Optimization of Machining Parameters during Drilling of Aluminium 2014 Alloy using CATIAV5R19 and DEFORM-3D: Numerical Simulation and Experimental Validation

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Abstract

Drilling, a hole generating process is especially important because it accounts for a large portion of overall machining. Out of all machining operations, drilling is the most commonly applied method for producing holes using twist drill for mechanical assemblies with rivets and fasteners. Burr removal is a very important part of the manufacturing process. Stacks of material on sections of an aircraft are assembled and drilled by hand. Due to extensive burr formation the sheets must be destocked so that burrs can be removed and then the stacks are reassembled and fastened together. If burrs are minimized in the drilling process, this would reduce the necessity for the sheets to be destocked and deburred. One approach to minimizing burrs is to lower the thrust force in drilling through suitable modification of the drill geometry. HSS-R (DIN 338) two flutes uncoated conventional twist drills of 3 different diameters (8, 10 and 12mm) with 118^0 point and 30^0 helix angles are used. Drill bits tool geometry altered by tool&cutter grinder, obtained 110^0, 100^0 point angles. Further clearance angles also varied by 4^0, 6^0 and 8^0. Drilling was performed on Al 2014 alloy work piece of rectangular cross section having dimensions 300mmx50mmx10mm as per taguchi L_{27} orthogonal array. A kistler (type 9272), four components (F_X,F_Y,F_Z and T) dynamometer was used to measure thrust force (F) and Torque (T) and the signal was processed to a computer by a multichannel signal amplifier (Kistler 5070 type) was used to record the thrust force and torque. Finally, confirmation test have been carried out to compare the predicted values with the experimental values to confirm its influence in the analysis of thrust force and torque. This paper focuses on the optimization of the thrust force and torque for drilling and analyzes their relationship with burr size as a function of the drill geometry and parameters. In the study, three dimensional (3D) computer aided engineering (CAE) based simulation of drilling by using commercial software DEFORM 3D has been compared to the experimental results of thrust force and torque in machining of Aluminium 2014 alloy. In the following analysis, orthogonal cutting models are proposed, considering several processing parameters such as cutting speed, feed, drill diameter, point angle and clearance angle. A modelling at the tool-work interface is carried out. Work material flow around the cutting edge is carefully modelled with adaptive re-meshing simulation capability of DEFORM 3D. The process simulations are performed at variable feed rate (18, 20, 26 mm/min), cutting speed (465,695,795 rpm) and analysis is focused on thrust force and torque generated during the process of machining. Close agreement is observed between the CAE simulation, analytical modeling and experimental values.

Keywords: Al 2014 alloy, Thrust Force, Torque, Taguchi-Design of Experiments, Modeling and simulation

1. INTRODUCTION

Burr removal is a non-value added process [1] and might represent as much as 30 percent of the cost of finished parts. As deburring is non-productive and costly finishing process, it should be minimized or avoided. Any material leading to limited burr formation is therefore advantageous. Recent studies and literature have pointed out tremendous issues related to burr formation and deburring operations. So it is necessary to push the understanding of the burr to something much greater than just a nuisance to be removed or ignored. One approach to minimizing burrs is to lower the thrust force in drilling through suitable modification of the drill geometry. It is found from the literature that there is a scope for comparing CAE analysis with experimental results. The main advantage of CAE analysis over experimentation is that simulation can be performed for wide range of input parameters to enumerate their behavior on performance characteristics. The values of thrust and torque obtained experimentally found, which are (depicted in table.1) to be correlating with the values from DEFORM 3D simulation [2, 3].

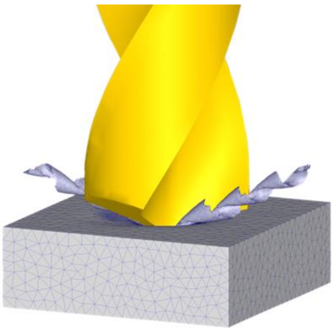

Fig.1 Drilling Simulation in DEFORM-3D

2. EXPERIMENTATION

In this study, the experiments were carried out on a radial drilling machine (Make: Siddapura Machine Tools, Gujarat, INDIA) to performed holes on Al 2014 alloy work piece. The drill tools used were HSS-R (DIN 338) twist drills made by Bosch and commercially available with diameters of 8, 10 and 12mm with 118^0 point angle and 30^0 and 136^0 chisel edge angles are used. Drill bits tool geometry altered by tool&cutter grinder (shown in fig.2). A Kistler type 9272, Kistler

ISBN: 978-93-80689-28-9

Instrumente AG, CH8408, Winterthur, Switzerland, four components (F_X, F_Y, F_Z and M_Z) dynamometer was used to measure thrust force and torque and the signal was processed to the computer by a type 5070 multichannel signal amplifier. The finite element analysis was executed by DEFORM-3D software. It is developed by SFTC (Columbus, OH), The FEM analyses in DEFORM-3D (shown in fig.1) having three steps: preprocessor, simulation and post processor (Deform 3D-V6.1, User's Manual). In the pre-processor, the original data for modeling and simulation should be set 9. The study shows drilling of rectangular shape aluminum 2014 alloy using a HSS drill bit. The tool and Workpiece are modeled as plastic geometry shape and figure 3 presents the meshed model of tool and work piece. In this, drill bit having elements of 8780 and nodes of 2886 and work piece has elements of 46394 and nodes of 10364.

2.1 Material Properties

The composition of Alluminium 2014 alloy consists of Chromium: 0.1%, Copper: 3.9% - 5%, Iron: 0.5% ,Magnesium: 0.2% - 0.8%,Manganese: 0.4 - 1.2%, Silicon: 0.5% - 0.9 Titanium: 0.15%, Titanium : 0.2% Zinc: 0.25% and remaining is alluminium.

1. PLAN OF EXPERIMENTS AS PER TAGUCHI METHOD

The orthogonal array forms the basis for the experimental analysis in the Taguchi method. The selection of orthogonal array is concerned with the total degree of freedom of process parameters (depicted in table.1). Total degree of freedom (DOF) associated with five parameters is equal to 10 (5X2).The degree of freedom for the orthogonal array should be greater than or at least equal to that of the process parameters. There by, a L27 orthogonal array having degree of freedom equal to (27-1) 26 has been considered, which is used to optimize the cutting parameters for thrust force and torque using the S/N ratio and ANOVA for machining of Alluminium 2014 alloy and predicted results were nearer to the experimental results.

Table 1: Levels and Factors

LEVELS	FACTORS				
	Spindle Speed (rpm)	Feed rate (mm/min)	Drill diametr (mm)	Point angle (deg)	Clearance angle (deg)
	A	B	C	D	E
1	465	18	8	100	4
2	695	20	10	110	6
3	795	26	12	118	8

Fig.2 Alteration of drill geometry using tool &cutter grinder

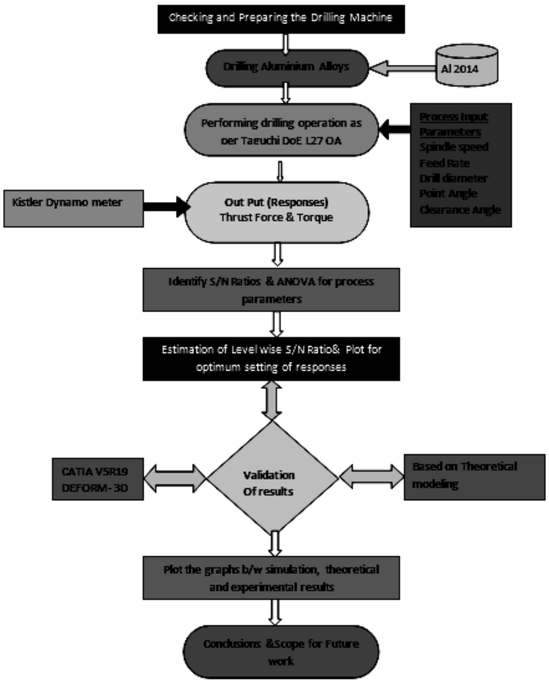

Fig.3.Flow chart for scope of work

Table 2: Plan of experiments based on Taguchi L_{27} orthogonal array and compare experimental, analytical and simulation results

RUNS	Experimental		Analytical		Simulation	
	F_{th} N	M N m	F_{th} N	M N m	F_{th} N	M N m
1	262	155	282	125	338	165
2	288	197	300	223	426	245
3	241	154	270	185	372	235
4	235	105	280	132	423	164
5	335	187	355	205	512	265
6	252	110	300	136	452	166
7	241	155	295	175	492	195
8	335	197	325	202	525	241
9	395	194	405	206	436	238
10	232	152	272	172	378	152
11	248	179	298	195	308	147
12	265	217	335	211	381	272
13	316	187	346	172	406	202
14	286	147	321	177	391	129
15	202	179	242	203	346	223
16	208	257	268	295	284	195
17	265	137	295	167	395	217
18	265	110	305	130	408	154
19	316	176	296	196	422	147

20	286	197	305	207	361	187
21	252	164	282	194	389	172
22	241	152	281	142	381	191
23	135	174	165	196	275	240
24	395	179	409	198	429	159
25	186	157	212	172	324	183
26	252	271	272	251	316	217
27	316	218	336	228	471	208

3. SIMULATION

DEFORM (Design Environment for Forming)-3Dfor developing numerical simulation for metal cutting processes, which is a commercially available FEM solver that can be applied to several manufacturing processes. Even though its original area of specialty was metal forming operations like forging, it has expanded to include modules that support machining operations .By giving drill geometry and material properties in standard manner, simulation results (shown in fig.3&4) are obtained.

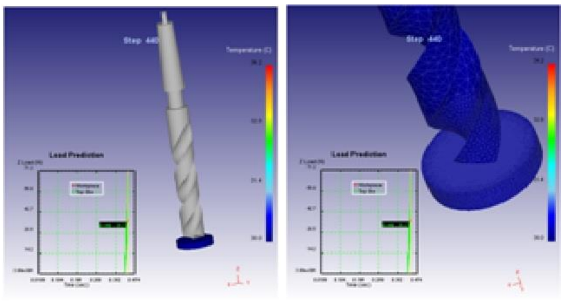

Fig.3 Drill bit CATIA Model and Deform-3D load simulation Model

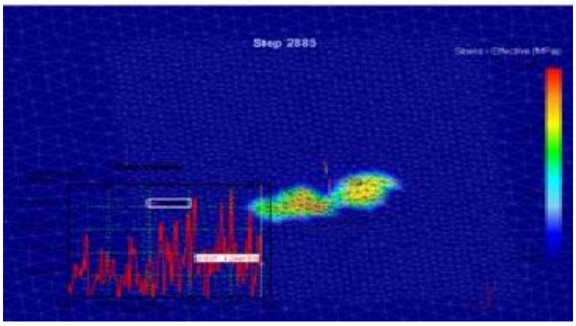

Fig.4 Deform-3D thrust and torque simulation models

4. ANALYTICAL MODELING

From basic metal cutting principles by shaw and oxford, saffron's (fig.5) and Rochester's model equations [4, 5,6] By taking the following data thrust force and torque calculated analytically then from theory of plasticity, burr height and thickness empirical relations obtained by supporting from previous researchers [7-10]. These relations are functions of thrust force, torque, drill geometry and material properties such as hardness and shear strength, so that the results obtained from these are more effective. Solutions of these model equations are solved by Matlab@2010 version; experimental values are given as inputs, obtained outputs.

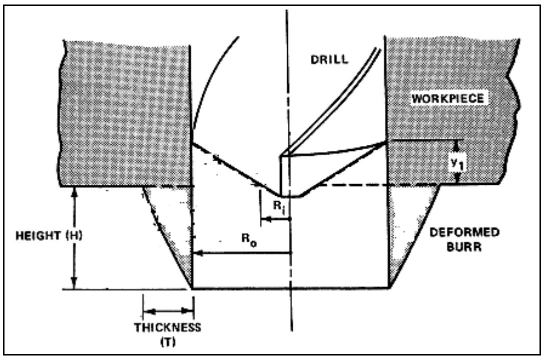

Fig 5 Saffron's Burr formation model [7]

Helix angle =30^0
Drill point angle = 118^0
β = Drill point angle / 2 = 59^0
Drill diameter = 10mm
R_0 = Drill diameter/2 = 5mm
Web thickness=1.6mm
Chisel edge length= 3.2mm

$$\tan\vartheta = \frac{(1-q^2\sin^2\beta)\tan\delta}{\sqrt{(1-q^2)}\sin\beta} - \frac{(q\cos\beta)}{\sqrt{(1-q^2)}} \quad \text{-----------------1}$$

$\vartheta = normal\ rake\ angle$
$\mu = drill\ friction\ angle$

$$\mu = \frac{\pi}{6} + \frac{\vartheta}{2}$$

$\delta = Helix\ angle$
$\beta = Half\ of\ the\ point\ angle$

$$q = \frac{web\ thickness\ of\ drill}{diameter\ of\ the\ drill}$$

f=feed, mm/rev
y_1 = Initiation height of the burr

$$\tau_\omega = shear\ strength\ of\ the\ material, \frac{N}{mm^2}$$

$$\varphi = \frac{\pi}{4} + \frac{\vartheta-\mu}{2} = chip\ shear\ plane\ angle$$

$$\frac{F_z}{\tau_w y_1^2} = \epsilon \tan\beta\left(\frac{\cos(\mu-\vartheta)}{\sin\varphi\cos(\varphi+\mu-\vartheta)}\right) \quad \text{--------------------2}$$

F_Z = Cutting force of the drill

$$F_z = \frac{F_{thrust}}{\sin\beta\tan(\mu-\vartheta)}$$

$$\epsilon = \frac{f}{2y_1}$$

$$B_h = \frac{R_0^2 - R_i^2}{3R_0^2} \quad \text{------------------------3}$$

$$R_i = R_0 - y_1\tan\beta$$

$$B_t = \frac{(R_o-R_i)}{\tan\beta} \quad \text{------------------------4}$$

$$\frac{F_{thrust}}{d^2 H_B} = 0.55\frac{S^{0.8}}{d^{1.2}}\left[\left(\frac{1-K}{(1+K)^{0.2}}\right) + 2.2K^{0.8}\right] + 0.07K^2 \quad \text{----------5}$$

$$K = Ratio\ of\ chisel\ edge\ length\ todrill\ diameter = \frac{c}{d}$$

5. RESULTS and DISCUSSIONS

After conducting experimentation, measured the responses then from minitab@17 design of experiments software S/N Ratios for means estimated. For significant parameters through ANOVA, the following regression equations obtained.

Regression Equation, Thrust Force (F_{thrust}) = 57- 0.0818 (A) + 1.07 (B) + 9.17 C+ 0.85 (D) + 9.63(E)
Regression Equation, Torque (M) = 1924 - 0.430 (A) - 12.5(B) - 36.4 (C) - 9. (D) + 39.4 (E)

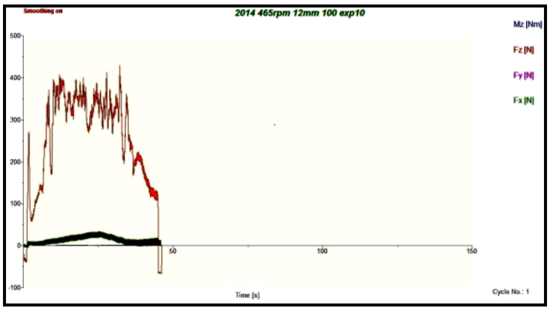

Fig 6 thrust and Torque graph obtained from Kistler Dynamometer (exp.10)

From dynamometer graphs (fig.6) average values of thrust and torque recorded, these values are compared by analytical values obtained from equations (1), (2) and (5). After that burr height and burr thickness are determined using equations (3) and (4).

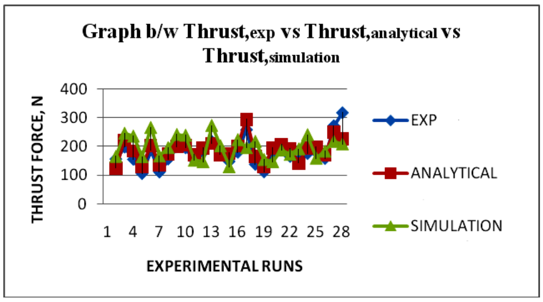

Fig 7 Comparison of thrust force results

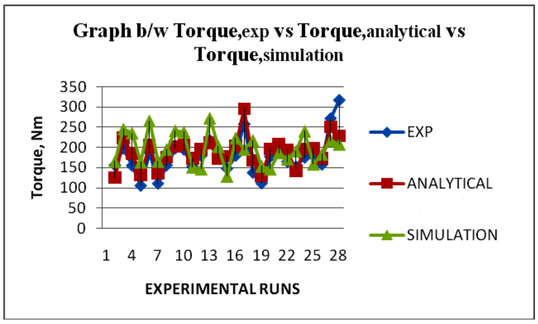

Fig 8 Comparison of torque results

Once the optimal level of machining parameters is selected the final step is to predict and verify the improvement of the performance characteristics using the optimal level of the machining parameters. The estimated the optimum level of the machining parameters can be calculated as,

$$\hat{\gamma} = \gamma_m + \sum_{i=1}^{q} (\bar{\gamma}_j - \gamma_m)^2 \qquad \text{--------------------------------} \ (6)$$

Based on Equation (6), optimum results to minimize burr size with optimum combination of machining parameters influenced by thrust force and torque obtained. After that, from analytical and Deform-3D software's responses are generated corresponding optimum combination of process parameters obtained from taguchi method. The graphs (shown in fig.7&8) are drawn from experimental, analytical and simulation results, found that all these are fitted close to each other.

6. CONCLUSIONS

In this study, experimental, analytical and finite element modeling (using Deform - 3D) investigations on drilling operations with variable geometry are presented. By considering variable lip clearance angles on drill bit influenced around 10%on thrust force to minimize exit burr size, which is observed from analytical, experimental and simulation results. Also it is observed (from ANOVA) that feed rate and point angle are more significant factors to influence on thrust force and torque. From Taguchi predicted values with corresponding optimum combination of parameters, calculated analytically and obtained 90% close values. Good agreement has shown in case of all responses in both the experimentation and CAE simulated results for Al2014 alloy material.

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