EFFECT OF DRILLING PARAMETERS ON THRUST FORCE AND TORQUE DURING DRILLING OF ALUMINIUM 6061 ALLOY - BASED ON TAGUCHI DESIGN OF EXPERIMENTS

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Abstract: *Hole generating process with drill bit called as drilling, which is very important because large portion of overall machining of any component in production industry needs assemble of parts to make a final shape with rivets and fasteners. It is well known that the drill point geometry has a significant effect on thrust force exerted by a drill bit while drilling. In this study, experimentally investigate the influence of drilling parameters such as point angle, clearance angle, cutting speed, feed rate and drill diameter on the thrust force and torque in drilling. Drilling experiments have been conducted over a wide a range of machining conditions such as cutting speed varied in the range 500 rpm to 1000 rpm in 3steps, feed rate varied from 0.3 to 0.6mm /min in three steps using two flutes uncoated conventional twist drills of three different diameters (8, 10 and 12mm) with 118^0 point and 45^0 helix angles. Drill bits tool geometry altered by tool&cutter grinder and obtained 110^0, 100^0 point angles also clearance angles varied by 4^0, 6^0 and 8^0. Holes are performed on Aluminium 6061 alloy material of rectangular cross section having dimensions 300mmx50mmx10mm as per taguchi technique. A kistler (type 9272), four components drill tool dynamometer was used to measure thrust force (Th) and torque (M) exerted by the drill bit during hole making on a work material further the signal was processed to a computer by a multichannel signal amplifier (Kistler 5070 type) was used to record the thrust force and torque. Finally, ANOVA test have been carried out to confirm the significance of factors considered during drilling and compare the predicted values with the experimental values on influence of factors on responses.*

Key Words: *Al 6061 alloy, Thrust Force, Torque, Taguchi-Design of Experiment*

INTRODUCTION

In general, the drilling performance measured includes thrust force, torque and surface quality. Each of these measures is affected by various factors and variables such as the tool and work piece materials properties, the tool geometry, the cutting conditions, cutting fluid and machine tool. Also this chapter separately reviews what has been done in the past in the area of drilling parameters to optimize surface roughness, thrust force and torque.

LITERATURE REVIEW

J.S. Strenkowski et al[1] focused on development of FEM for oblique cutting by taking forces and moments acting on drill, which was based on visco elastic effects on drill bit geometry for oblique sections. An analytical model for oblique cutting was described to analyze a single section in the cutting lip region of the drill bit. S. Madhavan et al[2] conducted drilling experiments on GFRP material using taguchi design of experiments, but they concentrated on the effect of delamination factor by varying the cutting speed, feed rate, thrust force and torque during drilling operation. R. Vimal Sam Singh et al[3] developed a fuzzy logic based model for forecasting thrust force and torque during drilling, but not considered the changes on geometry of drill. P. V. Gopal Krishna et al[4] concentrated their experiments on friction drilling which is unconventional drilling process in which a cone type rotating tool penetrate into material and generate a hole, without generating chips. Aluminum (AA6351) is taken as work material and friction drilling is carried out by hss conical rotating tool, finally they developed mathematical models for axial thrust force and torque. M. Pirtini et al[5] considered principles of mechanics to develop mathematical models in drilling to predict cutting forces and surface finish of a hole. This model is able to simulate the cutting forces for various machining conditions in the process in order to obtain drilled profiles. Therefore, in addition to predict the forces, the new model allows finding and visualization of drilled hole shapes in 3D. M Sundeep et al[6] investigated experimentally on drilling behavior of

AISI 316 and attempt made to optimize the process parameters using taguchi design of experiments method. The process parameters of spindle speed, feed rate and drill diameter are affected by thrust and torque during drilling operations. B.Suresh kumar et al[7] reveals the conclusions after conducting experiments on drilling operation by using computer numerical control and conventional machines on titanium alloy; the conventional drilling machine produces higher vibrations than computer numerical control machines. The higher spindle speed with lower feed rate generates lower frequency in conventional drilling machine. But in CNC the higher spindle speed with higher feed rate produces the lower frequency. Comparatively CNC machine create higher thrust force and torque due to its strength and stiffness. Conventional machines acquire higher machining time at lower spindle speed with lower feed rate than CNC machine. Similarly CNC machines consume higher machining time at higher spindle speed with lower feed rate. M.Vijaya Kumar et al[8], presented in their paper ,effect of drilling parameters of AMMC to minimize the thrust force, temperature and surface finish using DFA method. Naseer Ahmed[9] applied a three dimensional thermo mechanically coupled finite element model of drilling process of AISI 2080 to study the effect of cutting parameter on thrust force and torque. For this experiments are performed to validate the results from simulations. A three dimensional thermo mechanically couple finite element close-to-real model of drilling process was developed to study the effect of variation in the cutting parameters on the thrust forces and torque inside the drill bit, finally concluded that the thrust force increased with increasing the cutting speed and feedrate. Vaishak N L et al[10] put their efforts to understand the effect of parameters like thrust force and torque that are generated during drilling of granite particulate reinforced epoxy composite. The results said that cutting speed and feed rates are influenced more on induced damage in drilling. S. Prakash et al[11] conducted experimental study drilling operation towards medium density fibre (MDF) board. They focussed on to the study of various drilling parameters such as feed rate, spindle speed, drill diameter and board thickness on the thrust force generated during drilling.

EXPERIMENTAL PROCEDURE

Material and its composition

Aluminium 6061 alloy material of rectangular cross section of 300mmx50mmx10mm size is used to conduct experiments. The composition of Alluminium alloy 6061consists of 0.63% Silicon, 0.096% Copper, 0.091% Zinc, o.466% Iron, 0.179% Manganese, 0.53% Magnesium, 0.028% Titanium, 0.028% Chromium, and remaining alluminum.

Tools and Equipment

In this study, the experiments were carried out on a radial drilling machine (Make: Siddapura Machine Tools, Gujarat, INDIA) to perform different size of holes on Al 6061 alloy work piece. The drill tools used were HSS-R (DIN 338) twist drill bits made by Bosch Company and commercially available with diameters of 8, 10 and 12mm with 118^0 point angle and 45^0 helix angle. Drill bits tool geometry altered by tool&cutter grinder, obtained 110^0and100^0 point and 4^0,$6^0$and 8^0 clearance angles. Kistler type 9272(Kistler Instrumente AG, CH8408, Winterthur, Switzerland make) four components (F_X, F_Y, F_Z and T) dynamometer was used to measure thrust force (Th) and torque (M) and the signal was processed to the computer by a type 5070 multichannel signal amplifier (shown in Fig.1).

Figure 1. Kistler dynamometer type 9272 (Kistler Instrumente AG, CH8408 Winterthur, Switzerland), Multichannel signal amplifier (kistler type 5070) and radial drilling machine (Make: Siddapura Machine Tools, Gujarat, INDIA).

EXPERIMENTAL PARAMETERS AND DESIGN

An experimental plan based on taguchi method[12] has been considered to get the experimental and response data. In this connection, an orthogonal arrays, signal to noise (S/N) ratios and analysis of variance (ANOVA) were involved to test the influential parameters on drilling of Aluminium 6061 alloy using HSS twist drill bits. The complete procedure in taguchi design method can be divided into three phases: system design phase, parameter design phase, and tolerance design phase. Out of the three design phases, the second phase – the parameter design phase, is the most important stage. Taguchi's orthogonal array gives a combination of well-stabilized experiments with less number of experiments to be conduct, and signal-to-noise ratio (S/N), which is logarithmic functions of required output in the process optimization. The signal-to-noise ratio is the ratio of the mean (signal) to the standard deviation (noise). Factors and their levels of the experiments are shown in table1. Experimental plan and responses are depicted in table 2.

Table1: Process parameters and levels of the Experiment

Levels	**Factors**				
	Cutting Speed (rpm)	Feed Rate (mm/min)	Drill Diameter (mm)	Point Angle (^{0})	Clearance Angle(^{o})
	CS	FR	D	PA	CA
1	600	0.3	8	118^0	4^0
2	800	0.5	10	110^0	6^0
3	1000	0.6	12	100^0	8^0

Table 2: Experimental runs and responses

RUNS	Taguchi experimental design table							S/N Ratio (β)
	Choosen Parameters					Meseared Responses		
	Cutting Speed (rpm)	Feed Rate (mm/min)	Drill Diameter (mm)	Point Angle (Degrees)	Clearance Angle (Degrees)	Thrust Force (Kgf)	Torque (Kgm)	
	CS	FR	D	PA	CA	Th	M	
1	1	1	1	1	1	108.36	272	-1.6278
2	1	1	1	1	2	119.21	352	4.4320
3	1	1	1	1	3	127.00	380	-7.0672
4	1	2	2	2	1	124.00	456	3.7360
5	1	2	2	2	2	223.00	482	-4.5433
6	1	2	2	2	3	241.00	431	-5.4292
7	1	3	3	3	1	328.00	340	-6.1495
8	1	3	3	3	2	127.00	276	-4.8008
9	1	3	3	3	3	225.00	232	-1.2765
10	2	1	2	3	1	329.68	308	-4.4935
11	2	1	2	3	2	331.00	420	-1.0965
12	2	1	2	3	3	226.42	341	4.9026

13	2	2	3	1	1	218.52	367	-4.2749
14	2	2	3	1	2	293.00	448	-5.1270
15	2	2	3	1	3	303.46	268	2.0188
16	2	3	1	2	1	367.00	403	-5.0137
17	2	3	1	2	2	315.00	246	-1.8190
18	2	3	1	2	3	296.00	372	-6.8348
19	3	1	3	2	1	125.81	384	-3.2417
20	3	1	3	2	2	127.80	364	-3.3032
21	3	1	3	2	3	224.00	388	-4.6847
22	3	2	1	3	1	122.00	454	-3.8870
23	3	2	1	3	2	302.00	374	-3.6437
24	3	2	1	3	3	268.74	358	1.5171
25	3	3	2	1	1	217.32	207	-2.7075
26	3	3	2	1	2	340.00	282	-4.7936
27	3	3	2	1	3	233.00	278	-5.1176

ANALYSIS OF S/N RATIO

In the taguchi design method, the term 'signal' represents the required value (mean) for the output response and the term 'noise' represents the undesirable value (standard deviation) for the output response. S/N ratio used to measure the quality characteristic deviating from the desired value. The S/N ratio is defined as $\beta = -10 \log (M.S.D)$, Where M.S.D is the mean square deviation for the output characteristic. The S/N ratio table for observed responses is shown in Table 3.

Table 3. S/N Ratio for Smaller is better

Level	Cutting Speed (rpm) CS	Feed Rate (mm/min) FR	Drill Diameter (mm) D	Point angle(°) PA	Clearance angle (°) CA
1	-2.525	**-1.797**	-2.660	**-2.103**	**-2.441**
2	**-2.415**	-2.181	**-2.171**	-3.459	-2.743
3	-3.318	-4.279	-3.426	-2.696	-3.073
Delta	0.902	2.481	1.255	1.356	0.632
Rank	4	1	3	2	5

DISCUSSION ON RESULTS

From normal probability plots were obtained by residual vs percentage deposition of experimental responses with 95% confidence level for thrust force and torque as shown in Fig.2 & Fig.3.

From Table 3, it is observed that feed rate, point angle, drill diameter, cutting speed and clearance angle has the order of influence on thrust force and torque during drilling of Al6061 alloy. The optimum parameters combination thrust force and torque are CS2FR1D2PA1CA1 corresponding to the largest values of S/N ratio for all control parameters.

From figure.4 main effects plots for means of thrust force and torque and for the combination of parameters individual rankwise are CS2FR3D 3PA3CA2 and CS3FR3D3PA2CA1, respectively.

From Figure 5 interaction plot, which shows individual parameter influence over the thrust force and torque during the drilling operation.

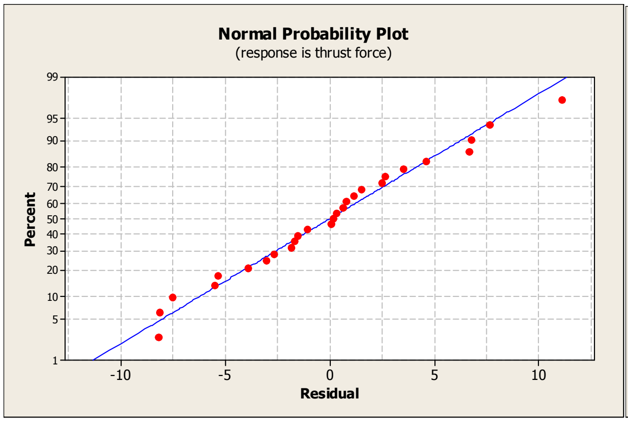

Figure 2. Normal probability plots for thrust force

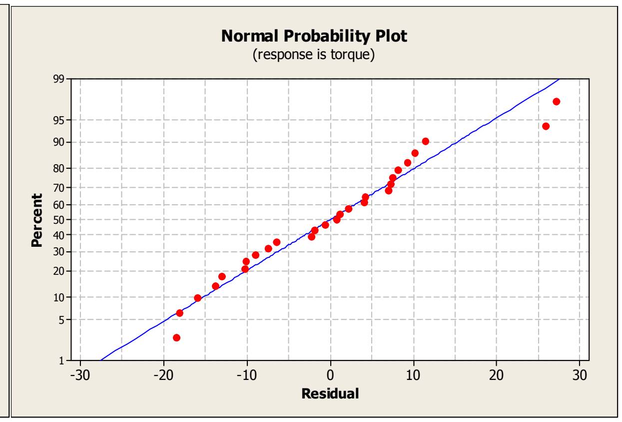

Figure 3. Normal probability plots for torque

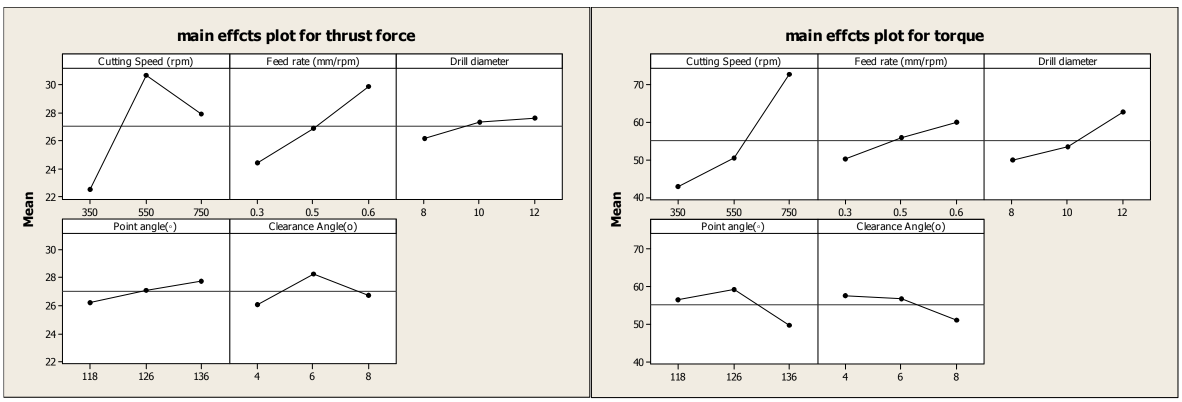

Figure 4. Response graphs for thrust force and torque

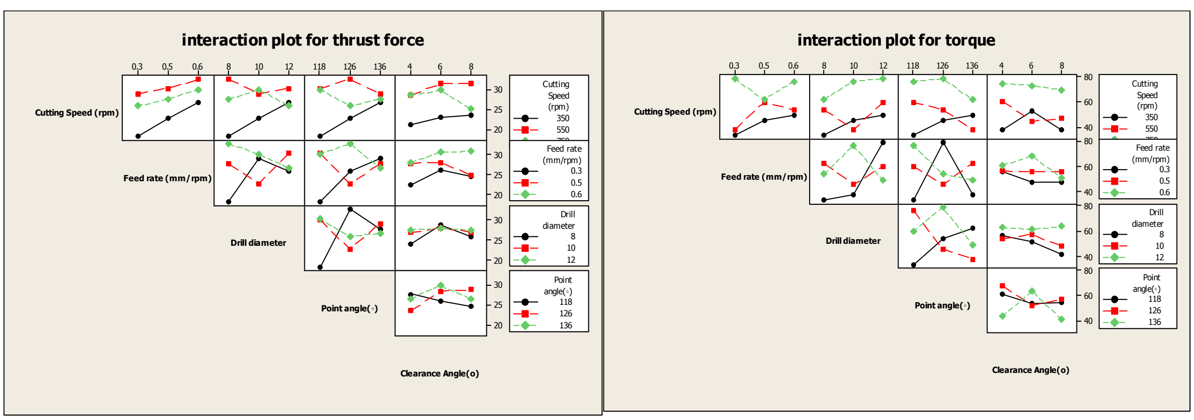

Figure 5. Interaction plot for thrust force and torque

Analysis of Varience (ANOVA) test for confirmation

The purpose ANOVA is to investigate, the significance of factors choosen in the beginning of experimentation because the factors are considered basically from experience or literature but in actual practice some of these factors may or may not be influence, so it will be known after ANOVA test.

Table 4 shows the results of ANOVA for thrust force, cutting speed, feed rate, drill diameter, and point angle are the more significant factors for the thrust force.

Table 5 shows the results of ANOVA for torque, cutting speed, feed rate, drill diameter, point angle and clearance angle are the significant factors for the torque.

Table 4: ANOVA for thrust force (Th)

Factors	DOF	SS	MS	F	
Cutting speed	2	0.00871	0.00435	36.25	significant
Feed rate	2	0.00292	0.00146	12.16	significant
Drill diameter	2	0.00218	0.00109	9.08	significant
Point angle	2	0.00684	0.00342	28.5	significant
Clearance angle	2	0.00140	0.00070	2.83	In significant
Error	16	0.001926	0.00012		
Total	26	0.023976			

F_{table} at 95%confidence level is $F_{0.05, 2, 16} = 3.63$, $F_{exp} \geq F$ table

Table 5: ANOVA for torque (M)

Factors	DOF	SS	MS	F	
Cutting speed	2	0.0066	0.0033	16.75	significant
Feed rate	2	0.0027	0.0013	6.598	significant
Drill diameter	5	0.0029	0.0015	7.614	significant
Point angle	2	0.00702	0.00351	17.766	significant
Clearance angle	2	0.0053	0.0027	13.705	significant
Error	16	0.00315	0.000197		
Total	26	0.02765			

Significant, F_{table} at 95%confidence level is $F_{0.05, 2, 16} = 3.63$, $F_{exp} \geq F$ table

Table 6. Optimal values of individual machining characteristics

machining characteristics	Optimal combination of parameters	Significant parameters(at 95% confidence level)	Predicted optimum value	Experimental value
Thrust force(Th)	CS2FR3D3PA3CA2	CS,FR,D,PA	98.43Kgf	108.36Kgf
Torque (M)	CS3FR3D3PA2CA1	CS,FR,D,PA,CA	197.87Kgm	207.27Kgm

Confirmatory experiments were conducted for thrust force and torque, corresponding their optimal setting of process parameters to validate the used approach, obtained the values of 98.43 Kgf, 197.87Kgm for thrust force and torque respectively. Predicted and experimental values of responses are depicted in table 6.

CONCLUSIONS

The taguchi design of experiments method was a way of optimizing the process parameters in drilling for A16061alloy.

From response table of S/N ratio, it is observed that feed rate, point angle, drill diameter, cutting speed and clearance angle has the order of influence on thrust force and torque during drilling of Al 6061 alloy. The largest values of S/N ratio for all controllable factors. It is the recommended levels of the controllable parameters for the process of drilling as the minimization of thrust force and torque.

The result of ANOVA for thrust force, cutting speed and point angle are more significant parameters for affecting both the thrust force and torque in an order.

The optimal setting of process parameters to validate thrust force and torque are CS2FR3D3PA3CA2 and CS3FR3D3PA2CA1 respectively, obtained the values of 108.36 Kgf, 207.27 Kgm respectively. Percentage improvement between the experimental and optimal setting of parameters after conformation test conducted by choosing significant factors from ANOVA are 9.16% in thrust force and 4.53% in torque.

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