RESEARCH PROGRESS IN MECHANICAL AND MANUFACTURING ENGINEERING VOL. 3 NO. 1 (2022) 117-123

RPMME

Homepage:http://penerbit.uthm.edu.my/periodicals/index.php/rpmme
e-ISSN: 2773 - 4765

A Simulation Study On The Effects of Cutting Fluid in Drilling Process

M. Amar Imran Azman[1], Rasidi Ibrahim[1]*

[1]Faculty of Mechanical and Manufacturing Engineering,
University Tun Hussein Onn Malaysia, 86400 Parit Raja, MALAYSIA.

*Corresponding Author Designation

DOI: https://doi.org/10.30880/rpmme.2022.03.01.012
Received 15 Nov. 2021; Accepted 15 April 2022; Available online 30 July 2022

Abstract: Nowadays, manufacturing is the transformation of a starting material's geometry, properties, and appearance for the production of components or products using technical physical and chemical processes. This is because it is crucial to maintain the quality of the cutting tool product. In this project, the workpiece material is Carbon Steel S45C type and the material on drill bits is Carbon Steel. This project uses two methods to investigate the effect of drill bit temperature: dry drilling and drilling with cutting fluids. DEFORM 3D has been utilized for the drilling process in the current in the current study. The 3D drill bit was designed using SOLIDWORKS software with STL file and then executed in simulation software. When the point angle is 135° and the feed rate is 0.10mm/rev, the highest dry drilling temperature is 428°C. When the point angle is 135° and the feed rate is 0.125mm/rev, the highest drilling temperature is 317°C for a drill using cutting fluid. When the point angle is 135°, the highest stress effective value is 1980mm/rev for dry drilling, and 1860mm/rev for drilling with cutting fluid when the point angle is 130°. The value of drill bit temperature increased with the increasing value of feed rate and the value of stress effective is increased when the value of the point angle of the drill bit is increase.

Keywords: Drilling, Carbon Steel S45C, DEFORM 3D, Temperature, Effective Stress

1. Introduction

Manufacturing is the use of technical physical and chemical processes to change the geometry, properties, and appearance of a starting material for the manufacture of components or products. Machining is considered as an important technique in manufacturing processes. Variety of work, part shapes and special geometry features can be formed through machining process. A part of machining will also influence the dimensional accuracy and surface finish achieved on the workpiece. One of the most important machining techniques for creating a hole or widening a hole in an area is known as drilling. Drilling is a cutting process that uses drill bits to cut circular cross-holes in solid material. The workpiece object is pressed and forced by bits on it while rotating at a certain rate so that the

**Corresponding author: rasidi@uthm.edu.my*

workpiece can penetrate, and holes can form in the workpiece. . In this project, the workpiece material is Carbon Steel S45C type and the material on drill bits is Carbon Steel. High steel also has many common applications, such as milling equipment, grinding instruments such as chisels and high-strength cables.

Kolahdoozan et al. [Kolahdoozan, Azimifar and Yazdi (2014)], analyzed the impact of varying spindle speed, feed rate, and tool diameter with a constant depth of cut on tool wear while drilling Inconel 718 using a cement coated carbide tool (TiAlN). They developed a model by utilizing Minitab and FEA (DEFORM-3D, Lagrangian approach) to predict the tool wear. The predicted and experimental results were compared and reported a percentage error of 4-6%. Parida [Parida (2018)] simulated the drilling of Ti-6Al-4V using DEFORM-3D to study the effects of varying cutting speed and feed rate on torque, effective stress, effective strain, thrust, drill bit temperature. And observed that there is an increase in drill bit temperature with an increase in feed rates. Along with a reduction in the hardness of the workpiece with an increase in cutting speed due to thermal softening resulting in a low temperature drill bit. These results were validated with experiments and a good agreement between the simulated and experimental results were found. Chatterjee, Mahapatra, and Abhishek [Chatterjee, Mahapatra, and Abhishek (2016)] developed a finite element model using DEFORM-3D to predict the thrust force, torque required and circularity of the holes at the entry and exit while drilling titanium which validated the experimental results. Ucun [Ucun (2016)] compared the performances of twist and 3-flute drills while drilling Al7075-T6 alloy by varying the feed rate and cutting speed, the simulations were performed in DEFORM 3D. The thrust force, tool stress, and torque were obtained using the simulations and were compared with experimental results, and there was no significant error between them. And he also concluded that the twist drill performed better than the 3-flute drill.

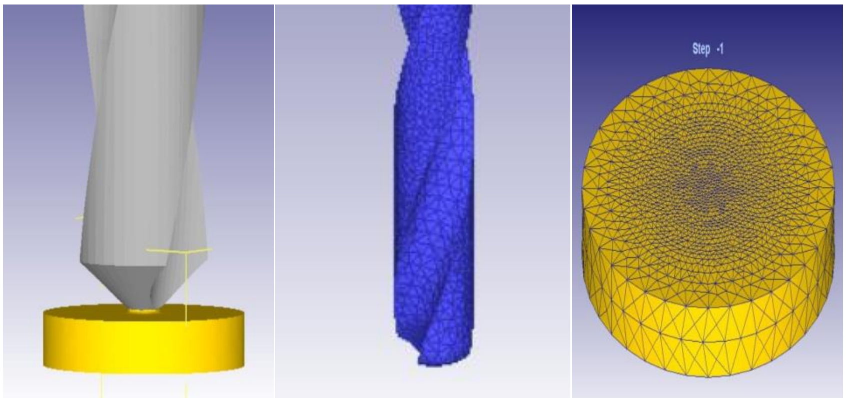
Cutting fluids provide reduced friction between the tool and part, corrosion prevention of metal, the transportation of chips during machining and cooling for the workpiece. Furthermore, the coolant also provides a reduction in the dimensional variations between machined parts (Tasdelen et al., 2018, Fluid Application- MQL, 2006). These include the wear of the cutting tool, the safety during machining, the pollutants produced and the vibrations associated the machine (Fratila et al.,2007).

2. Experiments and results

The finite element model is developed using DEFORM-3D 10v software to find the temperature of drill bit and the effective stress for dry drilling and drilling with cutting fluid. The Lagrangian approach was employed for the mesh. The work piece was considered as perfectly plastic. And the tool was considered as rigid. The DEFORM-3D software uses extended finite element machining to simulate the cutting of the work piece. And the thermo-mechanical contact algorithm is used in the DEFORM software. The material is modeled by the Johnson-Cook(JC) material model as shown in Eq. (1).

$$\sigma = \left[\mathrm{A} + \mathrm{B}\,p^{n} + \mathrm{C}\ln\left(\frac{\dot{p}}{\dot{\varepsilon}_0}\right)\left[1 - \left(\frac{\theta-\theta_R}{\theta_m-\theta_R}\right)^{m}\right]\right]$$

Where, σ is the flow stress, p is the plastic equivalent strain, ṕ is the plastic strain rate, θm is the melting temperature and θR is the initial temperature, n is the hardening coefficient and m the thermal softening coefficient, coefficients A, B, and C are the yield strength (MPa), hardening modulus (MPa) and the strain rate sensitivity coefficient. The assumptions made in this analysis are given in Tab. 3. The geometric model, mesh of the work piece, and drill bit is shown in Figs. 1(a)-1(c).



(a) (b) (c)

Figure 1: (a-c); (a) Geometric model, (b) Mesh of drill bit, (c) Mesh of workpiece

DEFORM-3D is divided into two steps, namely pre-processor step and post processor step. In the pre-processor step, a 3D model is developed and the drilling parameters namely: spindle speed, feed rate, and point angle are considered as the machining parameters and the assumptions made in this simulation is given in Tab. 1. The second step is the post processor, in which simulation and drilling performance results are observed. Summary of comparison between temperature of dry drilling and drill using cutting fluids in Tab. 2. Summary of comparison between effective stress of dry drilling and drill using cutting fluids in Tab. 3.

Table 1: Assumptions of the FEA Model

Assumptions	Values
Shear friction factor	0.6
Heat transfer coefficient	45N/sec/mm/C
Element type	Tetrahedral
Mesh type	Fine Mesh
Node	10 nodes
Relative mesh type (drill bit)	30000
Size ratio (drill bit)	4
Relative mesh type (Work)	25000
Size ratio (Work)	7
Work material type	Plastic & Isotropic
Workpiece shape	Cylinder
Tool Material	Carbon Steel
Coolant	Not used (Dry Drilling) Use (Drilling with Cutting Fluid)
Environment Temperature	20°C
Convection Coefficient	0.02 (Dry Drilling) 50 (Drilling with Cutting Fluid)
Heat transfer coefficient	45
Number of Simulation Steps required to complete the drill	7000
Step increment to save	25

Table 2: Summary of comparison between temperature of dry drilling and drill using cutting fluids

No.	Cutting Speed (rpm)	Feed Rate (mm/rev)	Diameter (mm)	Point Angle (°)	Temperature (Dry Drilling) (°C)	Temperature (With Cutting Fluids) (°C)
1	750	0.05	8	118	116	47
2	750	0.05	8	130	146	111
3	750	0.05	8	135	201	178
4	750	0.10	8	118	300	223
5	750	0.10	8	130	281	146
6	750	0.10	8	135	428	253
7	750	0.125	8	118	269	238
8	750	0.125	8	130	247	146
9	750	0.125	8	135	333	317

Table 3: Summary of comparison between effective stress of dry drilling and drill using cutting fluids

No.	Cutting Speed (rpm)	Feed Rate (mm/rev)	Diameter (mm)	Point Angle (°)	Effective stress (Dry Drilling) (mm/rev)	Effective Stress (with Cutting Fluids) (mm/rev)
1	750	0.05	8	118	1550	1380
2	750	0.05	8	130	1700	1620
3	750	0.05	8	135	1800	1710
4	750	0.10	8	118	1770	1750
5	750	0.10	8	130	1890	1860
6	750	0.10	8	135	1800	1740
7	750	0.125	8	118	1780	1750
8	750	0.125	8	130	1770	1680
9	750	0.125	8	135	1982	1740

3. Results and discussion

In this research work, a DEFORM-3D finite elemental model has been developed for predicting the drill bit temperature, and effective stress in drilling S45C Steel.

3.1 Simulation of drill bit temperature

Based on Fig. 2, the maximum temperature changes in drilling contact area where maximum temperature variation is identified in the point angles and feed rate. For the dry drilling, the maximum temperatures of the drill bit are shown a downward trend after the first increase, with the increase in the feed rate. Meanwhile, for the maximum temperature for drilling with cutting fluid are show increases with the increase of the feed rate. Furthermore, there is different between the maximum temperature of dry drilling and drilling with cutting fluid which is 23°C for feed rate 0.05mm/rev. But for feed rate of 0.10mm/rev, there is big different which is between dry drilling and drilling with cutting fluid which is 175°C. It is because, in the simulation there is some error for dry drilling and it makes dry drilling more higher in temperature. Finally, for feed rate of 0.125mm/rev, it show slightly different between dry drilling and drilling with cutting fluid for only 16°C differ.

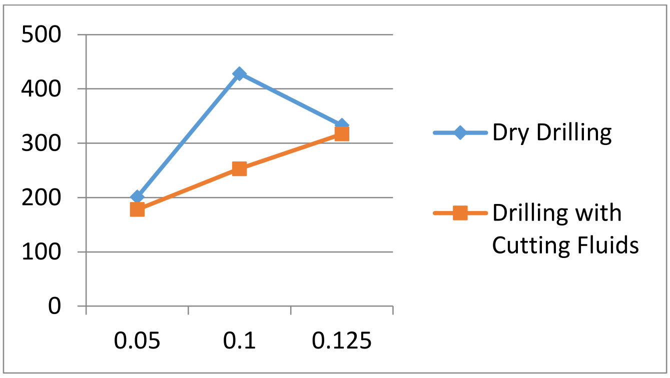


Figure 2: Graph of drill bit temperature vs. feed rate

3.2 Simulation on Stress Effective in Drilling Contact Area.

Based on Figure 4.3, the graph is the summary from the simulation result of stress effective with three different values of point angle. It showed that linear graph where from point angle of 118° to 135° showed an increasing gradient of maximum value stress effective for dry drilling but drilling with cutting fluids showed dropped from 1860Mpa to 1740Mpa. The effect of stress effective on the workpiece depends on the point angle and material itself, including its former heat treatment. Usually residual tensile stress increase in the workpiece sub-surface layer when critical stress is exceeded, depending on changes in material within the microstructure. If the intensities are even greater, hardened zones over a tempered substructure are so-called white layers. First heat generation is basically adiabatic, which causes high contact temperatures to exceed the workpiece melting temperature.

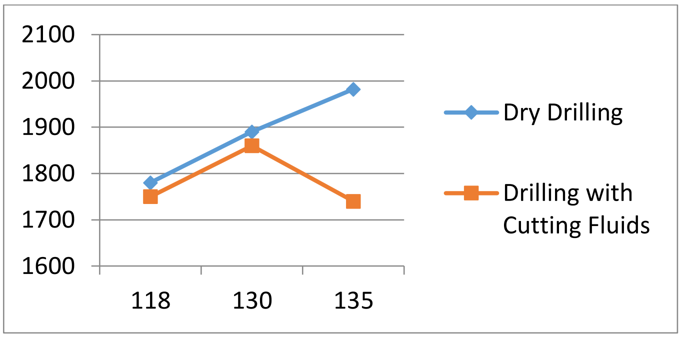


Figure 3: Graph of stress effective vs. point angle of drill bit

4. Conclusion

The simulated results obtained via DEFORM 3D model are listed below:

- The magnitude of the thrust force increases when the level of the feed rate and the point angle is increased; however, there is in the magnitude of the cutting force at 135°, while increasing the feed rate from 0.05 mm/rev to 0.125 mm/rev.
- This study shows the maximum temperature variation of the drilling contact area at various drill bit point angle, indicating an upward trend for drilling with cutting fluid and downward for dry drilling for feed rate 0.10mm/rev to 0.125mm/rev.
- For maximum effective stress, the result show that upward trend for dry drilling but for the drilling using cutting fluids show downward pattern from point angle 130° to 135°.

Acknowledgement

The authors would also like to thank the Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia for its support.

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