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FABRICATION AND FRICTION DRILLING OF ALUMINUM SILICON CARBIDE METAL MATRIX COMPOSITE

Somasundaram G., Rajendra Boopathy S.

Department of Mechanical Engineering,
College of Engineering Guindy, Anna University,
Chennai – 600 025, India.

ABSTRACT

This study investigates the friction drilling process, a nontraditional hole-making technique, for thermal aspects, energy and power in friction drilling of aluminum silicon carbide metal matrix composites (AlSiC MMC). This type of MMC is finding applications in making automotive pats like Engine, brake system and drive shaft.

In friction drilling, a rotating conical tool is applied to penetrate work-material and create a hole in single step. The main concern in the present study is the effectiveness and advantages of this novel technique on dry friction drilled holes. The parameters considered are the composition of work piece, temperature of work piece, work piece thickness, spindle speed, and feed rate. The interaction effect of these parameters was analyzed using design of experiments applied response surface methodology. The AlSiC MMC plates were fabricated by liquid metallurgy method which is an economical and efficient one. A low volume low cost fabrication technique is adopted. Friction drilling process is compared with the conventional twist drilling process.

Keywords: Friction Drilling; AlSiC MMC plate; Chip less hole making, Thermal aspects, Interaction effect.

I. INTRODUCTION

Friction drilling is a nontraditional hole-making method that utilizes the heat generated from friction between a rotating conical tool and the work piece to soften and penetrate the work-material and generate a hole in a work piece. Friction drilling is also called thermal drilling, flow drilling, form drilling, or friction stir drilling. It forms a bushing in-situ from the thin-walled work piece and is a clean, chip less process [1]. This process is typically applied to ductile sheet metal, but there is a lack of research in friction drilling of Aluminum Silicon Carbide (AlSiC) cast metals.

Fig.1 illustrates stages in friction drilling of metal work piece. First, the tool comes into initial contact with the work piece. Next, at the main thrust stage, the tool penetrates the work piece and a high axial force is encountered. The friction force on the contact surface produces heat and softens the work material. Then, in the material separation stage, the tool penetrates through the work piece and makes a hole. Finally, the tool retracts and leaves a hole on the work piece.

AlSiC Cast metals are widely used for industrial, particularly automotive applications. The goal of this research is to fabricate Aluminum Silicon Carbide Metal Matrix Composite (AlSiC MMC) with proper composition and make holes using the novel tool Friction Drill.

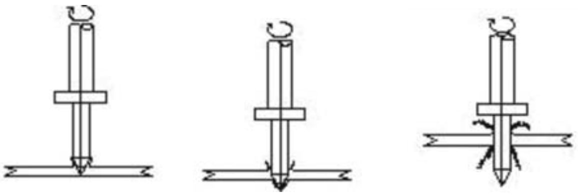

Fig.1. Stages in friction drilling process

Fig.2. Induction furnace with stirrer

A. Fabrication of Composites and properties of the composites

Fig. 2 shows the picture of the Induction furnace of 5 kg melting capacity with thermal cut off relay and stirrer attachment is fabricated exclusively for this research work. AlSiC MMC plates containing five levels of SiC particles (5, 10, 15, 20 and 25 wt%) of mean particle size 37 %m were prepared using a melt stirring-gravity casting route. The matrix material was BS 1490 Grade LM6 Aluminum casting alloy. Prior to the particulate addition, 0.5 wt% Mg was also added to improve the wetting [2]. The composite materials were faced and cut to a plate of 100×100 and thickness 2, 2.5,3, 3.5 and 4 mm

B. Physical properties of Composites

Specimens were prepared from each composition of SiC as per ASTM –E 562 and tested for its strength, density, composition and results are presented in Table 1.

Table 1 Mechanical Property of Fabricated AlSiC MMC Work Pieces

Composition of SiC	wt %	5 %	10 %	15 %	20 %
UTS N/mm^2	175.0	117.0	92.0	92.0	159.0
Micro Hardness HV @ 0.5 Kg load	68.0	62.1	68.1	68.1	69.7
Density gm/cc	2.569	2.535	2.472	2.482	2.543

C. Friction drilling of AlSiC MMC

The drilling tests were performed in ARIX vertical machining center. The work piece was kept on Hylam sheet to insulate of heat generated by Friction drilling and clamped firmly as there was a tendency to rotate the work piece because of the high torque involved. The experimental setup used in this work is presented in Fig. 3

Fig. 3. Experimental set up

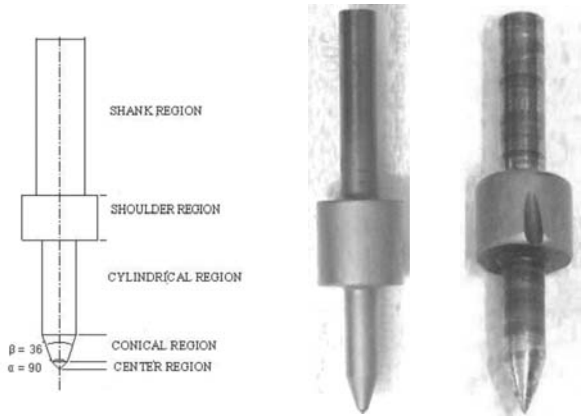

Fig. 4. Line Diagram of the tool

The holes are drilled by using friction drill specially fabricated by using HSS material. In the present study ratio of t/d (thickness of plate to drill diameter) is varied between 0.377 and 0.754. Line diagram and picture of the friction drill used for the present study is presented in Fig. 4 and the tool geometry is presented in Table 2. The tool used for the present investigation is TIN Coated High speed steel, the coating thickness is 4 %m and the coating film hardness is 2800 HV.

Table 2 Friction drilling tool geometry and Key dimensions

Dia (d), mm	α, deg	β, deg	Center region, length, mm	Conical region, length, mm	Cylindrical region, length/ dia, mm	Shoulder region	length/ dia
5.3	90	36	1	10	15/5.3	7/12	30/10

Pictures of friction drilled holes on AlSiC MMC Plates are shown in Fig. 5. The image is taken after drilling the work piece. The figure shows the extrusion mark and burrs formed on the work piece.

After the drilling operation, the drilled holes burrs are removed and smoothened by using flat file. The smoothened hole is presented in Fig. 6. The plates were used in as cast condition for the experiments.

Fig. 5. Pictures of friction drilled holes with extrusions

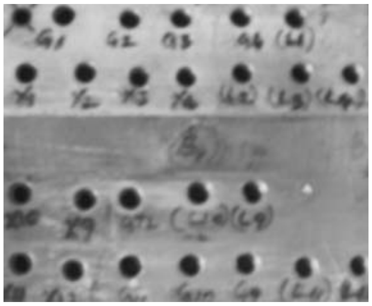

Fig. 6. Pictures of holes after hand filing

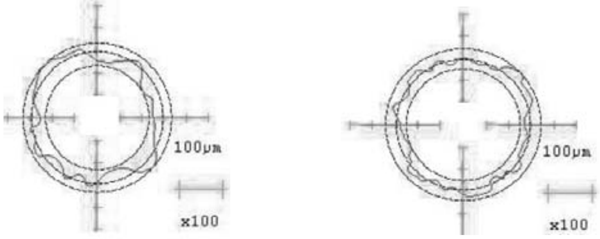

Fig. 7. Roundness profile observed

II. DEVELOPING THE EXPERIMENTAL DESIGN MATRIX

Considering the slightly wider ranges of the factors, a five level, central composite, rotatable design matrix is opted for optimizing the experimental conditions. Central composite rotatable designs of second order have been found to be the most efficient tool in response surface methodology (RSM) to establish the mathematical relation of the response surface using the smallest possible number of experiments without losing its accuracy.

In the present case, the size of the experiment is 31 for four machining parameters. The notations, units and their levels chosen are summarized in Table 3.

Table 3. Important factors and their levels

S.No.	Parameter	Notation	Unit	Levels				
				(-2)	(-1)	0	$(+1)$	$(+2)$
1.	Spindle speed	S(X_1)	rpm	2000	2500	3000	3500	4000
2.	Tool feed rate	F(X_2)	mm/min	40	50	60	70	80
3.	Weight % of SiC	W(X_3)	%	5	10	15	20	25
4.	Plate thickness	P(X_4)	mm	2	2.5	3	3.5	4

Table 4 shows the 31 set of coded conditions used to form the central composite rotatable design matrix. It comprises of full replication of $2^4 = 16$ factorial design plus 7 centre points and 8 star points. All chosen variables at the intermediate level (0) constitute the centre points and the combinations of each of the variables at either its lowest (-2) or highest $(+2)$ with the other three variables of the intermediate levels constitute the star points. Thus the 31 experimental runs allowed the estimation of the linear, quadratic and two way interactive offers of the variables on the hole quality. The method of designing such a matrix is dealt in [3]. In the present work hole quality in terms of roundness error as well as thermal effects are analyzed. The roundness errors [4] were measured using Carl-Zeiss Rondcom 54 and presented in Table 4. The roundness profile observed is shown in Fig. 7. Work piece temperature is measured by an Infra Red Sensor and presented in Table 4.

Table 4 Layout of central composite rotatable design with results

Trial No	Spindle speed, (S) rpm	Feed rate, (F) mm/min	Wt. % of SiC (W)	Thickness of plate, (P) mm	Temperature, °C		Roundness error, μ m	
					Twist Drill	Friction Drill	Twist Drill	Friction Drill
1	2500	50	10	2.5	43.3	246	54	110
2	3500	50	10	2.5	50	234	64	125
3	2500	70	10	2.5	47	229	106	186
4	3500	70	10	2.5	49	204	107	244
5	2500	50	20	2.5	57	313	74	142
6	3500	50	20	2.5	60	295	121	141
7	2500	70	20	2.5	51	201	61	100
8	3500	70	20	2.5	60	189	68	121
9	2500	50	10	3.5	59.5	255	51	107
10	3500	50	10	3.5	37	311	62	122
11	2500	70	10	3.5	48	300	96	232
12	3500	70	10	3.5	54	292	128	266
13	2500	50	20	3.5	59	238	62	188
14	3500	50	20	3.5	48.5	251	443	196
15	2500	70	20	3.5	60	232	68	190
16	3500	70	20	3.5	52	202	285	227
17	2000	60	15	3	58.4	220	750	103
18	4000	60	15	3	50	216	53	143
19	3000	40	15	3	51	264	43	151
20	3000	80	15	3	45	246	129	244
21	3000	60	5	3	52	221	66	222
22	3000	60	25	3	61	247	375	194
23	3000	60	15	2	36	274	86	112
24	3000	60	15	4	38	254	35	189
25	3000	60	15	3	47	263	132	176
26	3000	60	15	3	46	257	78	192
27	3000	60	15	3	36	306	63	198
28	3000	60	15	3	47	277	56	168
29	3000	60	15	3	43	274	101	192
30	3000	60	15	3	54	225	78	175
31	3000	60	15	3	76	259	37	182

III. DEVELOPING THE MODEL

Representing the hole quality (roundness error) as "Y", the response function can be expressed as

$$R_a = f(S, F, W, P) \tag{2}$$

The model chosen was a second degree response surface expressed as follows:

$$\begin{aligned} R_a = {} & \beta_0 + \beta_1 (S) + \beta_2 (F) + \beta_3 (W) + \beta_4 (P) + \beta_5 (S^2) \\ & + \beta_6 (F^2) + \beta_7 (W^2) + \beta_8 (P^2) + \beta_9 (SF) + \beta_{10} (SW) \\ & + \beta_{11} (SP) + \beta_{12} (FW) + \beta_{13} (FP) + \beta_{14} (WP) \end{aligned} \tag{3}$$

The values of the coefficients have been calculated by regression with the help of (4) – (7) [3].

$$\beta_0 = 0.142857\Sigma (Y) - 0.035714\Sigma (X_{ii}Y) ; \tag{4}$$

$$\beta_i = 0.041667\Sigma (X_i Y) \tag{5}$$

$$\begin{aligned} \beta_{ii} = {} & 0.03125\Sigma (X_{ii}Y) + 0.003720\Sigma (X_{ii}Y) \\ & - 0.035714\Sigma (Y) \end{aligned} \tag{6}$$

$$\beta_{ij} = 0.0625\Sigma (X_{ii}Y) \tag{7}$$

Student's *t*-test [5] has been used to eliminate the insignificant effects of parameters. After determining the significant coefficients, the final model was developed and is given as follows:

Hole Quality (Roundness error, R_a),

$$\begin{aligned} = {} & 4.55297 - (0.49042 * S) + (0.432087 * F) \\ & - (0.38042 * W) + (0.654589 * P) \\ & + (0.49339 * S^2) - (0.17563 * S * F) \\ & + (0.499375 * F * W) + (0.205625 * F * P) \end{aligned} \tag{8}$$

A. Mechanism of Chip formation in Friction drilling and Application of Peclet criterion

In general metal cutting is regarded as one of the shearing processes such as blanking, punching, etc. However, no chips are produced in such processes. Moreover, the indentation of a ductile material, in which a pointed or rounded indenter pressed into a surface under a substantially static load, causes extensive shearing; however, the chip does not form even if extremely high load is applied.

The real cause for chip formation is the combined stress in the deformation zone consisting of the compression and bending stresses [6]. In the case of friction drilling few displaced material protrudes from the surface looking like chips. This protrusion of material is unwanted and to be removed.

The Peclet number is a similarity number, which characterizes the relative influence of the cutting regime t_1 with respect to the thermal properties of the work piece material (ω_w).

Peclet criterion [7] is defined as

$Pe = vt_1/\omega_w$, where v is cutting speed m/s, t_1 is uncut chip thickness mm, ω_w is the thermal diffusivity of work piece material, m^2/s

$\omega_w = k_w/(c\rho)w$, where k_w is the thermal conductivity of work piece material, J/(ms°C), $(c\rho)\,w$ the volume specific heat of work piece material, J/(m^3°C).

If Pe > 10 [8,9] then the heat source (the cutting tool) moves over the work piece faster than the velocity of heat wave propagation [10] in the work material so the relative influence of the thermal energy generated in cutting on the plastic deformation of the work material is only due to residual heat from the previous tool position.

If 2 < Pe < 10 then the thermal energy makes its strong contribution in the process of plastic deformation during cutting.

In this research work the peclet number; Pe is 3.6 which show the influence of thermal energy in plastic deformation. Moreover, it allows revealing the mutual influence of the cutting regime, tool geometry and physical properties of the work material on this plastic deformation. For example, it is clearly shown that the amount of plastic deformation in cutting for a work material having low thermal conductivity is greater compared with that in cutting a work material having higher thermal conductivity if other cutting conditions remain the same [11].

B. Comparison with conventional drilling process

In friction drilling tool wear is very minimal in comparison with twist drill. Also the unwanted chips are not produced and the walls of the hole drilled are stronger in grain orientation in comparison with twist drill where holes are made by cutting the grains abruptly. Only concern of friction drilling is the higher thrust force, clamping force and elevated temperature which were within tolerable level in this experimentation. It can be observed from Table 4 that the roundness errors are higher in comparison with twist drill but it is of non significant order when comparing the severity of the friction drilling process.

IV. RESULTS AND DISCUSSION

The influence of different machining parameters like spindle speed, feed, composition percentage and thickness of the work piece on roundness error has been analyzed based on the developed mathematical model and discussed below.

A. Influence of spindle speed on hole quality

Hole quality in terms of Roundness errors which is minimal at and above 3000 rpm owing to the heat generated, which is sufficient for the penetration of the tool with less thrust force and torque. This trend indicates that, the increase of spindle speed increases the roundness error up to 3000 rpm and then reduces. 3000 rpm may be considered as a critical speed and after that the roundness error will reduce in friction drilling of AlSiC composite material. The reason being at higher speed, the matrix and SiC particles are pushed out easily there by producing good roundness.

B. Influence of tool feed on hole quality

Hole quality in terms of Roundness errors is minimum at the middle range owing to the reduced contact time of the tool with the work piece and the associated heat generated is sufficient for the penetration of the tool with less thrust force and torque. Further increase of feed increases thrust force, associated vibrations and thereby increases the roundness error.

C. Influence of composition (weight percentage) of SiC on hole quality

Hole quality in terms of Roundness errors is minimum at the middle range owing mainly to the number of SiC particles present at the tool-work piece interaction area is supporting the hole formation by disintegrating themselves from the matrix for the penetration of the tool with less thrust force and torque [12]. More deviation at the 25 wt% of SiC particles may be due to the clustering behavior of the particles when their number is large enough [13].

D. Influence of work piece thickness on hole quality

Hole quality in terms of Roundness errors is minimum at and above 3 mm owing to the tool stability due to the presence of the newly drilled surface and heat retained by the plate for easy plastic deformation. The temperature of the work piece throughout the experiment is between 180°C and 320°C.

V. CONCLUSION

Mathematical model for hole quality in terms of roundness error has been developed to correlate the important machining parameters in friction drilling of AlSiC MMC work piece. The experimental plan is of rotatable central composite design. The four important input variables considered for the present research study is spindle speed, tool feed rate, thickness of the work piece and weight % of SiC. The influences of all machining parameters on hole quality have been analyzed based on the developed mathematical model. The following conclusions are drawn based on this study:

1. Hole quality in terms of roundness error increases with the increase in spindle speed.

2. Hole quality in terms of roundness error increases with the increase in feed rate.

3. Hole quality in terms of roundness error decreases with the increase in weight percentage of SiC.

4. Hole quality in terms of roundness error increases with the increase in the thickness of plates.

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