the total mean of the composite desirability value can be calculated as:

$$SS_T = \sum_{i=1}^{p} (\gamma_j - \gamma_m)^2 \tag{3}$$

Where *p* is the number of experiments in the orthogonal array and is the mean composite desirability value for the jth experiment. The total sum of the squared deviations SS_T is decomposed in to two sources: the sum of the squared deviations SS_d due to each machining parameter and its interaction effects and the sum of the squared error SS_E. The percentage contribution by each of the machining parameter in the total sum of the squared deviations SS_T can be used to evaluate the importance of the machining parameter change on the performance characteristic. In addition, the Fisher's F- test can also be used to determine which machining parameters have a significant effect on the performance characteristic. Usually, the change of the machining parameters has a significant effect on performance characteristic when F is large.

Results of analysis of variance for composite desirability value (Table 5) indicate that feed rate and point angle are the most significant machining parameters for affecting the multiple performance characteristics. Based on the above discussion, the optimal machining parameters are the cutting speed at level 1, feed rate at level 1, drill diameter at level 3,point angle at level 1 and cutting fluid mixing ratio at level 3(A1B1C3D1E3).

Table 5: ANOVA for composite desirability value

Symbol	CuttingParameters	DOF	SS	MS	F	
A	Cutting speed	2	0.22396	0.11198	3.28	In Significant
B	Feed rate	2	0.29416	0.14708	4.31*	Significant
C	Drill diameter	2	0.10007	0.05003	1.46	In Significant
D	Point angle	2	0.26157	0.13078	3.83*	Significant
E	Cutting fluid mixing ratio	2	0.06801	0.03400	0.99	In Significant
Error		16	0.54624	0.03414		
Total		26	1.49401			

*Significant, F_{table} at 95%confidence level is $F_{0.05, 3, 16} = 3.63$, $F_{exp} \geq F$ table

Confirmation experiment

Once the optimal level of machining parameters is selected the final step is to predict and verify the improvement of the performance characteristics using the optimal level of the machining parameters. The estimated composite desirability value using the optimum level of the machining parameters can be calculated as,

$$\hat{\gamma} = \gamma_m + \sum_{i=1}^{q} (\bar{\gamma}_j - \gamma_m)^2 \tag{4}$$

Where is the total mean of the composite desirability value, is the mean of the composite desirability value at the optimum level and q is the number of machining parameters that significantly affects the multiple performance characteristics. Based on Eq (4) the estimated composite desirability value using the optimal machining parameters can then be obtained. Table 6 shows the results of the confirmation experiment using the optimal machining parameters. Thrust force (Ft) is greatly reduced from 303.46 Kgf to 124.63 Kgf and the Torque (T) is reduced from 268 Kg-m to 254.72 Kg-m. It is clearly shown that multiple performance characteristics in the drilling of Al 6061 are greatly improved through this study.

Table 6: Results of confirmation experiment

	Initial machining parameters	Optimal machining parameters	
		Prediction	Experiment
Setting level	A2B2C3D1E3	A1B1C3D1E3	A1B1C3D1E3
Thrust force (Ft)	303.46 Kgf		124.63 Kgf
Torque (T)	268 Kg-m		254.72Kg-m
Composite desirability value (d_G)	0.4372	0.5932	0.8797

Improvement in composite desirability value = 0.4425

Conclusion

The use of orthogonal array with desirability function analysis to optimize the Al 6061 alloy drilling with multiple performance characteristics has been reported in this paper. The desirability function analysis of the experimental results of thrust force and torque can convert optimization of the multiple performance characteristics in to optimization of the single performance characteristic called the composite desirability value. As a result, optimization of the complicated multiple performance characteristics can be greatly simplified through this approach. It is shown that the performance characteristics of the drilling of Al 6061 alloy such as thrust force and torque are improved together by using the method proposed in this study.

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