Prediction Of Thrust Force And Torque In Drilling On Aluminum 6061-T6 Alloy

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Abstract

Drilling is probably the most important conventional machining process and it is undoubtedly the most widely used machining operations. Predictions of cutting forces for any set of cutting parameters are essential in optimal design and manufacturing of products. It has been predicted that most of the problems associated with hole making operations, such as drilling can be attributed to the force generated during cutting operation. In addition, accurate estimation of forces helps in design and evaluation of cutting tools and fixtures.

The present paper is aimed to investigate the influence of important machining parameters like thrust force and torque in drilling processes of Aluminum 6061-T6 alloy using conventional simple two-flute twist drill with different drill diameters and Depth of cuts. Some of these parameters are expected to affect the machinability directly and others indirectly. The present work proposes to identify the parameters that affect the drilling directly or indirectly. A comparative study will also be made between the theoretical and experimental values.

1. Introduction

Metal cutting operations such as turning, milling and drilling are widely used in manufacturing to produce a variety of mechanical components. Hole drilling is by far the most widely used process in manufacturing. Although it appears to be a relatively simple process, it is actually a very complex one. One has to consider that, there are two basic tool areas, the main cutting lips and the chisel edge, where thrust force is generated. The drilling point's chisel edge is dominant at the generation of the tool thrust force, while the torque is heavily depended on the action of the cutting lips.

A number of techniques have been used to make holes in Aluminum alloys, but conventional drilling by far is the most widely accepted hole generation method. Drilling of Aluminum alloy materials presents a plethora of questions to the engineers and scientists. A number of research endeavors have been made in the recent past to fully characterize the drilling process for Aluminum alloys and FRP composite materials. The efforts have been made in the direction of optimization of the operating variables and conditions for minimizing the drilling induced damage. Many analytical and numerical models have been developed by many researchers in the past 50 years for predicting torque and thrust force in drilling. Early drilling models have been developed by Shaw [1], Oxford [2], Shaw and Oxford [3], Pal et al [4], Williams [5, 6], Armarego [7,8]. A methodology was presented by Armarego and Cheng [7,8] in which a series of oblique cutting slices was used to model the drilling process. This approach was further expanded by Watson [9–12] for more detailed modelling of material removal in both the cutting lip and chisel edge regions.

Chen [13] observed that the effect of the cutting speed on the cutting forces is insignificant for the same drill material. The cutting forces on the other hand were found to be lower at lower feed rates. It was further concluded that in order to improve the hole quality at exit, the feed rate at exit needs to be decreased during the drilling process. Bhattarcharya et al. [14] studied hole drilling in kevlar composites under ambient and cryogenic conditions, the latter being obtained by the application of liquid nitrogen at the drill site. The drill bits under cryogenic conditions underwent a much lower wear rate, resulting in much lower thrust forces and material damage. Ramulu et al. [15] observed that in case of drilling with HSS and HSS-Co drills, the highest temperatures occurred at higher cutting speeds and lower feeds. Increasing speed leads to increased tool wear, larger entrance and exit burrs, larger damage rings and decreased number of holes drilled. Increasing feed leads to increased drill thrust and torque, smaller entrance and exit burrs, reduced damage width and increased number of holes drilled.

Chen [13] studied the effect of tool geometry on cutting forces. Various tool geometry parameters such as point angle, helix angle, chisel edge rake angle and web thickness were analyzed. The tangential force, that is, torque was found to decrease with the increasing point angle, whereas the thrust force increased. Bhattarcharya et al. [14] proposed the use of modified drill point geometries to effectively drill holes in Kevlar composites.

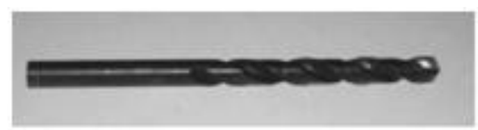
2. Scope of work:

The difficulty of carrying out experimental tests on drilling processes like drilling force estimation (thrust & torque), drilling time estimation etc is that the drilling takes place in about a few microseconds. The resultant peak effects have to be recorded in such short durations. Dynamo meters, Strain gauge techniques, optical sensors are a few techniques available for measuring cutting forces in order to assess the structural integrity. In the Present Paper, Theoretical and experimental methods are used to determine cutting forces of drill bit of various diameters like 6,8 10 and 12 mm on Aluminum6061 alloy during drilling operations. A few test cases are carried out in order to establish the methodology for experimentation. The forces are compared as obtained from the theoretical and the experimental tests. The advantages and limitations of the techniques are highlighted.

3. Theoretical methodology

Tool materials and geometry

Tool geometry is a relevant aspect to be considered in drilling of Aluminum alloys, particularly when the quality of the machined hole is critical. The effect of the machining parameters is another important aspect to be considered. It can be seen that cutting speeds from 20 to 60 m/min are usually employed, whereas feed rate values lower than 0.3 mm/rev are frequent. Cutting speed is not a limiting factor when drilling aluminum alloys, particularly with hard metals, therefore, the use of cutting speeds below 60 m/min may be explained by the maximum rotational speed of conventional machining tools, since drill diameters above 10mm are rarely reported. Another reason for keeping cutting speeds below 60 m/min may reside in the fat that higher cutting speed values lead to higher cutting temperature, which in turn may cause the softening of the matrix. The use of feed rates below 0.3 mm/rev may be associated to the delamination damage caused when this parameter is increased. Finally, Fig. 1 shows that HSS tools are preferred when drilling at higher cutting speeds and, in contrast to metals, also at higher feed rates.



HSS twist drill

Fig. 1. Tools used on Aluminum alloy - HSS Twist drill

Cutting forces in drilling to be considered:

While drilling the drill is subjected to the action of forces. This can be conveniently resolved into three components, a tangential component PZ, a radial component PY and an axial component PX. PX is the thrust force in drilling.

Various empirical formulae exist for calculation of the axial force PX. But because of uncertain conditions at the chisel edge and other more suitable factors, there are considerable variations in the computed values. The following equations are taken from Machine Design Data Book and Metal cutting theory books.

$$\text{Thrust force (PX)} = 0.195 HB S^{0.8} d^{0.8} + 0.0022 HB\, d^2$$

$$\text{Torque (PZ)} = C\, d^2 S^{0.8} HB^{0.7}$$

Where: HB= Brinell's hardness number (95 for Al 6061 alloy), S = feed (m/rev), d = diameter of drill bit (m), C = constant = 2×10^6

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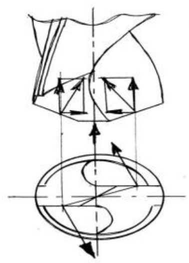

Fig. 2. Cutting forces in drilling.

Specifications of Work piece:

Material: Aluminum 6061-T6 alloy.

Size: 36x36x11 mm.

Work piece material properties:

Property Name	Values (Units)
Density	2.7 g/c.c
Brinell's Hardness	95
Rockwell Hardness 'A'	40
Rockwell Hardness 'B'	60
Ultimate Tensile Strength	310 Mpa
Tensile Yield Strength	276Mpa
Elongation at break	12%
Modulus of Elasticity	68.9 Gpa
Ultimate bearing Strength	607 Mpa
Bearing Yield Strength	386 Mpa
Poisson's Ratio	0.33
Fatigue Strength	96.5 Mpa
Shear Modulus	26 Gpa
Shear Strength	207 Mpa
Specific Heat Capacity	0.896 J/g-°C
Thermal Conductivity	167 W/m-k

Work piece material composition:

Element Name	Percentage composition by weight
Aluminum	95.86 – 98.56 %
Chromium	0.04 – 0.35 %
Copper	0.15 – 0.40 %
Iron	0.7 % max
Manganese	0.15 % max
Magnesium	0.8 – 1.2 %
Silicon	0.40 – 0.80 %
Zinc	0.25 % max
Titanium	0.15 % max
Trace Elements	0.15 % max

4. Experimentation

The drilling tests were performed on a Radial drilling machine using a high speed steel two flute twist drill with a 3.2 mm web thickness, 300 helix angle, and 1180 point angle. The work piece was an aluminum6061 alloy. A spindle speed of 170 rpm was used. Three drills with 6, 8, 10 and 12 mm diameters were used for feed rate of 0.2 mm/rev.

Fig.3. Instrol device for Drill Dynamometer

Fig.4. Drill Dynamometer setup

Fig.5. Drilling machine Setup

A drilling torque dynamometer was available to directly measure the thrust force and torque. However, the same cutting force components that comprise the thrust force are also used to calculate the torque. Therefore, it is reasonable to assume that since good agreement was found between the measured and predicted thrust forces, good agreement would also occur between the measured and predicted torque.

Table 1 shows the measured thrust force and torque of different drill diameters with varying depth of cuts while experimentation.

Experimental results of aluminum 6061 alloy:

S. No	Diameter of Drill Bit(mm)	Speed of Spindle (rpm)	Feed of the spindle (mm/rev)	Depth of cut (mm)	Axial Thrust (N)	Torque (N-cm)
1	6	170	0.2	Near the tip	402.2	245.2
2	6	170	0.2	Middle of the work piece	313.9	186.3
3	6	170	0.2	Through the Work piece	235.4	147.1
4	8	170	0.2	Near the tip	500.3	382.5
5	8	170	0.2	Middle of the work piece	421.8	343.3
6	8	170	0.2	Through the Work piece	313.9	313.9
7	10	170	0.2	Near the tip	667.0	578.7
8	10	170	0.2	Middle of the work piece	549.3	529.7
9	10	170	0.2	Through the Work piece	431.6	500.3
10	12	170	0.2	Near the tip	794.6	841.2
11	12	170	0.2	Middle of the work piece	686.7	765.1
12	12	170	0.2	Through the work piece	578.7	725.9

The thrust force and the torque are the two important response variables under investigation in the present study. The thrust force increases with the increase drill diameter and decreases with the increase depth of cut for all the feed rates used during experimentation.

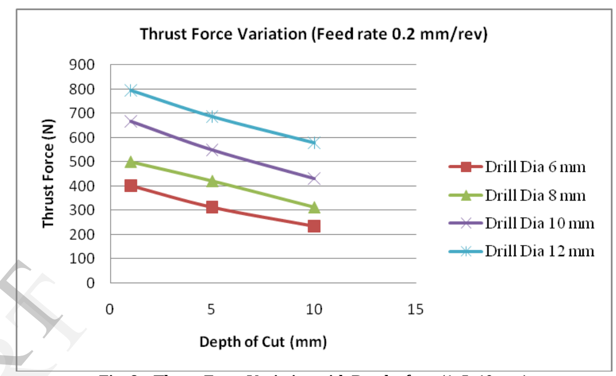

Fig. 6.a Thrust Force Variation with Depth of cut (1, 5, 10 mm)

The torque behaviour was also influenced by the drill point angle and the feed rate. The torque increased with an increase in the drill diameter and decreased with an increase depth of cut for all the feed rates, as seen in Fig. 3a. The torque increased with an increase drill diameter for the entire feed rates fig 3a.

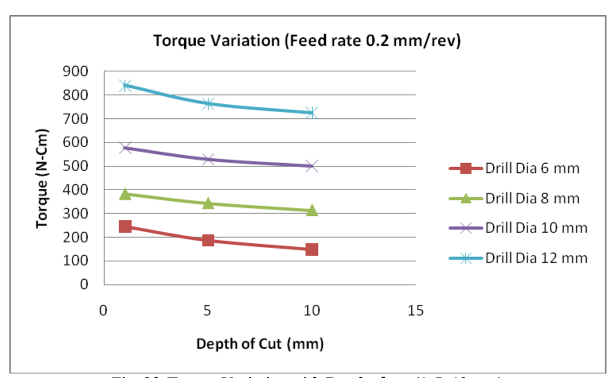

Fig. 6.b Torque Variation with Depth of cut (1, 5, 10 mm)

5. Results and Discussion

A comparison of the predicted and measured torque and thrust forces are very good agreement for the drilling thrust force was observed. As expected, a larger thrust force occurred for larger diameter drills and higher feed rates.

The following table-2 compares the results obtained from the Theoretical and experimental cutting forces while drilling on Aluminum 6061 T6 Alloy.

Drill bit Diameter (mm)	Axial Force (N)		Torque (N-cm)	
	Theoretical	Experimental	Theoretical	Experimental
6	350.31	317.19	194.2	192.9
8	429.89	412.89	353	346.6
10	586.30	549.36	540	536.2
12	711.46	686.39	770.1	768.4

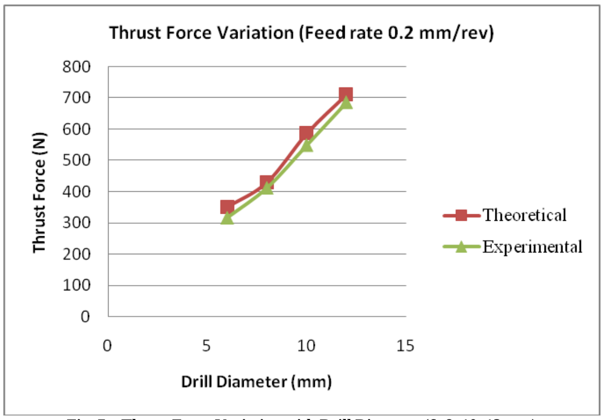

Fig. 7.a Thrust Force Variation with Drill Diameter (6, 8, 10, 12 mm)

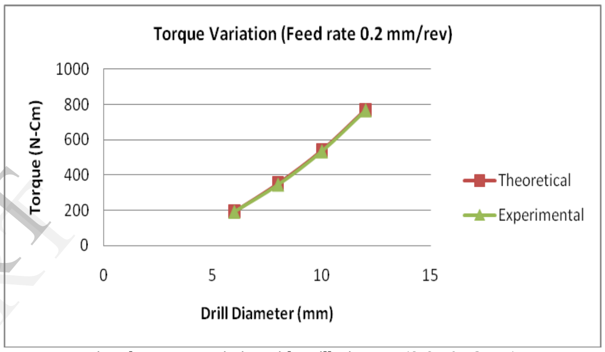

Fig. 7.b Torque Variation with Drill Diameter (6, 8, 10, 12 mm)

6. Conclusions

A Three-dimensional drilling model has been described for determining the thrust force and torque in drilling. The model is applicable to general drill geometries, as characterized by the point and flute geometry, under cutting conditions. The predicted forces can be readily coupled with solids models, so that complex drill geometries can be accurately represented. Because the technique described is independent of any specific drill geometry, it can be readily applied to non- conventional drills other than standard twist drills. Other applications of the technique include drill design and selection for high speed and dry drilling. This technique can be extended to predict drill tip temperatures, which is an important indicator of drill life and drilling performance. Research has been conducting to predicting the deformations and stresses through finite element methods while drilling on composite materials.

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