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Optimization Of Friction Drilling Process Parameters For AA6082 Aluminum Alloy Using Taguchi Approach

Hend S. Yassin[1], Sameh Habib[2], Samah S. Mohammed[2]

1Modern University for Technology and Information
2 Faculty of Engineering at Shoubra, Benha University

Abstract

As a novel method in drilling machining process, friction drilling is a non-conventional hole making process that uses the heat generated from friction between the rotating conical tool and the workpiece to soften, penetrate and form a hole in a thin work-piece. The process involves forcing a rotating, pointed tool through a sheet metal workpiece which used to generate heat by friction to soften and generate the required hole. In this search, the selected rotational spindle speeds were 500 rpm, 800 rpm, 1250 rpm, and 2000 rpm as well as the selected feed rates were 0.04m/min, 0.06m/min, 0.10m/min, and 0.13m/min. The tool was designed with 24°, 36°, 48°, and 60° conical angles. Proper experimental design using Taguchi approach was developed in this work. The effect of rotational spindle speed, feed rates and tool conical angle on the bossing height, bushing height, hole diameter, base diameter, total bushing height and the bushing wall thickness were analyzed.

Keywords: Friction drilling, tool conical angle, bushing height, bushing wall thickness, hole diameter and Taguchi approach

1. Introduction

Friction drilling process is a non-traditional hole drilling process formed by thermal friction having the most important features such as no pollution, short machining time and long tool life. In this study, a tool with conical angle is used to generate heat by friction to soften and form a hole in a thin workpiece. The soften material flowed in tool movement direction and forming bushing under of hole. Some of the soften material flowed in counter tool movement direction and forming flake called bossing height at the top of the hole. Around the hole some of the material is spread with the effects of feed rate, torque and spindle speed [1].

The friction drilling process consists of five steps. At first, the tip of the conical tool approaches and contacts the workpiece. Then, the friction force on the contact surface produces heat and softens the work material. The tool is then extruded into the workpiece. When the tool pushes the softened work-material sideward, and pierces through the workpiece, the tool tip penetrates the workpiece. After that, the tool moves further forward to push aside more work-material and form the bushing using the cylindrical part of the tool. Finally, the tool retracts and leaves a hole with a bushing on the workpiece [2].

The most important goal of this process is to increase the bushing wall thickness for threading and available clamp load from the thin workpiece. This is provided by the bossing forming at the top of the hole and the bushing forming at the under of the hole [3].

Literature survey presented a little information about friction drilling. Some researchers studied and discussed the parameters of friction drilling process.

Dehghan et al. [4] studied the effects of process parameters such as spindle speed and feed rate on bushing height and shape, hardness and tool wear in friction drilling of titanium alloy Ti-6Al-4V were experimentally investigated using tungsten carbide tool.

ÖZEK et al. [5] demonstrated the effect of tool conical angle on the bushing height and bushing shape were analyzed of A7075-T651. The results revealed that, with increasing both tool conical angle and spindle speed the cracks in obtained bushing were advanced and the shape of bushing becomes as petal. But with increasing feed rate the bushings shapes were not changed.

Somasundaram et al. [6] discussed the roundness (hole diameter accuracy) errors on dry friction-drilled holes of Al/SiCp metal matrix composites. It is observed that the roundness error increases gradually with the increase in spindle speed within the range of 2000–3000 rpm and then reduces until 4000 rpm. The roundness error increases with the increase in feed rate within the range of 50 to 80 mm/min.

Kerkhofs et al. [7] Presented a comparison between machining by uncoated cemented carbide and (Ti, Al) N-coated flowdrills in AISI 304 stainless steel, to show the effect of coating on tool life depending upon the produced holes number. It was found that for the uncoated tools, the tool life was about 5000-15000 bushed holes, while for the (Ti, Al) N-coated flowdrills, tool lifetimes of about 100000-160000 bushed holes can be obtained.

Chow et al. [8] applied Taguchi method to explore how different process parameters such as friction angle, friction contact area ratio, feed rate, and drilling speed would affect the produced hole surface roughness, while drilling AISI 304 stainless steel by sintered carbide drill. The optimal drilling conditions that produced the smallest surface roughness were: 30^{o} friction angle, 50% friction contact area ratio, 100 mm/min feed rate, and 90 m/min drilling speed.

Fernández et al. [9] analyzed, through controlled tests at different rotational speeds and feed rates, the friction drilling of austenitic stainless steel with different thicknesses by tungsten carbide with cobalt matrix tool. The results showed that as the temperature of the workpiece increases, the form of the burr is more cylindrical with a greater depth. Higher feed rate leads to a maximum temperature reduction.

Ku et al. [10] studied the optimal machining parameters for thermal friction drilling of SUS 304 stainless steel by tungsten carbide tool. The considered machining parameters are spindle speed, feed rate, friction angle, and friction contact area ratio. The results reported that the friction contact ratio and the spindle speed were the significant machining parameters that affect the multiple performance characteristics.

Skovron et al. [11] studied different preprocess material temperatures of Al6063-T5A are to determine the effect of material temperature on the process time, the installation torque, and other joint measurable. The results reported that, a 52% reduction compared to that of a non-heated material, Reduction the installation torque by 20%.

Kaya et al. [12] investigated the effects of drilling parameters such as Friction contact area ratio (FCAR), feed rate and spindle speed on workpiece surface temperature. The tool material is tungsten carbide coated with TiN treatment. Experimental results showed that the workpiece temperature increases with the increase of drilling speed. Increasing or decreasing the friction angle and FCAR has no significant effect on the workpiece surface temperature.

El-Bahloul et al. [13] investigated experimentally the optimal parameters combination of the thermal friction drilling using experimental design method coupled with Fuzzy Logic technique.

Rajesh et al. [14] studied the mechanism and formation of the bushing length of galvanized steel. The relationship between the input parameters such as the rotational speed, tool angle and workpiece thickness, and the output parameters like the bushing length is modeled through an Artificial-Neural-Network Modeling (ANN) technique.

The purpose of this study is to analyze the bossing height, bushing height, bushing wall thickness, hole diameter, base diameter and total bushing height of AA6082 according to the tool conical angles based on taguchi approach.

2. Experimental Setup and Procedure

In the present work, the friction drilling experiments were carried out at automatic drilling machine A Z3050×16 (I). In this work, sheets of Al Alloy 6082 (Al- Mg-Si-Cu) with dimensions of 100 mm (length) × 100 mm (width) × 1.5 mm (thickness), were drilled using Friction Drilling as shown in Fig 1.

The workpiece was drilled using (S600) high speed steel tool. Figure 2, shows a schematic graph of the tool. Four tools used in this study have diameter (d) is 10 mm, center region (h_c)=2mm and center angle (α) = 45°, with conical angles of 24^{o}, 36^{o}, 48^{o} and 60^{o}. After drilling, for each condition, JMicro Vision measurement computer program was used to measure the bossing height, bushing height, hole diameter, and base diameter. Then the workpieces were cut along the hole diameter using wire cut to measure the bushing wall thickness by using JMicro vision also.

Experimental Design

This experimental investigation is established based on selecting three parameters, these parameters are cutting speed (v), feed rate (f), tool conical angle (β) in consideration four levels for each parameter as it is presented in Table 1 process.

Table 1 Input process parameters and their levels

Machining Parameters	Level No.			
	1	2	3	4
Cutting Speed (RPM)	500	800	1250	2000
Feed Rate (m/min.)	0.04	0.06	0.1	0.13
Tool Angle (°)	24	36	48	60

Taguchi technique was conducted to specify an optimal number of experiments for designing the experiment as well as to optimize the machining parameters for maximizing bossing height, bushing height, bushing wall thickness, total bushing height in friction drilling

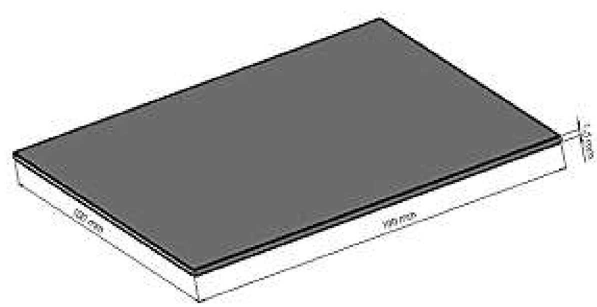


Fig. 1 Workpiece geometrical dimension

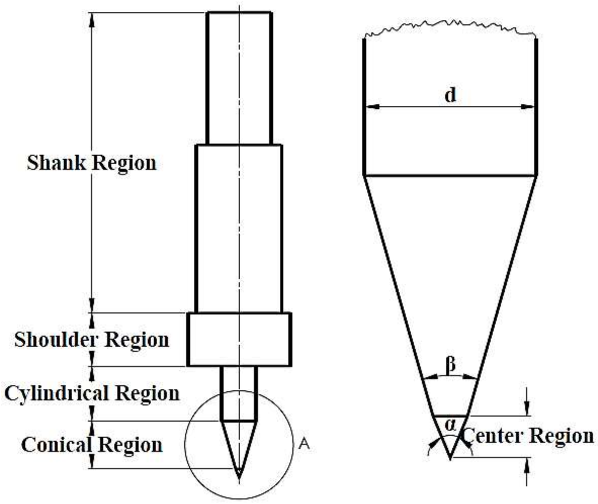


Fig. 2 Tool geometrical dimensions

Taguchi technique is a statistical approach providing an effective and briefly number of experiments by transforming the experimental data into input factors and levels. Furthermore, orthogonal array estimates the impacts of input parameters on the response mean and deviation. Based on the Taguchi's L16 orthogonal array, using Minitab statistical software there are three parameters and four levels gives sixteen experiments of FD. As the design matrix is equivalent to L16 orthogonal array of Taguchi method, the data was analyzed for contributions and for identification of optimal parameters.

3. Results and Discussion

The observations of this experimental work are investigated by using the S/N and ANOVA analyses. Based on the analysis of these observations, optimal parameters which maximize the bossing height, bushing height, bushing wall thickness, total bushing height are obtained. A set of 16 experiments is drilled in an automatic drill. After drilling each experiment the bossing height, bushing height, total bushing height, hole diameter, and base diameter were measured using J-Micro Vision measurement computer program. Then the workpieces were cut along the hole diameter using wire cut to measure the bushing wall thickness by using JMicro vision also.

Signal-to-noise (S/N) ratios were a determined for each experiment. The responses of the bossing height, bushing height, bushing wall thickness, total bushing height, hole diameter, and base diameter are analyzed using Taguchi and ANOVA analysis.

***A*. Effect of process parameters on bossing height**

In Fig. 3, main effect plots for S/N signal to noise ratio of the bossing height is plotted as it clarified. If the line for a process parameter is almost horizontally, then the parameter has no statistically significant effect and therefore this parameter has no practically significant. Otherwise, if the line for a process parameter is almost vertically, then the parameter has the most significant effect. From Fig. 3, it is very clear from the main effect plots that angle (β) is the most significant process parameter, while cutting speed (V) and feed rate (F) possess the following effect respectively. According to the larger-the-better quality criteria for the bossing height, based on the maximum point on the graph, the optimum condition for each factor indicated is β1 (24°), V3 (1250 rpm), F2 (0.06 m/min.)

The S/N ratio is an indicator of the larger variance of the output characteristics around the desired value. The higher value of bossing height value represents better criteria of friction drilling process, so the largest value of bossing height assigned by the largest value of S/N ratio. The mean S/N ratio for each level of the bossing height is summarized and called the mean S/N response table for bossing height Table 2. The impact of process parameters can be ranked as follows (angle, cutting speed and feed).

ANOVA is a statistical technique that can be used to analysis the experimental data. The method is very useful for revealing the contribution level of factor(s) on a particular response. Table 3 presents the ANOVA results for bossing height. The ANOVA table presents the P-Value and the statistical significance of each parameter. Therefore, comparing between the P generally used α-level = 0.05, it is found that if the P-value for each parameter is less than or equal to α, it can be indicated that the impact of this parameter is significant; otherwise it is not significant impact. The most effective parameter on bossing height is angle (β) contribution percentage (0.013), cutting speed (V) 0.488 and feed (F) 0.929 is the least effective parameters.

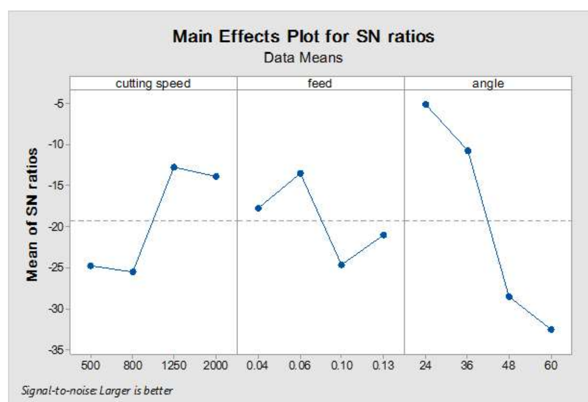


Fig. 3 Main effect plots for S/N signal to noise ratio of the bossing height

Table 2 S/N ratio Height response table for Bossing

Level	cutting speed	Feed	Angle
1	0.22075	0.26000	0.56550
2	0.17250	0.23850	0.35000
3	0.30750	0.30550	0.07050
4	0.34350	0.24025	0.05825
Delta	0.17100	0.06700	0.50725
Rank	2	3	1

Table 3 ANOVA results for Bossing Height

Sequence of variation	Degrees of freedom (DF)	Sum of squares (SS)	Mean square MS = SS/DF	Contribution	P-Value
Cutting speed	3	0.07368	0.024561	7.69%	0.488
Feed	3	0.01167	0.003891	1.22%	0.929
Angle	3	0.71216	0.237385	74.28%	0.013
Error	6	0.16120	0.026867		
Total	15	0.95871			

***B*. Effect of process parameters on bushing height**

In Fig.4, main effect plots for S/N signal to noise ratio of the bushing height is plotted as it clarified. It is very clear from the main effect plots that angle (β) is the most significant process parameter, while feed rate (F) and cutting speed (V) possess the following effect respectively. According to the larger-the-better quality criteria for the bushing height, the optimum condition for each factor indicated is β2 (36°), F4 (0.13 m/min.), and V3 (1250 rpm).

Table 4 presents the impact of process parameters can be ranked as follows (angle, feed and cutting speed). Table 5 presents the ANOVA results for bushing height. The most effective parameter on bushing height is feed rate (F) contribution percentage (46.07%), angle (β) 30.79%, and cutting speed (V) 18.25% is the least effective parameters.

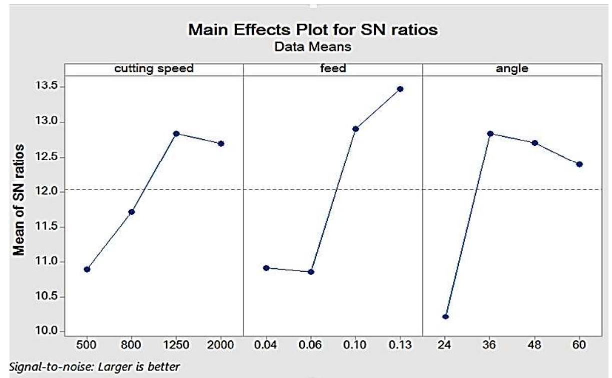


Fig.4 Main effect plots for S/N signal to noise ratio of Bushing Height

Table 4 S/N ratio Height response table for Bushing Height

Level	cutting speed	Feed	Angle
1	10.90	10.91	10.21
2	11.72	10.86	12.83
3	12.84	12.91	12.70
4	12.69	13.47	12.40
Delta	1.94	2.61	2.62
Rank	3	2	1

Table 5 ANOVA results for Bushing Height

Sequence of Variation	Degrees of freedom (DF)	Sum of squares (SS)	Mean square MS = SS/DF	Contribution	P-Value
Cutting speed	3	1.6696	0.55652	18.25%	0.019
Feed	3	4.2139	1.40444	46.07%	0.002
Angle	3	2.8165	0.93884	30.79%	0.005
Error	6	0.4474	0.07456		
Total	15	9.1468			

***c*. Effect of process parameters on bushing wall thickness**

In Fig.5, main effect plots for S/N signal to noise ratio of the bushing height is plotted as it clarified. It is very clear from the main effect plots that feed rate (F) is the most significant process parameter, while angle (β) and cutting speed (V) possess the following effect respectively. According to the larger-the-better quality criteria for the bushing wall thickness, the optimum condition for each factor indicated is F2 (0.06 m/min.), β3 (48°), and V2 (800 rpm),

Table 6 presents the impact of process parameters can be ranked as follows (feed rate, tool angle, and cutting speed). Table 7 presents the ANOVA results for bushing wall thickness. The most effective parameter on bushing wall thickness is feed rate (F) contribution percentage (35.83%), angle (β) 19.59%, and cutting speed (V) 14.65% is the least effective parameters.

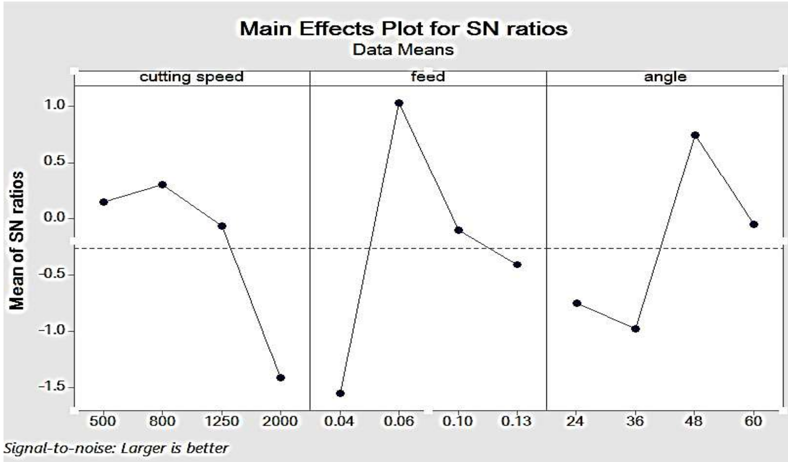


Fig.5 Main effect plots for S/N signal to noise ratio of Bushing Wall Thickness

Table 6 S/N ratio response table for Bushing Wall Thickness

Level	cutting speed	Feed	Angle
1	0.14460	-1.55091	-0.75281
2	0.29711	-0.10136	0.74547
3	-0.06160	-0.10136	0.74547
4	-1.41629	-0.40983	-0.05049
Delta	1.71340	-0.40983	1.72381
Rank	3	1	2

Table 7 ANOVA results for Bushing Wall Thickness

Sequence of Variation	Degrees of freedom (DF)	Sum of squares (SS)	Mean square MS = SS/DF	Contribution	P-Value
Cutting speed	3	0.06978	0.02326	14.65%	0.463
Feed	3	0.17069	0.05690	35.83%	0.167
Angle	3	0.09332	0.03111	19.59%	0.355
Error	6	0.14257	0.02376		
Total	15	0.47637			

***D*. Effect of process parameters on total bushing height**

In Fig.6, main effect plots for S/N signal to noise ratio of the total bushing height is plotted as it clarified. It is very clear from the main effect plots that feed rate (F) is the most significant process parameter, while cutting speed (V) and angle (β) possess the following effect respectively. According to the larger-the-better quality criteria for the bushing wall thickness, the optimum condition for each factor indicated is F4 (0.13 m/min.), V3 (1250 rpm) and β2 (36°).

Table 8 presents the impact of process parameters can be ranked as follows (feed rate, cutting speed and tool angle). Table 9 presents the ANOVA results for bushing wall thickness. The most effective parameter on bushing wall thickness is feed rate (F) contribution percentage (50.35%), cutting speed (V) 26.46% and angle (β) 17.81% is the least effective parameters.

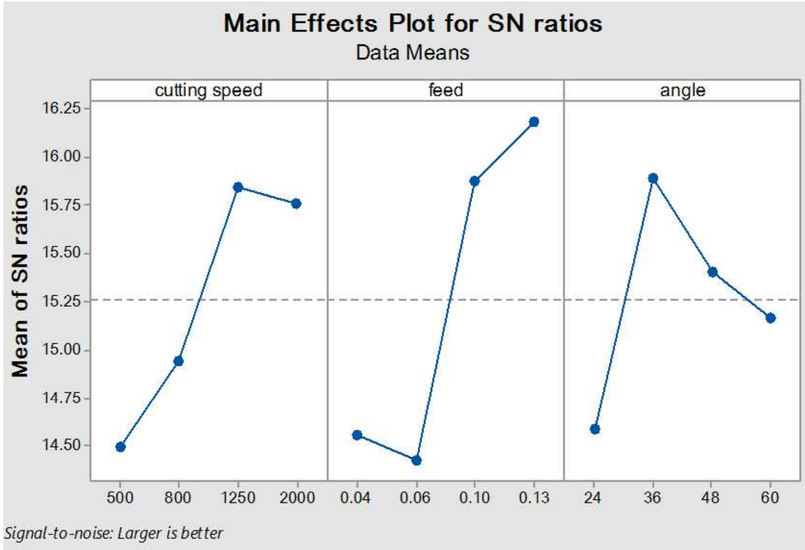


Fig.6 Main effect plots for S/N signal to noise ratio of total bushing height

Table 8 S/N ratio response table for Total Bushing Height

Level	cutting speed	Feed	Angle
1	14.49	14.55	14.59
2	14.94	14.42	15.89
3	15.85	15.88	15.40
4	15.76	16.19	15.16
Delta	1.35	1.76	1.30
Rank	2	1	3

Table 9 ANOVA results for Total Bushing Height

Sequence of Variation	Degrees of freedom (DF)	Sum of squares (SS)	Mean square MS = SS/DF	Contribution	P-Value
Cutting speed	3	2.2825	0.76084	26.46%	0.010
Feed	3	4.3436	1.44788	50.35%	0.002
Angle	3	1.5363	0.51184	17.81%	0.025
Error	6	0.4644	0.07740		
Total	15	8.6261			

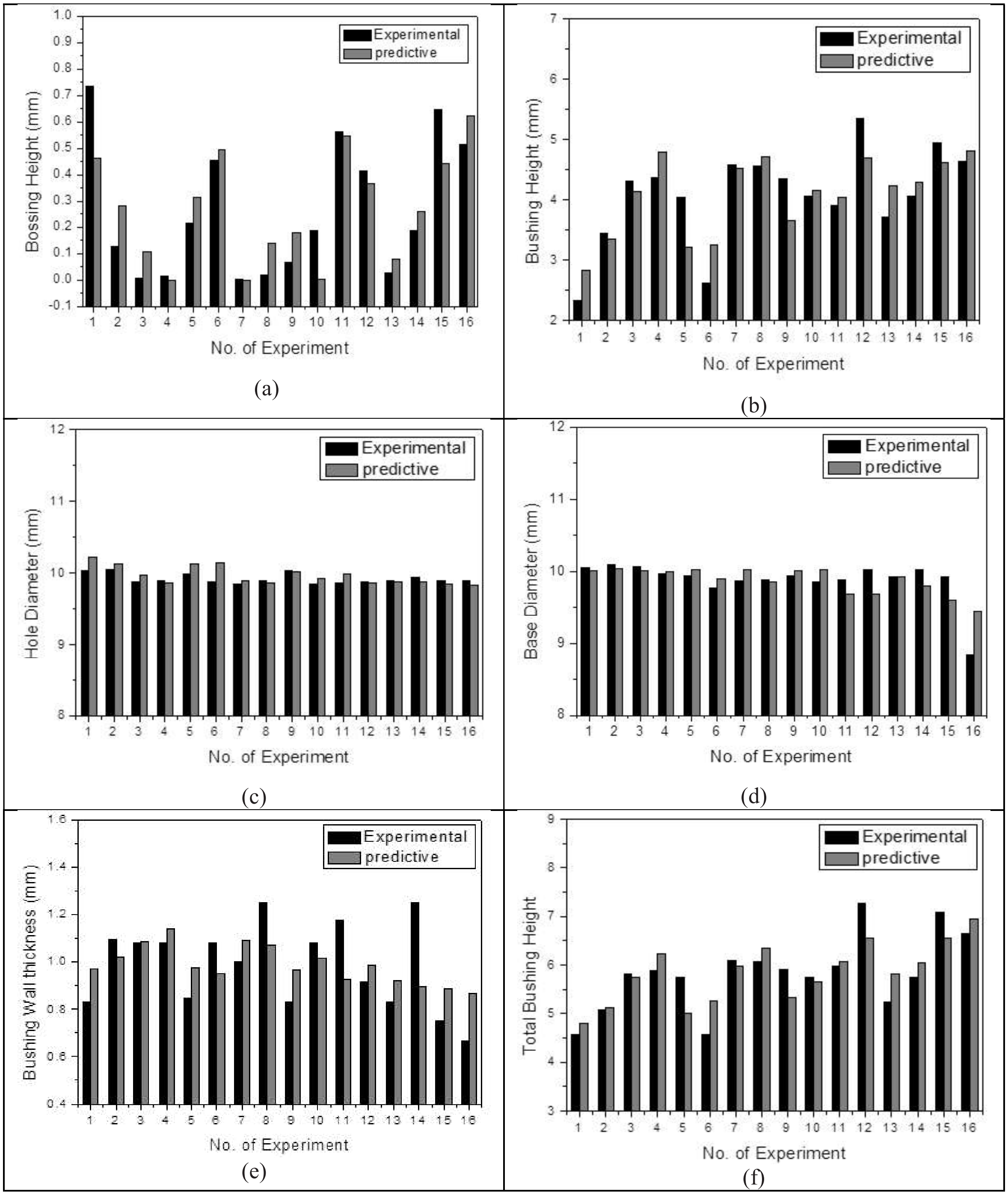
A mathematical model is developed to relate the response parameters namely bossing height, bushing height, hole diameter, base diameter, bushing wall thickness, and total bushing height with their machining parameters (cutting speed, feed rate, and tool conical angle) to facilitate the optimization process for machining Al Alloy (6082). Linear relationships are considered for the responses as shown in Table 10. The equation is in the form " Y = a+ b V + c F + d β ", Where y is the selected response, V is cutting speed, F is feed rate, β is the tool conical angle and a, b, c and d are constants. As shown in Table 10.

A Comparison between experimental and predictive values of the bossing height, bushing height, hole diameter, base diameter, bushing wall thickness, and total bushing height as shown in table 11. It can be shown that the predictive values are very close to the experimental values.

Table 10 development of Linear equation

Response Parameters	**Linear Equation**
Bossing Height	$\boldsymbol{H_{bossing}}$ =0.768198 + 0.000103311 **V** + 0.0701282 **F** - 0.0150104 **β**
Bushing Height	$\boldsymbol{H_{bushing}}$ =1.56862 + 0.000472555 **V** + 14.1654 **F** + 0.0191625 **β**
Hole Diameter	$\boldsymbol{D_{hole}}$ =10.4775 - 0.000123311 **V** - 2.32859 **F** - 0.00428958 **β**
Base Diameter	$\boldsymbol{D_{base}}$ =10.0731 - 0.000213664 **V** - 2.75346 **F** + 0.00656458 **β**
Bushing Wall Thickness	$\boldsymbol{W_{thickness}}$ =0.921969 - 0.000107761 **V** + 0.641923 **F** + 0.00318958 **β**
Total Bushing Height	$\boldsymbol{H_{total}}$ =3.83682 + 0.000575866 **V** + 14.2355 **F** + 0.00415208 **β**

Table 11 shows the experimental and predictive values of the responses



Conclusions

This investigation studies the friction drilling process of 6082 aluminum alloy using Taguchi approach. The effect of variation of cutting speed, feed rate and tool conical angle on friction drilling process were studied. Leading to the following conclusions:

(1) The optimum condition of bossing height is cutting speed 1250 rpm, feed rate 0.06 m/min and tool conical angle 24°.

(2) The optimum condition of bushing height is cutting speed 1250 rpm, feed rate 0.13 m/min and tool conical angle 36°.

(3) The optimum condition of bushing wall thickness is cutting speed 800 rpm, feed rate 0.06 m/min and tool conical angle 48°.

(4) The optimum condition of total bushing height is cutting speed 1250 rpm, feed rate 0.13 m/min and tool conical angle 36°.

(5) The experimental and predictive values of the bossing height, bushing height, hole diameter, base diameter, bushing wall thickness, and total bushing height are very close to each other.

(6) Stray bending was observed on workpiece in case of tool conical angle equals 60°.

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