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Optimization of Drilling Parameters for Thrust Force and Torque in Friction Drilling Process

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Abstract: Friction drilling is a novel machining process in this process rotating a conical tool used to make a hole in aluminium 6061-T6 alloy. Tool is rotated high speed and the heat generated by friction softens and penetrates a thin work piece and create a bushing without generating a chip. In this process high speed steel conical tool is used to make a hole. In this work machining experiment was carried out using CNC vertical machine centre and with kistler quartz 3-component dynamometer to measure thrust force and torque. Taguchi optimization methodology is applied to optimize cutting parameters in friction drilling of aluminium 6061-T6 alloys. Analysis of variance (ANOVA) is used to study the effect of process parameters on machining process. The taguchi method indicates that among the all significant parameters, speed is more influential thrust force than the feed force. The correlation between thrust force and cutting parameters is obtained by multivariable linear regression and compared with the experimental results.

Key words: Friction drilling · Taguchi technique and regression analysis

INTRODUCTION

Friction drilling is a non-traditional hole-making method that utilizes the heat generated from the friction between a rotating conical tool and the work piece Aluminium 6061-T6 alloys [1]. The tool is made of h.s.s and rotates at high speed, which produces friction heat. The frictional heat energy thus produced softens and penetrates the work piece. The process forms a bushing in situ and is clean and chips less. This chipless machining process has the advantages of reducing the time required for drilling and incurring less tool wear, thus lengthening the service life of the drill. In this process no coolant required.

The Friction drill and how it Works: The Friction drill is a thermal drilling and bush forming tool that attaches to the chuck of any high-powered drill press. Rotating the form drill at high speed under high axial load (the drill bit strongly pushed towards the workpiece) generates frictional heat [2].

Unlike a convetional drill, the strengh of workpiece is not compromised by the removal of material.Instead, the heated material forms away from its original position to form a 360 degree bush around a periphery of the hole. During initial stages of the form drill process, the heated material rises aganist the tool's leading taper but once the surface is complety penetrated, the bulk of the displaced material forms to the underside of the hole. This underside bush usually project downwards of the material..

Figure 1. shows a schematic illustration of the five steps in friction drilling. The tip of the conical tool approaches and contacts the work piece, as shown in Fig. 1.(a). The tool tip, like the web center in twist drill [3], indents into the workpiece and supports the drill in both the radial and axial directions [4]. Friction on the contact surface, created from axial force and relative angular velocity between tool and workpiece, produces heat and softens the workpiece material. As the tool is extruded into the workpiece, as shown in Fig. 1.(b), it initially pushes the softened work-material sideward and upward. With the workpiece material heated and softened the tool is able to pierce through the workpiece, as shown in Fig. 1. (c). Once the tool penetrates the workpiece, as shown in Fig. 1.(d), the tool moves further forward to push aside more workpiece material and form the bushing using the cylindrical part of the tool. As the process is completed, the shoulder of the tool may contact the workpiece to collar the back extruded burr on the bushing. Finally, the tool retracts and leaves a hole with a bushing on the workpiece (Fig. 1. (e))

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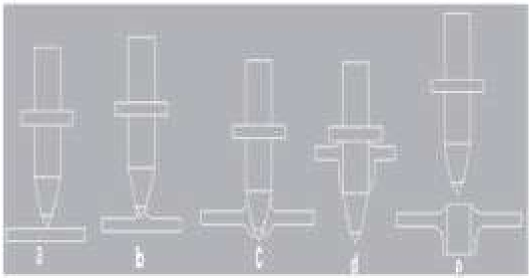

Fig. 1: Illustration of Stages in Friction Drilling Process.

Tool Preparation: The friction drilling is a special type of tool which is not available commercially hence is to project work the h.s.s bar was purchased in 8 mm diameter [5]. The bar was required shape and size after machining, heat treatment and grinding. Tool was refer as per given specification in figure. The tool material is h.s.s M2 grade diameter 5 mm

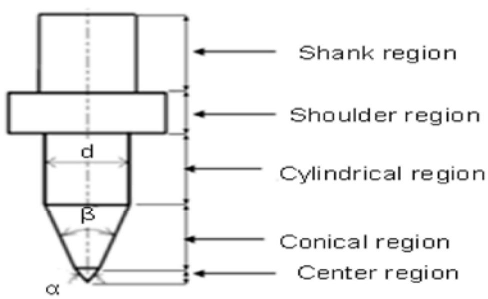

Fig. 2: Nomenclature of friction drilling

Center Region: The cone-shape center has the angle α and height hc. The angle is usually blunt. The effect of blunting is to generate more force and, therefore, heat at the start of the drilling. The center region, like the web in a twist drill, provides the support in the radial direction for the friction drilling process and keeps the tool from walking at the start of the process.

Conical Region: This region has a sharper angle than the center region. The drill in this region rubs against the work piece to generate the friction force and heat and pushes the work-material sideward to shape the bushing. The angle and length of the cone-shape conical region are marked as β and hn, respectively.

Cylindrical Region: This region helps to form the hole and shape of the bushing. The length and diameter of this region are designated as hl and d, respectively.

Shoulder Region: The shoulder of this region may touch the work piece to round the entry edge of the hole and bushing.

Shank Region: This is the area of the tool gripped by the tool holder of the machine

Experimental Procedure: The experiments had been carried out in a aluminium 6061-T6 Alloys in this experimental study, a high speed steel friction drill bit 5 mm diameter was used. Machining experiments were conducted on vertical machining center (VMC 100). A kistler piezoelectric dynamometer with the appropriate load amplifier was used to measure the thrust force and torque was measured in lab view data acquisition system [6].

Tool material	H.S.S
Diameter (d)	5 mm
Point angle (α)	90°
Friction angle (β)	36°
Centre region (hc)	1 mm
Conical region (hn)	6 mm
Cylindrical region (hl)	7 mm
Shoulder region	10mm
Shank region	40mm

Table 1: Levels of the Variables Used in the Experiment, Drill Diameter 5 mm

Levels	A. Feed rate (mm/min)	B. Speed (rpm)
1	100	3000
2	75	2000
3	50	1500

A, B Parameters Designation

Experimental Data: Drilling operation were conducted on the aluminium 6061-T6 alloys material and the thrust force and torque on the tool were observed for each experiment the assignment of the results for nine tests is plotted on table 3. below. These data are used to measure the percentage of contribution and obtain the optimal combination of cutting velocity and feed rate on the response variables [7].

Table 3: Thrust Force and Torque for Various Cutting Velocity and Feed Rate for Friction Drill Bit.

Speed (Rpm)	Cutting Velocity (m/sec)	Feed (mm/min)	Thrust (N)	Torque (Nm)
3000	0.785	100	446.87	1
		75	393.8	0.915
		50	335.89	0.89
2000	0.523	100	480.4	1.11
		75	474.4	1.03
		50	410.36	0.97
1500	0.392	100	614.3	1.19
		75	564.8	1.045
		50	534.8	0.986

Mathematical Formulation: The treatment of the experimental results is based on the analysis of variance (ANOVA) and the regression and correlation techniques to estimate the contribution of the variable parameters and their relations towards the response variables.

Regression analysis is used for observing the line of best fit through the data in order to make estimates and predictions about the behavior of the variables. Finally the optimal combinations of the variables were analyzed to obtain a high quality drilled holes.

Analysis of Variance (ANOVA): This method was developed by Sir Ronald Fisher. Analysis of Variance is a statistically based, objective decision making tool for detecting any difference in average performance of group of items tested. ANOVA is a technique to estimate quantitatively the relative contribution in which each controlled parameter makes on the overall measured response and is expressed as a percentage [8]. The decision rather than pure judgment, takes variation into account.

Regression and Correlation Analysis: Regression analysis is the mathematical process of using observations to find the line of best fit through the data in order to make estimates and predictions about the behavior of the variables. This line of best fit may be linear (straight) or curvilinear to some mathematical formula. Correlation analysis is the process of finding how well (or badly) the line fits the observations, such that if all the observations lie exactly on the line of best fit, the correlation is considered to be 1 or unity. In a regression problems level of independent variables (X_1, X_2, X_3,….., X_n) are set and observations are made on the dependent variable Y and the given level of X is assigned at random to each experimental units in study. The linear population model is given as,

$$Y = B_0 + B_1X_1 + B_2X_2 +..... + B_nX_n \quad (1)$$

B's are the true coefficients to be used to weight the observed X's

Cutting Velocity(X_1): Independent Variable1
Feed Rate(X_2): Independent Variable2
Response factor (Y): Dependent Variable

The equation describing the relationship among three variables is;

$$Y = a + b_1X_1 + b_2X_2 \quad (2)$$

By making the sum of squares of the errors of estimate the following least square equations can be derived.

$$\Sigma Y=na+b_1\Sigma X_1+b_2\Sigma X_2 \quad (3)$$

$$\Sigma X_1Y=a\Sigma X_1+b_1\Sigma(X_1)^2+b_2\Sigma X_1X_2 \quad (4)$$

$$\Sigma X_2Y=a\Sigma X_2+b_1\Sigma X_1X_2+b_2\Sigma(X_2)^2 \quad (5)$$

The values of a, b_1 and b_2 can be found by substituting the values of n, ΣY, ΣX_1, ΣX_2, ΣX_1Y, $\Sigma(X_1)^2$, ΣX_1X_2, ΣX_2Y and $\Sigma(X_2)^2$ in the above equations and solving them. Then the values of a, b_1 and b2 are substituted in the equation (2) to get the corresponding regression equation. From the experimental values the regression equation is derived for the Torque and the thrust force. The percentage prediction accuracy of the model is checked by the formula given below.

$$PPA=100/n\ \Sigma\ [(Exp\ value-Pre\ value)/Pre\ value] \quad (6)$$

n= Number of Experiments
Exp value =Experimental value
Pre value = Predicted value

RESULTS AND DISCUSSION

Axial Thrust Force and Torque: Figure 3. displays the variation in measured axial thrust with respect to distance from contact in friction drilling. The variations in axial thrust force fall into four different regions. Region A shows an abrupt increase in axial thrust force. It is the time when the drill makes initial contact with the work piece and drilling begins. Under constant high speed drilling between the cutting tool and work piece, friction heat is generated and the temperature rises above the recrystallization temperature of the work piece. High temperature softens and eventually melts the work piece, allowing easy penetration of the cutting tool, as evidenced by the marked decrease in axial thrust force in region B. Further drilling in region C pushes up the metal melted in region B and breaks into the work piece, thus making a hole, during which the increase in axial thrust force is gradual. Finally, in region D, with hole made, drilling stops as evidenced by the abrupt drop in axial thrust force.

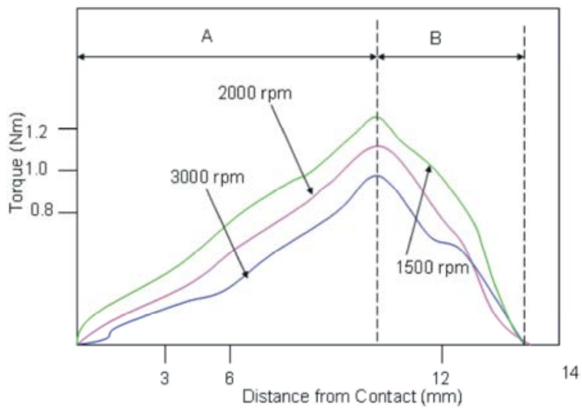

Fig. 3: Thrust Force at Friction Drilling of Al 6061-T6 Alloys at Different Cutting Velocity and Feed rate.

The figure 4. shows the variation in torque during friction drilling. The variations in torque with respect distance from contact fall into two different regions. When the drill comes into contact with the work piece resulting in enhanced friction between the two, thus causing the torque to increase. On the other hand, when the conical part of the drill has fully penetrated into the work piece and reached the depth to be machined, further drilling has little impact on the interaction between the cylindrical part of the drill and the work piece and the torque thus decreases.

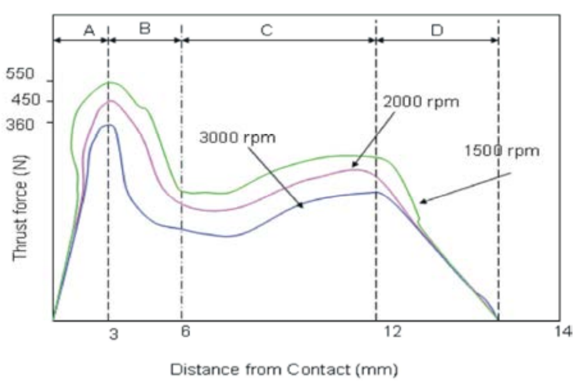

Fig. 4: Thrust Force at Friction Drilling of Al 6061-T6 Alloys at Different Cutting Velocity and Feed Rate.

ANOVA Table 5 for Thrust Force on Friction Drill

Source of variance	DOF	Sum of squares	Mean square	Test F	Percentage of contributions (%) (C)
Velocity	2	49547.1	24773.5	100.7	79.98
Feed	2	11416.3	5708.2	23.21	18.42
Error	4	983.6	245.9		1.58
Total	8	61947			

The analysis shown in table 5 was undertaken for level of significance of 5% that is, for level of confidence 95%. The table value of frequency for degree of freedom (2, 4) for both velocity and feed. Here table value is less than calculated value and then the calculated value presents a statistical significance, if not there is no statistical significance

Table Value = 6.94

The column C in table indicates that the percentage of each variable on the Thrust force. Cutting velocity is the greater influence factor on thrust force over feed rate. The percentage of contribution of cutting velocity is 79.98% followed by Feed rate is 18.42% for friction drilling of aluminium 6061-T6 alloys. The percentage of contribution of error is less than the percentage of contribution of cutting velocity and feed rate

ANOVA Table 6 for Torque on Friction Drill

Source of variance	Degree of freedom	Sum of squares	Mean Square	Test F	Percentage of Contribution (C)
Velocity	2	0.0309	0.015	23.0	44.56 %
Feed	2	0.0358	0.018	26.7	51.58 %
Error	4	0.0026	0.000		3.84 %
Total	8	0.0694	668		

The analysis shown in table 6 was undertaken for level of significance of 5% that is, for level of confidence 95%. The table value of frequency for degree of freedom (2, 4) for both velocity and feed. Here table value is less than calculated value and then the calculated value presents a statistical significance, if not there is no statistical significance

Table Value = 6.94

The column C in table indicates that the percentage of each variable on the torque. Feed rate is the greater influence factor on torque over cutting velocity. The percentage of contribution of feed rate is 51.58% followed by cutting velocity is 44.56% for friction drilling of aluminium 6061-T6 alloys. The percentage of contribution of error is less than the percentage of contribution of cutting velocity and feed rate.

Thrust Force for Various Cutting Velocity and Feed Rate for Friction Drill Tool: Figure 5 and 6 shows the variation of the thrust force with varying cutting velocity and feed rate in drilling holes using high speed steel friction drill tool. The thrust force is plotted along the y- axis and the cutting velocity and feed rate along x-axis.

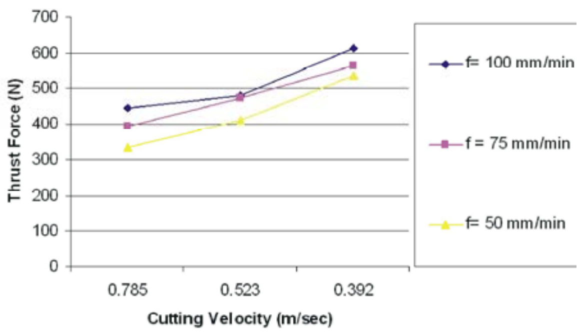

Fig. 5: Thrust Force Vs Cutting Velocity for the Friction Drill Bit

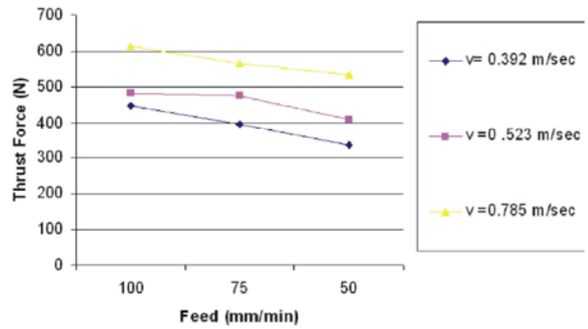

Fig. 6: Thrust Force Vs Feed Rate for the Friction Drill Bit

The figure 5 and 6 shows the response of the thrust force with varying feed rate and cutting velocity. We infer the thrust force increases with increase in feed and decreases with increase in cutting velocity. Increases in speed level producing more heat because reduce the thrust force.

Torque for Various Cutting Velocity and Feed Rate for Friction Drill Tool: Figure 7 and 8 shows the variation of the torque with varying cutting velocity and feed rate in drilling holes using high speed steel friction drill tool. The torque is plotted along the y- axis and the cutting velocity and feed rate along x-axis.

The figure 7 shows the response of the torque with varying feed rate and cutting velocity. We infer the torque increases with increase in feed and decreases with increase in cutting velocity. Increases in speed level producing more heat because reduce the torque.

The thrust force for the holes drilled by the friction drill tool with cutting velocity and feed rate as the independent variables. By solving equation 1 and 2, 3. We will get required equation

$$Y = 583.38 + (-424.94 * X_1) + (1.763 * X_2) \quad (7)$$

Thrust force

$$Y = 0.9911 - (0.3582 * X_1) + (0.00302 * X_2 \quad (8)$$

Torque

Table 7: Prediction of Thrust Force and Error in Various Cutting Velocity and Feed Rate

Speed (rpm)	Cutting Velocity (m/sec)	Feed (mm/min)	Thrust Force (N)	Pre Thrust Force (N)	Error %
3000	0.785	100	446.87	423.37	5.55
		75	393.8	379.87	3.66
		50	335.89	336.37	-0.144
2000	0.523	100	480.4	534.72	-10.15
		75	474.4	491.22	-3.42
		50	410.36	447.72	-8.34
1500	0.392	100	614.3	590.40	4.04
		75	564.8	546.90	3.27
		50	534.8	503.40	6.23

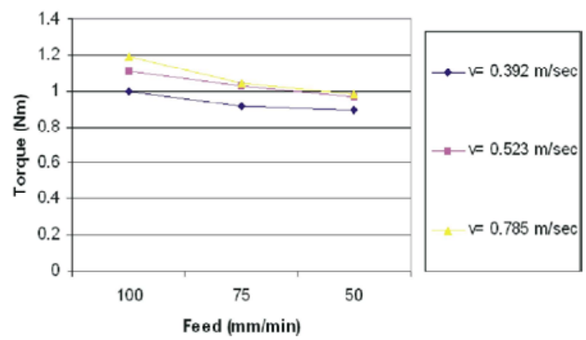

Fig. 7: Torque Vs Feed for the Friction Drill Bit

Validations of the Predicted Values with the Experimental Values for the Friction Drill Tool

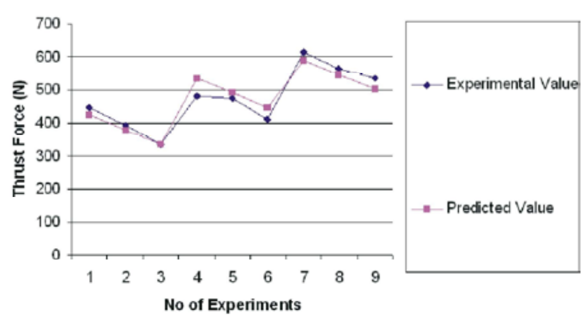

Fig. 9: Predicted Values and Experimental Values of Thrust Force for Friction Drill for the nine Experiments

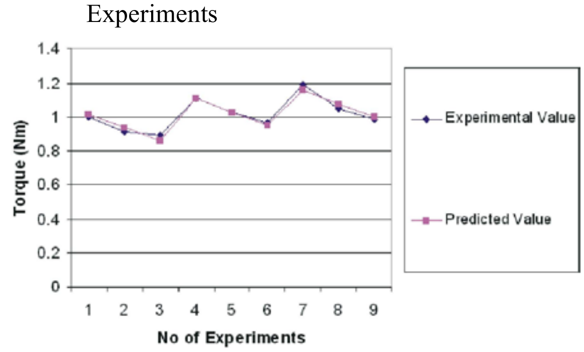

Fig. 10: Predicted Values and Experimental Values of Torque for Friction Drill for the nine Experiments

Table 8: Cutting Condition in Verification Tests for Thrust Force and Torque

Test no	Speed rpm	Feed (mm/min)	Exp Value (N)	Pre Value (N)	Error (%)	Exp Value (Nm)	Pre Value (Nm)	Error (%)
1	3000	50	310.00	336.37	-7.84	1.06	1.03	2.912
2	3000	50	360.87	336.37	7.28	1.01	1.03	-1.94
3	3000	50	367.23	336.37	9.17	1.05	1.03	1.94
4	3000	50	325.98	336.37	-3.09	0.999	1.03	-3.88

The from above figures 9 and 10 are plotted for the experimental values and the predicted values for thrust force and torque as response variables. The values along the x axis are the number of tests conducted and the values along y axis are the response variables. The following figures show the accuracy of the regression model by plotting graphs on the predicted values and the experimental values for the nine holes drilled using high speed steel friction drill bit. From the above graphs it is clear that the predicted values traces the same path similar to that of the experimental values, so the graphical image of the regression mode is holding good.

Confirmation Experiment: The verification test is the last step of Taguchi method. The cutting conditions used in this test are shown in Table 8 and indicates the comparison between the foreseen values by the model developed in Equation (7, 8) and the experimental results of thrust force. Equation (7, 8) is thus considered a feasible and an effective way for the evaluation of thrust force and torque in friction drilling of aluminium 6061-T6 Alloys material by h.s.s drill bit.

CONCLUSION

In friction drilling induced more thrust force, the selection of operating condition are important an experimental approach to the evaluation of thrust force and torque in drilling of Aluminium 6061-T6 alloys by h.s.s drill bit using taguchi methods was presented in this work. The experimental result shows that the in thrust force, speed is more influence than feed rate. The increases speed and reduce the feed rate. The thrust force is minimum. The similar case is in torque also. The correlation between thrust force, torque and cutting parameters was obtained by multi variable linear regression and compared the experimental results a feasible method for the evaluation of thrust force and torque in drilling of Aluminium 6061-T6 alloys.

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