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Effect of Changing Drilling Parameters on Thrust Force and Torque

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Abstract: Machining, a material removal process, is one of the most widely used manufacturing process. Drilling is a type of machining operation where a multipoint cutting tool is used to create holes inside the workpiece. Being such a common process, there is still lack of research in order to fully understand the complexity of the process. The fact that drilling is performed inside a hole, prevents most of the direct observation techniques to evaluate the process. This paper presents a 3D thermomechanically coupled finite element model of drilling process of steel 2080 to study the influence of cutting parameter on thrust force and torque. Experiments are performed to validate the results from simulations.

Key words: 3D Finite element analysis · DEFORM^{TM} 3D · Force analysis · Drilling

INTRODUCTION

Machining is one of the most widely used manufacturing process. In machining, the shape of the object is altered by removing material in the form of chips. There are many types of machining; turning, milling, grinding, drilling, sawing and facing etc. Drilling is a type of machining process where a multi-point cutting tool is utilized to drill a hole in the workpiece. The cutting speed (v) in drilling is calculated at the surface on outside diameter of the drill. This can be obtained from the rpm of the drill bit by using the following relationship.

$$N = \frac{v}{\pi D}$$

Feed in drilling is specified in mm/rev and can be converted to feed rate by using the following relationship:

$$f_r \left({mm}/{min} \right) = N \left({rev}/{min} \right) . f \left({mm}/{rev} \right)$$

This equation can be used to calculate the time to machine T_m.

$$T_m = \frac{t}{f_r}$$

Also, the material removal rate in drilling can be calculated using.

$$MRR = \frac{\pi D^2 f_r}{4}$$

During drilling process, the observable forces are the thrust force applied by the rotating drill bits to the workpiece and torque applied by the spindle speed to maintain the drill rotation. The life of a drill bit depends on the amount of heat generated due to friction and thrust force it sustain during drilling operation. In order to prolong the tool life, good understanding of the effect of different process parameters such as feed rate, cutting speed and lubrication on thrust force, torque and temperature of the cutting zone is needed to avoid the stopping of production line. Finite element method (FEM) is a main computational tool for simulation of the process zone and of tool-work piece interaction in metal cutting. Itis of great interest to the researchers for modeling and simulating the machining operation in order to gain a better understanding of the cutting forces, chip formation mechanisms, heat generation in cutting zones, tool-chip interaction and residual stresses developed in the work piece.

Many experimental, analytical and numerical methods have been developed to determine the thrust force and torque values that exist during drilling process. The variation of the cutting forces with or without delamination during drilling operation and the effect of tool geometry and cutting condition on cutting forces

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variation in carbon fiber reinforced plastic (CFRP) were studied in [1]. The variation of thrust force and torque at the entrance and exit were observed differently with and without delamination. Linear relationship between thrust force and delamination was achieved in unidirectional and multi directional CFRP.

Lin, S.C. *et al.* [2] studied the effect of high cutting speed on thrust force, torque, tool wear and hole quality in drilling of carbon fiber reinforced composite material with multifaceted drill and twist drill. For simplification only average values of thrust force and torque were taken in the analysis. It was found that thrust force was larger when using the multifaceted drill bit then the twist drill bit. The thrust force increased drastically with the increase of cutting speed. The torque also increased with the increase of cutting speed however the effect of cutting speed on torque is much smaller than the thrust force. Torque increased with the increase of feed rate however the effect of feed rates on torque was more dominant then the cutting speeds.

Thrust force and torque were predicted theoretically to validate the drilling model using the orthogonal cutting model [3]. Experiments were also performed to validate the model. The sensitivity of thrust force and torque was established to feed rate and cutting speed and also that their values increased with the increase of feed rate and spindle speed.

Computer simulation were performed for the drilling process by Yang J.A. *et al*. [4]. The model was implemented using C++ language with an interface to I-DEASCTM CAE software system. The effect of the cutting parameters; cutting speed and feed rate has been investigated in the work. Experiments were performed to validate the simulation results. Thrust force and torque was analytically predicted by Strenkowski J.S. *et al*. [5] by using Eulerian finite element technique. The author considered the cutting lips of the drill bit as a series of oblique section and treated the chisel edge as orthogonal cutting section. The oblique cutting model of [6] used in the analysis which was further extended to drilling process to investigate thrust force and torque in drilling process.

The finite element model for the drilling process was also verified experimentally on a Bridgeport milling machine using a high speed steel twist drill. For all the tests, a Kistler model 9255B three-axis piezoelectric force dynamometer was used to measure the thrust force and torque in drilling process. It was concluded that the thrust force and torque increases with the increase of cutting speed (Rpm) and drill diameter.

Abrao A.M. *et al*. [7]studied the effects of shape and composition of cutting tool on thrust force when drilling glass fiber reinforce epoxy composites. From experiments it was observed that thrust force increased with increase in the feed rate due to the fact the shear area was elevated and the cutting forces was not influential considerably by increasing the cutting speed within the cutting range.

In [8], thrust forces during vibration-assisted drilling were predicted using a thrust force model for drilling of aluminum 6061-T6. The model incorporated plowing force and strain rate-dependent shear strength to provide more accurate prediction than the existing model. The comparison showed that the difference between the predicted and the experimental measurements was 20% using the existing model and only 7% using the proposed model.

In [9, 10], a 3D model of drilling process of AISI 1010 steel was presented. The simulations were performed on a close to real model and the results were validated using experiments. It was concluded that increase in feed and speed affected the thrust force and torque.

Riaz in [11-14] presented the effect of changing drilling parameters for machining of Ti-alloys at elevated temperatures. Comparatively less forces were recorded when drilling at elevated temperature compared to the same set of parameters but at room temperature.

In [15], artificial neural networks (ANN) soft computing code was used for determining milling cross-section temperature in machining processes for various diameters of milling blades. It was concluded that the ANN method can easily be used to determine new results for temperature prediction in milling process simulation with considerably less computational cost and time.

Finite Element Model: Thermomechanically coupled 3D FE models for drilling process was develop using commercial FE code DEFORM 3D [8] to investigate deformation process. Due to the non-availability of sufficient computational power and memory storage in the past as well as the complex drill-workpiece interaction, most of the drilling simulations were performed with a certain level of simplification such as reducing the three-dimensional problem to a two-dimensional formulation [16], by assuming the cutting lips as a combination of small elementary cutting tools performing an orthogonal cutting operation [17] or considering one cutting lip of the drill bit in 3D FE simulation [9]. The current model has a number of advantages compared to the previously

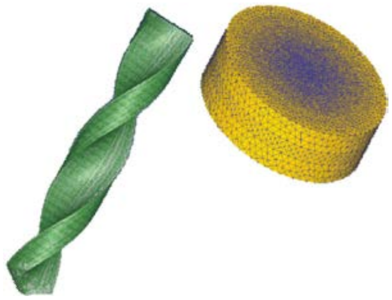

Fig. 1: Drill bit and workpiece meshing

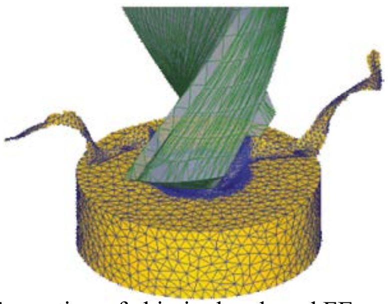

Fig. 2: Formation of chip in developed FE model

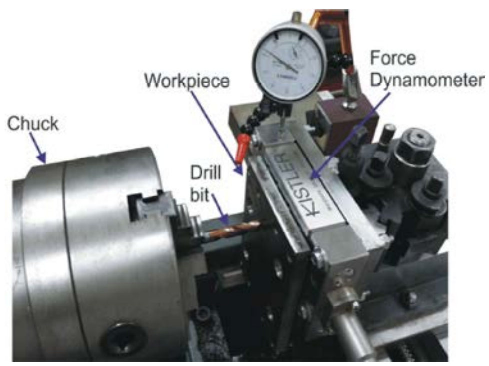

Fig. 3: Experimental setup for analysing the effect of changing drilling parameters on thrust force and torque

developed 2D and simplified 3D models and it allows us to study the tool-workpiece-interaction using the full geometry of a twist drill bit.

In the current FE simulations of drilling, a deformable workpiece with a diameter of 10 mm, a helix angle of 30°, a point angle of 118° and a web thickness of 0.9 mm was modelled. An adaptive meshing of the workpiece was performed with fine mesh close to the cutting lips. A rigid drill bit with a tungsten-carbide coating. The drill bit was meshed with 4-noded tetrahedral elements (Figure 1).

The bulk distortion of elements in the tool-workpiece vicinity was handled using global remeshing in which the distorted elements were actively replaced with the one's having non-distorted structure [18]. The formation of chip that resulted from remeshing is shown in Figure 2.

Table 1: Cutting parameters and their respective values

Parameters	Magnitude
Speed (rpm)	360, 700, 1000, 1400
Feed (mm/rev)	0.125, 0.176, 0.25, 0.352

Table 1 shows the details of variables for drilling; these include the speed and feed rate. The variables are selected on the basis of availability of similar variables on the lathe machine.

In order to have a clear understanding of the features of a drilling process under the effect of changing cutting conditions, a set of case studies into the effect of various parameters was planned.A final list of cases was developed by combining various values out of speed and feed.

Experimental Setup: Experiments are performed by machining steel slabs using lathe machine type Pinacho S-90/165. The lathe machine is equipped with digital readout for accurate control of feed and depth of cut. The workpiece is mounted on the Kistler 9129 force dynamometer and holding the drill bit inside the chuck of lathe. Machining is performed using the same variables mentioned in Table 1. The results for the thrust force and torque are recorded using the Multichannel charge amplifier and the DAQ-System. Figure 3 presents the experimental setup.

RESULTS AND DISCUSSION

In the current work, FE simulations of drilling processes were carried. The effect of increasing cutting speeds and feed rate on the thrust force was studied. Figure 4 presented the results of thrust forces for various feed rates and cutting speeds. A constant increase is visible in the thrust force as the cutting speed is increase from 300 rpm to 1400 rpm. The effect of changing feed rate is more prominent compared to that of cutting speed.

Figure 5 presents the results of experiments. A similar trend is observed in case of experimental results as that of simulation.

Figure 6 presented the results of changing the cutting speed and feed on the torque inside the drill body. The value of torque increases with the increase. At lower cutting speeds that effect of changing feed rate is not prominent but as the speed increases, the effect of changing feed rate becomes more prominent.

Figure 7 presents the results of experiments. Experimental results are in qualitative agreement with those of simulation.

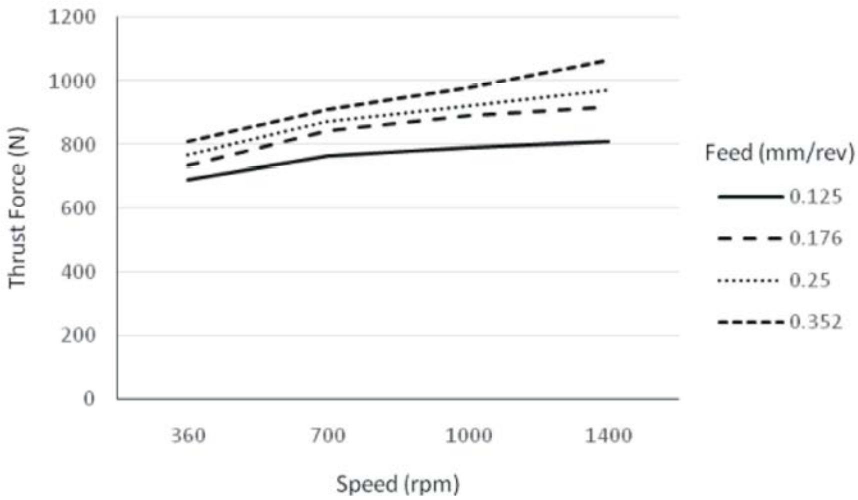

Fig. 4: Simulation results: Effect of cutting speed (rpm) and feed (mm/rev) on the thrust force (N)

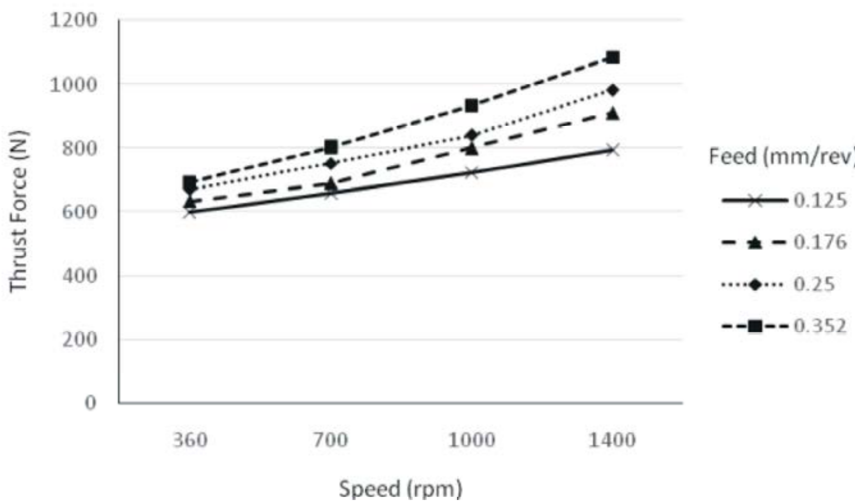

Fig. 5: Experimental results: Effect of cutting speed (rpm) and feed (mm/rev) on the thrust force (N)

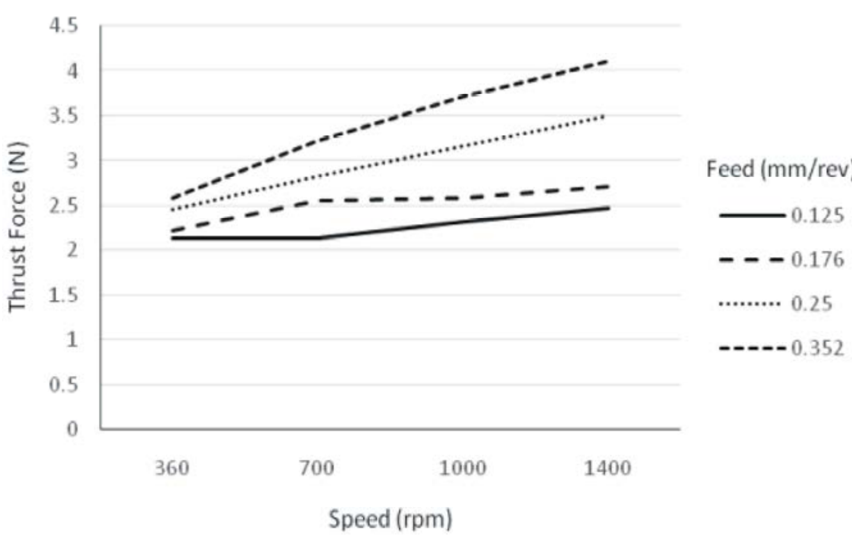

Fig. 6: Simulation results: Effect of cutting speed (rpm) and feed (mm/rev) on the torque (N-m)

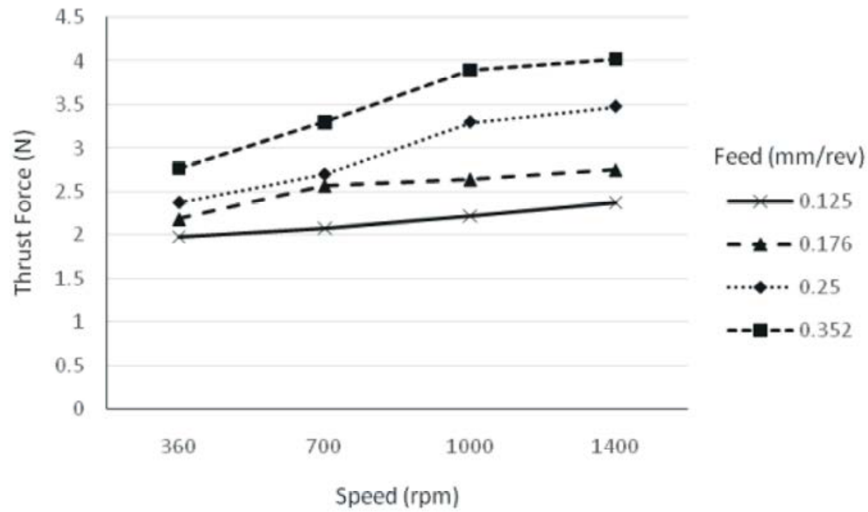

Fig. 7: Experimental results: Effect of cutting speed (rpm) and feed (mm/rev) on the torque (N-m)

CONCLUSION

A 3D thermomechanically couple finite element close-to-real model of drilling was developed to study the effect of changing cutting parameters on the thrust forces and torque inside the drill bit.

The thrust force increased with increasing the cutting speed and feed. Changing the feed had an approximate linear effect on the thrust forces. But in case of torque, the effect of changing feed rate increased the torque more at higher speeds compared to that at lower speeds. The results showed a good qualitative agreement with the experiments performed to validate them. The results are also in good agreement to what was reported in [2].

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REFERENCES

1. Chen, W.C., 1996. Some experimental investigation in the drilling of carbon fiber reinforced plastic (CFRP) composite laminates. International Journal of Mach Tool Manufacturing, 96: 1097-108.
2. Lin, S.C. and I.K. Chen, 1996. Drilling carbon fiber-reinforced composite material at high speed. Wear., 194: 156-62.
3. Elhachimi, M., S. Torbaty and P. Joyot, 1999. Mechanical modeling of high speed drilling 2: predicted and experimental results. International Journal of Machine Tools and Manufacture, 39: 569-71.
4. Yang, J.A., V. Jaganathan and R. Du, 2002. A new dynamic model for drilling and reaming processes. International Journal of Machine Tools and Manufacture, 42: 299-311.
5. Strenkowski, J.S., C.C. Hsieh and A.J. Shih, 2004. An analytical finite element technique for predicting thrust force and torque in drilling. International Journal of Machine Tools and Manufacture, 44: 1413-21.
6. Strenkowski, J.S., A.J. Shih and J.C. Lin, 2002. An analytical finite element model for predicting three-dimensional tool forces and chip flow. International Journal of Machine Tools and Manufacture, 42: 723-31.
7. Abroa, A.M., J.C.C. Rubio, P.E. Faria and J.P. Davin, 2007. The effect of cutting tool geometry on thrust force and delamination when drilling glass fiber reinforced plastic composite. Materials and Design.
8. Chang, S.S.F. and G.M. Bone, 2009. Thrust force model for vibration-assisted drilling of aluminum 6061-T6. International Journal of Mach Tool Manufacturing, 49: 1070-6.
9. Muhammad, R., N. Ahmed, M. Abid and V.V. Silberschmidt, 2010. 3D modeling of drilling process of AISI 1010 steel. Journal of Machining and Forming Technologies, 2: 201-16.

10. Muhammad, R., N. Ahmed, M. Abid and V.V. Silberschmidt, 2010. 3D finite element modeling of drilling process. In: 20th International Workshop on Computational Mechanics of Materials (IWCMM), Loughborough, UK.
11. Muhammad, R., N. Ahmed, Y.M. Shariff and V.V. Silberschmidt, 2012. Finite element analysis of forces in drilling of Ti-alloys at elevated temperatures. Solid State Phenomena, 188: 250-5.
12. Muhammad, R., N. Ahmed, A. Roy and VV. Silberschmidt, 2012. Numerical Modelling of Vibration-Assisted Turning of Ti-15333. Procedia CIRP., 1: 347-52.
13. Muhammad, R., V.V. Silberschmidt, N. Ahmed and Y.M. Shariff, 2011. Effect of cutting conditions on temperature generated in drilling process: A FEA approach. Advanced Materials Research, 223: 240-6.
14. Muhammad, R., N. Ahmed, A. Roy and V.V. Silberschmidt, 2012. Turning of Advanced Alloys with Vibrating Cutting Tool. Solid State Phenomena, 188: 277-84.
15. Tahavvor, A.R., Y. Rezaei and A. Afsari, 2012. Prediction of cross-section temperature during milling process using artificial neural networks. World Applied Science Journal, 19: 1674-80.
16. Bono, M. and J. Ni, 2002. A model for predicting the heat flow into the workpiece in dry drilling. Journal of Manufacturing Science and Engineering, 124: 773-7.
17. Ozcelik, B. and E. Bagci, 2006. Experimental and numerical studies on the determination of twist drill temperature in dry drilling: A new approach. Materials and Design, 27: 920-7.
18. Severdenko, V.P., V.V. Klubovich and A.V. Stepanenko, 1972. Ultrasonic rolling and drawing of metals, Consultants Bureau.