Tool selection and optimization of Heat generation in Form drilling Process by Taguchi

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Abstract

Form drilling, novel method of hole making process is performed on Aluminum 8011 work material with Tungsten Carbide conical Tool. In Form drilling, a rapid rotating conical tool use for heat generated by friction between work material and tool to soften, penetrate a thin walled work piece and create the bushing without generating chips. The thrust force and torque are measured by varying the process parameters such as Speed, Feed, Diameter of tool, Thickness of work material and Magnesium powder. Temperature of the work piece during the operation is measured by Infrared thermometer. The objective of this study is to identify the most effective parameters which gives a cylindrical shaped bushing without significant radial fracture or petal formation and effect of the Heat generated during bushing formation in form drilling. Taguchi method is applied to optimize the influence parameters in form drilling for heat generation.

Keywords- form drilling; friction; heat generation; Taguchi.

1. Introduction

Form drilling is also known as friction drilling, flow drilling, thermal drilling, friction stir drilling. Form drilling is a non-traditional hole making process. Heat generated from friction between rapid rotating conical tool and work material is use to soften the work material and penetrate a hole [1-4]. It forms a bushing in-situ from the thin walled work material and is a clean, chip less process. The purpose of the bushing is to increase the thickness for threading and available clamp load. The length of the bushing is two to three times the original thickness of the work material. This process is dry drilling process and hence unlike traditional drilling, cutting fluids and coolants are not used. Figure 1 shows the various stages of form drilling. In stage 1, the conical tool comes in contact with workpiece. In stage 2, the tool has nearly, penetrated the workpiece and in this stage the thrust force is peak and slightly bush is formed. Stage 3 shows the work material ductility encompassing the tool tip. Extrusion of materials sideward to form boss can be identified. In stage 4 the tool penetrates into workpiece, the bushing of required hole is formed. In stage 5 the tool is retracted from the workpiece.

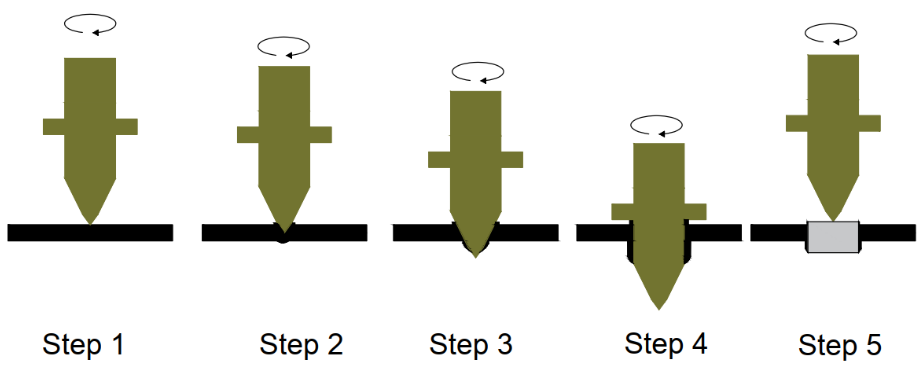


Figure 1: Illustration of stages in form drilling

1.1. Literature Survey

Scott F. Miller[1], observed thrust force and torque decreased by pre-heating the work piece temperature and bushing shape improvement with increased workpiece temperature. Scott F. Miller[2], Studied the Tool wear due to friction. Han-Ming chow[5], studied the machining characteristics of Friction Drilling on AISI 304 Stainless Steel. France et al. [6-8] investigated the strength characteristics of friction drilled holes in metal tubes. Ku et al. [9], investigated the thermal Friction Drilling effects on surface roughness and bushing length and the machining characteristics of the process were improved. Jamie D. Skovron [10], observed the reducing the process time by pre-heating the material. Kuau-yusu [11] investigated counter bore die to improve the petal formation without cracks. Mustafa kurt et al.[12] studied to utilize the Taguchi methods to optimize surface roughness and hole diameter accuracy in dry drilling of Al 2024.

2. Tool Selection

The hole is created because of frictional force developed between conical tool and work material. This frictional force develops heat, due to this the work material is softened and created the hole and bushing is formed in feed direction. The heat generation rate was calculated from the frictional toque.

Based on the pressure and contact area between the tool and workpiece, is established to predict the torque in form drilling. Two elemental tapered cylinder shapes are used to model the contact area, as shown in Figure 2. Tapered cylinder is defined by four parameters namely: two heights, h_c and h, and an angles α and β, depending upon the center and conical contact region of the tool Figure 2. A uniform pressure p, which can be estimated by the yield stress of the rigid-plastic work-material at a given temperature, is acting on the surface. The coefficient of friction μ is used to calculate frictional torque. The workpiece is sliding on the fast rotating tool surface with surface speed of V rpm. Equation for toque in the tapered cylinder area as shown in figure 2 with an inclusion angles α and β can be derived as

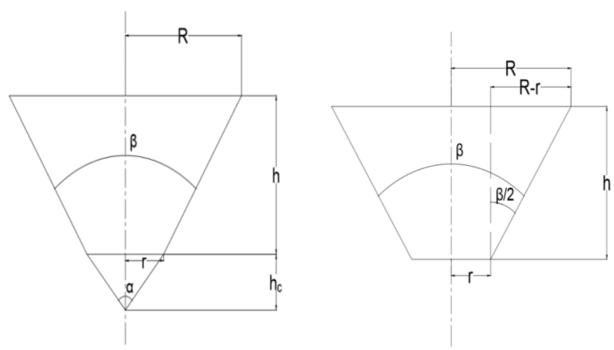


Figure 2: Center and Cone region of Tool

The torque developed in tool is sum of torque developed at central region of the tool and torque developed at cone region of the tool

$$T = T_1 + T_2 \qquad --- Eq.(1)$$

Total torque developed = T

Torque developed at central region of the tool = T_1

Torque developed at cone region of the tool = T_2

$$T_1 = \int_0^h \mu P r dA \qquad --- Eq.(2)$$

$$T_1 = \int_0^{h_c} \frac{2\pi\mu P \tan^2(\frac{\alpha}{2})}{\cos\left(\frac{\alpha}{2}\right)} h^2\, dh --- Eq(3)$$

$$T_2 = \int_0^h \frac{2\pi\mu P \tan^2(\frac{\beta}{2})}{\cos\left(\frac{\beta}{2}\right)} h^2\, dh --- Eq.(4)$$

$$T_2 = \frac{2\pi\mu P h^3}{3\cos\left(\frac{\beta}{2}\right)}\left(\frac{D}{2h} - \frac{r}{h}\right)^2 \quad --- Eq.(5)$$

Heat generation at central region and cone of the tool $(H_g) = T\omega$

$$H_g = \frac{2\pi N T}{60} \quad ----Eq.(6)$$

By solving the above equations, to get

$$H_g = \frac{2\pi N T_1}{60} + \frac{4\pi^2 \mu N P h^3}{180}\left(\left(\frac{D}{2h} - \frac{r}{h}\right)^2 + 1\right)^{1/2}\left(\frac{D}{2h} - \frac{r}{h}\right)^2 --- Eq.(7)$$

Let assume,

Yield strength of the work material (P) = 170 N/mm^2

Rotational speed of the tool (N) = 2000 Rpm

Co-efficient of friction between tool and workpiece (μ) = 0.5

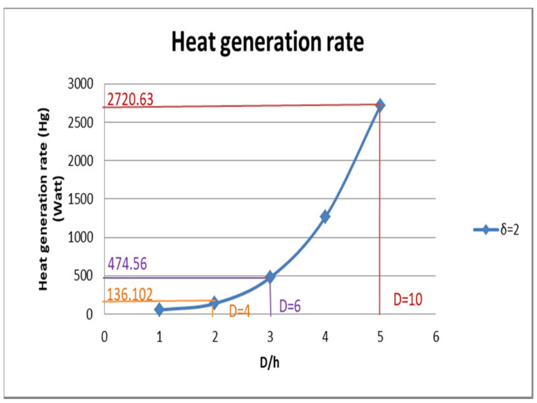
Central region cone angle (α) = 90^0 => the tool radius (r) = 1 mm

Cone angle = β

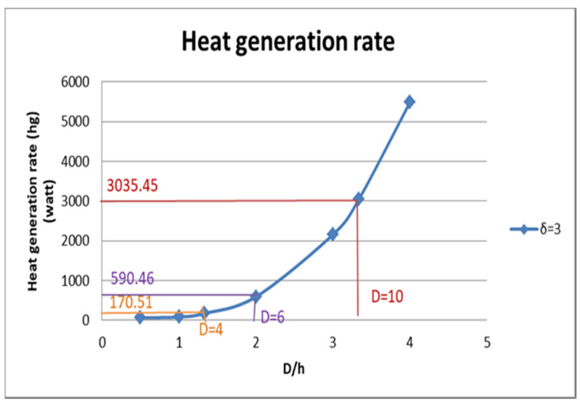
Cone height = h in mm

Assume the height of the cone is equal to thickness of the workpiece (i.e. h=δ)

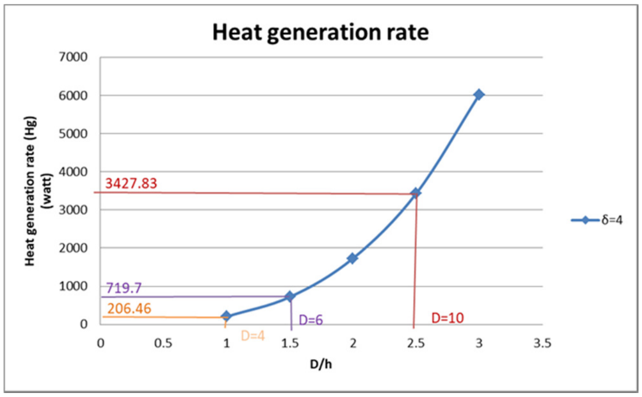
$$H_g = 52.73 + \frac{4\pi^2 \mu N P h^3}{180}\left(\left(\frac{D}{2h} - \frac{r}{h}\right)^2 + 1\right)^{1/2}\left(\frac{D}{2h} - \frac{r}{h}\right)^2 --- Eq.(8)$$



Graph 1: D/h vs Heat generation rat when workpiece thickness 2mm



Graph 2: D/h vs Heat generation rat when workpiece thickness 3mm



Graph 3: D/h vs Heat generation rat when orkpiece thickness 4mm

Figure 3: Formdrill tools

From Eq.(8) to draw the graphs for heat generation rate with respect to tool diameter and cone height ratio. In this graphs the heat generation rate is varying parabolically when the workpiece thickness is constant. From this graph, it is observed that tool diameter is the most influence parameter for heat generation rate in form drilling process. From this graph to select the tool diameters 4 mm, 6 mm and 10 mm for experimental heat generation. The selected tool must be with stand high temperature and wear resistance in form drilling due to this, tungsten carbide tool was selected.

3. Experimental Setup

A LMW JV-55 CNC Vertical machining center was used for the friction drilling of the work material Al 8011. The work material was held in a vice on the bed of the machine and the tool was held by a standard collets tool holder as shown in Figure 4 (a).Feed the program to perform form drilling according to design of experiments L18 of varying the process parameters as in Table 1. After running the form drilling program, the tip of tool mate with work piece and Heat generated by frictional force between rotational tool and work piece to soften, create a hole and penetrate bushing. During this process, thrust force and torque was measured by using dynamometer. The temperature during form drilling was measured by infrared thermometer. The sectional view of the bushing as shown in Figure 4(d)

(a) (b) (c) (d)

Figure 4 (a) Experimental setup in form drilling, (b) Infrared Thermometer, (c) Dynamometer,

(d) Cross sectional view of Bush formation

Table 1. Process parameters and their levels

Parameter	**Level 1**	**Level 2**	**Level 3**
Magnesium powder	With	without	-
Thickness of the work piece (δ)	2	3	4
Diameter of tool (D)	4	6	10
Speed (V)	2000	3000	4000
Feed (f)	0.1	0.2	0.3

Table 2. Output responses

S. No.	Mg powder	Thickness (δ) (mm)	Diameter (D) (mm)	Speed (V) (rpm)	Feed (f) (mm/rev)	Temp (Φ) (K)	Contact Time (t) (sec)	Torque (T) (N-mm)	Thrust Force (F) (Newton)	Heat Generation (Q) (Joules)
1	with	2	4	2000	0.1	306	2.8	1400	1010	821
2	with	2	6	3000	0.2	308	1.5	1520	1206	716.28
3	with	2	10	4000	0.3	354	1.2	1830	1230	919.85
4	with	3	4	2000	0.2	304	2.87	1500	1310	901.63
5	with	3	6	3000	0.3	313	2.41	1700	1352	1287.1
6	with	3	10	4000	0.1	349	3.5	1650	858	2419.02
7	with	4	4	3000	0.1	308	3.42	1470	907	1579.4
8	with	4	6	4000	0.2	320	1.87	1630	1130	1308.11
9	with	4	10	2000	0.3	330	2.02	1710	1573	723.44
10	without	2	4	4000	0.3	346	1.88	1500	1205	1181.24
11	without	2	6	2000	0.1	323	2.9	1610	1051	977.87
12	without	2	10	3000	0.2	356	3	1850	1270	1743.58
13	without	3	4	3000	0.3	343	2.2	1520	1358	1050.55
14	without	3	6	4000	0.1	336	2.5	1600	852	1675.5
15	without	3	10	2000	0.2	333	2.71	1690	1366	959.2
16	without	4	4	4000	0.2	346	2.71	1450	1108	1646
17	without	4	6	2000	0.3	344	2.27	1710	1530	813
18	without	4	10	3000	0.1	363	2.8	1930	950	1697.71

- **Heat generation in form drilling**

  The heat flux (q) generated by friction is calculated by

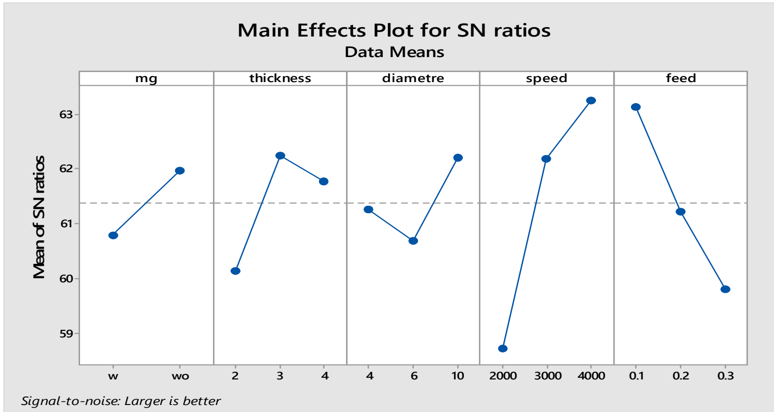
$$q = \frac{2\pi v T a}{60 A_i}$$

$$Q = q \times A_i \times t$$

Here, q= heat flux in W/m^2
Q=Heat generation in joules
V= spindle speed in rpm
T= Torque in N-m
A_i=area of interface in m^2
t = contact time of tool and workpiece
a=fraction of frictional energy converted into heat (assume a=1 i.e. 100% conversion)

4. RESULTS AND DISCUSSION

Taguchi method is used to determine the most influencing parameter in form drilling process for heat generation and the signal to noise ratio provides a measure of the impact of noise factor on performance. The S/N ratio are calculated for responses using the experimental values table 2.



Graph 2: S/N Ratios for Heat Generation

Table 3: Response table for Heat Generation

level	Mg powder	Workpiece thickness	Tool diameter	speed	Feed
1	60.79	60.12	61.26	58.70	63.14
2	61.97	62.25	60.69	62.19	61.22
3		61.77	62.20	63.26	59.79
Delta	1.18	2.13	1.51	4.55	3.35
Rank	**5**	**3**	**4**	**1**	**2**

From the performed Taguchi analysis for responses speed is the most influence parameter and next influence parameter is feed. The ranks obtained for Mg powder, workpiece thickness, tool diameter, speed and feed are 5, 3, 4, 1and 2 resspectively according to their influence on response heat generation.

5. Conclusion

In form drilling the heat is generated due to frictional force between rotational tool and workpiece. In this work the size of tools(i.e. 4mm, 6mm, 10mm diameters) selected based on the theoretical heat generation rate at the center and conical region of the tool. From the result maximum heat generation is 2419 joules at the process parameters speed 4000 rpm, feed 0.1 mm/rev, tool diameter 10mm, workpiece thickness 3mm and with using magnesium powder. From taguchi analysis the most influencing parameter for heat generation is speed and next feed.

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