Metallurgical and formability investigations on Al 8011 alloy upon form drilling

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Abstract

The investigation of microstructural analysis is very critical in knowing the metallurgical properties of any material in the field of material science engineering. The objective of the work is to draw the information about the influence of process parameters on microstructure of Al 8011. Form drilling is a method of machining in which no chips are formed and performed by the combined action of force and thermal energy. The journal covers the microstructural variations of Al 8011 alloy upon performing the form drilling by varying process parameters. Scanning electron microscope analysis was performed after form drilling of parent material Al 8011 and formability of the material is analyzed using petal formation.

Keywords Form drilling · Process parameters · SEM analysis · Microstructure · Formability

1 Introduction

In metal cutting drilling plays a major role because more than 40% of material removal processes are drilling. In conventional drilling High Speed Steels (HSS) drill is used. When HSS drill bits are used it generates high temperature during drilling because of friction [1]. Therefore, it causes the tool to wear away and leads to a shorter tool life. To increase the tool life a new type tool is used which is made of Tungsten carbide in form drilling operation called as form drill, which removes the material using thermal softening followed by penetration of tool into the work material. In this paper, the work material used for drilling is Al 8011 which has good wear resistance [2, 3]. The mechanics of material removal is due to combination of Thermal energy followed by application of Pressure. Form drilling also known as Friction Drilling, No-Chip Machining [4], Flow Drilling, Friction Stir Drilling and Thermal Drilling which is a non-conventional hole making method that utilizes the heat generated from friction between a rotating conical tool and the workpiece to soften, penetrate

the work material and generate a hole in work material. It forms a bushing from the work material and it is a clean, chip less process. The deformation of material and petal formation [5] i.e., fracture in the bushing, lip is similar to that in the plate perforation or hole flanging using a conical tool. Petal formation generates a bushing with limited surface area for making a hole. That means when the rotating conical tool touches the work surface, the heat is generated between tool and work material due to friction, this heat softens material up to plastic state and pushes sideward and forms bushing. For form drilling process parameters like speed, feed, thickness, diameter of the tool and coolant were considered [6, 7]. Boopathi et al. [8] experimentally investigated on Friction Drilling of Brass, Aluminium and Stainless Steel and measured thrust forces involved in the process of friction drilling for various speeds and feed rates with the help of drill tool dynamometer. The microscopic observations of the drilled holes are examined using Scanning Electron Microscope (SEM). Therefore, in the present work investigations are made on the metallurgical aspects using Scanning Electron

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Table 1 Composition of Al 8011

Element	Al	Fe	Si	Mn	Cu	Zn	Ti	Cr	Mg	Others
Weight%	98.1	0.6	0.5	0.2	0.1	0.1	0.08	0.05	0.05	0.22

Fig. 1 Friction drilling-Steps involved

Microscope [8–10] at a specified magnification for form drilled work material. The obtained microstructural alterations for Al 8011 material after form drilling were extracted and presented in this work.

2 Experimental procedure

A CNC Vertical machining center was used for the friction drilling [11] of the work material Al 8011 (Ref. Table 1). The work sheet was held in a vice on the bed of the machine and the tool was held by standard collets, tool holder. A sharp point is avoided and a small flat surface is provided on the cone head of tool to initiate frictional heat. As the cone penetrates into work sheet heat generation increases due to friction, subsequently material moves away due to plastic deformation and the diameter gradually increases as shown in Figs. 1 and 2. Overview of the setup in CNC machining center is shown in Figs. 3 and 4.

To machine the material, a high speed CNC machine (6000 rpm) is used to perform drilling operation. The process parameters considered were spindle Speed, feed, thickness of material and Coolants (dry, Vegetable oil, soluble oil with water). In this work L_{18} that is 18 experiments orthogonal array with mixed factorial design was considered. The process parameters are listed in the Table 2. Upon performing form drilling output responses obtained are listed in the Table 3 and the holes obtained are shown in Fig. 5a–c.

The friction force on the contact surface produces heat and softens the work material. The tool is then extruded into the workpiece, pushes the softened work material sideward, and pierces through the workpiece. Once the tool's tip penetrates into the work material,

Fig. 2 Basic Form drilling operation **Fig. 3** CNC machine with Siemens controller

Fig. 4 Experimental Setup in CNC

the tool moves further forward to push aside more work material and form the bushing using the cylindrical part of the tool. The shoulder of the tool may contact with the workpiece to trim the collar, the extruded burr on the bushing. The extruded portion of the material below the thickness of material is called “Petal”. Whereas, the extruded material above the thickness of material is called “Collar formation”. Finally, the tool retracts and leaves the hole with a “bushing” on the workpiece in addition to petal formation underneath of work material. Generally, the material composition, ratio of thickness to diameter of the tool, petal formation, cylindricity and roughness were made to judge the success of the friction drilled hole. In the present work petal formation is considered to judge the form drilling.

3 Metallurgical tests: SEM

To analyze the metallurgical aspects of form drilled work material, the drilled holes are sectioned, finished with different grades of emery papers and polished for effective examination of the work surface. After polishing Acetone solution is applied to the semicircular holes and examined the portion where form drilling is done. In this work to analyze the microstructure of form drilled holes, therefore Scanning Electron Microscope (SEM) tests are carried out at constant Magnification i.e. 2.00KX, 20 μ m and observations were made to identify major defects that occur during the form drilling process such as cracks, behavioral changes of the constituent elements forming the Al 8011 work material. The SEM images obtained at different machining conditions after testing are shown in Fig. 7 with the SEM code (A1, A2,... C5, C6) experiment wise which indicates the SEM image of work surface tested after machining which are shown below with their respective codes and also specified in Table 3.

In the microstructure of Al 8011 after form drilling when interior surface is examined it is evident that severe plastic deformation and surface delamination occurred. In addition, redeposition of work material from the tool is also observed through microstructural analysis. Through this, adhering tendency of Aluminium to the tool surface is noticed at different levels and it increases with the speed, feed and heat generation. The tedious pressure and temperature generated by the process causing the adhesion of work material to the tool is higher because of bonding energy is higher than the cohesive forces of the work material. Formability of the material increased as the heat generation and the process parameters are increased.

4 Results and discussion

Formability is estimated as a function of petal height [12] which is an indirect measurement method in production technology. By using micrometer petal height is measured for every experimental run as shown in Fig. 6a. When petal height is more the formability is more and the petal height,

Table 2 Design of experiments with levels

Parameter	Level 1	Level 2	Level 3	Level 4	Level 5	Level 6
Speed	2000	2500	3000	3500	4000	4500
Feed	0.1	0.2	0.3	–	–	–
Thickness	2	3	4	–	–	–
Coolant	Dry	Vegetable oil	Soluble oil + water (1:10)	–	–	–

Table 3 List of output responses

Exp. no.	Spindle speed (rpm)	Feed (mm/rev)	Thickness (mm)	Coolant	Petal height (mm)	SEM code
1	2000	0.1	2	Dry	3.00	A1
2	2000	0.2	3	Veg oil	3.00	B1
3	2000	0.3	4	Soluble oil mix	4.00	C1
4	2500	0.1	2	Veg oil	3.00	A2
5	2500	0.2	3	Soluble oil mix	3.00	B2
6	2500	0.3	4	Dry	3.00	C2
7	3000	0.1	2	Dry	3.75	A3
8	3000	0.2	3	Veg oil	2.50	B3
9	3000	0.3	4	Soluble oil mix	3.00	C3
10	3500	0.1	2	Soluble oil mix	3.50	A4
11	3500	0.2	3	Dry	3.75	B4
12	3500	0.3	4	Veg oil	3.00	C4
13	4000	0.1	2	Soluble oil mix	3.00	A5
14	4000	0.2	3	Dry	3.00	B5
15	4000	0.3	4	Veg oil	3.00	C5
16	4500	0.1	2	Veg oil	3.50	A6
17	4500	0.2	3	Soluble oil mix	3.00	B6
18	4500	0.3	4	Dry	3.00	C6

(a) Al 8011- 2mm thickness

(b) Al 8011- 3mm thickness

(c) Al 8011- 4mm thickness

Fig. 5 a–c Work material after form drilling

(a)

(b)

(c)

Fig. 6 a Petal formation. b Bush formation. c Collar

Fig. 7 Microstructures of form drilled holes at 2.00KX, 20 μm (**A1–C6**), (**A1, B1, C1** are at Speed=2000 rpm; **A2, B2, C2** are at Speed=2500 rpm; **A3, B3, C3** are at Speed=3000 rpm; **A4, B4, C4** are at Speed=3500 rpm; **A5, B5, C5** are at Speed=4000 rpm; **A6, B6, C6** are at Speed=4500 rpm at 0.1, 0.2, 0.3 mm/rev respectively)

formability are directly proportional to each other. From the output responses obtained (Table 3) petal height is maximum when low speeds and high feeds are utilized to machine the work material. Whereas petal height is minimum when moderate speeds, feeds are used. When single process variable is considered to control the form drilling process among the process variables feed is the most influencing. If only speed is varied, for high speeds the formability is more. Similarly, as the feed increases keeping remaining process variables as constant at higher feeds formability will be more. But here more than one parameter is varied simultaneously an optimized combination of input variables are obtained for effective output response.

The maximum formability is obtained in case of Experiment No. 3 and petal height is obtained about 4 mm, Minimum formability i.e., when petal height is about 2.75 mm in case of Experiment No. 8. From the Scanning Electron Microscope (SEM) tests the cross sectional images of form drilled holes are examined. Figure 7 shows the microstructure of parent material Al 8011 after form drilling. The microstructure contains solid solution of Aluminium and inter-dendrites network of aluminium, silicon eutectic mixture. Also, the following results were obtained.

1. The microstructure of Al 8011 reveals the formation of aluminium–silicon (Si) dendrites network structure which is formed due to casting of Al 8011 with fewer impurities present.
2. Whereas due to form drilling the silicon elements in the network bulged and few flown away from the hole drilled due to the combined effect of force and thermal energy, few adhered to the walls of the drilled hole.
3. When soluble oil with water mixture (1:10 ratio) is used as coolants due to the phenomenon of ‘Blow of fire’ (Explosions and fire flame propagation due to oil/water mixtures subjecting to very hot work surface) during form drilling, carbon deposits were observed in the microstructure.
4. The changes in the microstructure obtained after form drilling of Al 8011 will shows the element ‘Al’ leads to recrystallization which helps in improving tendency to grain growth which is observed when examined using SEM test.
5. The formability of material is one among main reasons which is cause for slight change of microstructure.
6. In Al 8011 alloy Si, Fe elements present, when they subjected to heat during form drilling their formability increases which helps the material to machine quicker.

From the Experimental investigations Process parameter’s influence is observed, as the speed increases the petal height increases till altering the Coolant and then

decreases which implies formability also increases and then decreases. Whereas feed, thickness are varying proportionally with respect to the petal height. From the experiments influence of coolants is very less when compared to other process parameters. All the results obtained are from both the Experiments as well as SEM Tests.

5 Conclusions

In the present work Al 8011 work material machined by using indigenously developed form drill tool with help of CNC JV-55 machining center. The microstructure of form drilled holes the Scanning Electron Microscope (SEM) tests were carried out at constant Magnification i.e. 2.00KX, 20 μ m. From the present work following conclusions were drawn:

1. From the analysis of metallurgical aspects, it is concluded that Bulging of silicon element and its influence is in positive manner (increases easiness to perform drilling) so as to increase the form drilling capability by improving its formability. Un-necessary chips aren’t produced at the walls of the hole drilled.
2. The drilled holes are stronger in grain orientation (Isotropic-directional property which gives strength) when machined using form drilling when compare to drilling using twist drills which cuts the grains abruptly [6].
3. Formability is more when heat generation is higher which makes the flow of material higher and increases petal formation.
4. Formability is maximum at speed 2000 rpm, feed 0.3 mm/rev and when soluble oil mixture is used as coolant.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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