USING OF FEM FOR CHIP FORMATION AND CUTTING FORCE PREDICTION WHEN DRILLING TOOL STEEL AISI D3

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This paper is focused on using FEM for design solid twist drill geometry. For this reason the series of numerical simulation have been conducted. The main observed parameters were chip shape and cutting forces. The results from numerical simulations were compared with experimental measurement.

Keywords
FEM, chip shape prediction, cutting force prediction, experiments

1. Introduction

The using of FEM (Finite Element Method) had been established mainly in automotive, aerospace and power industry in order to decrease costs on development process. In cutting tool industry the increasing demands on cutting tools like higher productivity, accuracy and economical machining of new difficult to cut materials also force manufactures to make their development more effective. However the classical trial-error testing is very time and thus financial consuming. Therefore it would be desirable to have information about cutting tool performance before the physical prototype is made. To satisfy this requirement it's possible to use FEM.

In this paper the using of FEM in design of solid twist drill geometry for drilling in to tool steel AISI D3 is presented. The FEM method is used via commercially available software package AdvantEdge 3D, where this method is implemented.

The structure of this paper is as follows. In the second section the brief description of solid twist drill geometry is presented. The third section presents the results from simulation, where chip shape and cutting forces are the main observed parameters. These parameters are compared with experimental measurement in the fourth section. The conclusion is presented in the last section.

2. Description of solid twist drill geometry

The geometry of solid twist drill is shown in Fig.1. The precision values of geometrical parameters are confidential and therefore, only the interval for each parameter will be presented. The drill has standard single point tip with angle ε=130°–140°. The helix angle ω, ranges between 10° – 15°. The chisel edge is thinned to 0.5 – 1 mm. The diameter of the twist drill is 12mm. The model of solid twist drill had been made in CAD software CATIA V5R18.

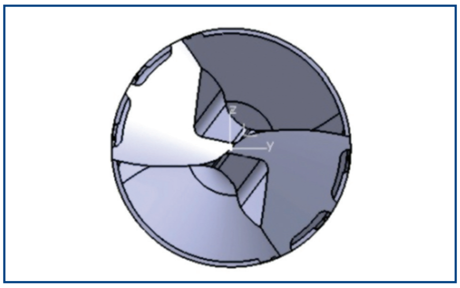

Figure 1. *The model of solid twist drill*

Results from simulation

Before the model of solid twist drill could be imported in to AdvantEdge 3D environment, it was necessary to create a model of custom workpiece also. The workpiece was cylinder with diameter 20 mm and length 10 mm. It must be noted that model of the solid twist drill was cleaned up from unnecessary features, which didn't have influence on results of simulations, but only made simulations more complicated.

When both models were imported in to AdvantEdge 3D environment, the models were meshed and the boundary conditions were set up, see Table 1.

Boundary condition	
Cutting speed v_c [m.min^{-1}]	25
Feed rate f_{rev} [mm.rev^{-1}]	0.08, 0.12
Cutting enviroment	Dry
Workpiece material	AISI D3(53HRC)
Cutting tool material	Carbide

Table 1. *Summary of boundary condition*

The magnitude of cutting speed v_c were chosen with respect to commonly used values. In order to select optimal feed rate f_{rev} for the given geometry and cutting speed, two values of feed were choosen. The aim was to compare effect of feed on chip formation in order to satisfy formation of segmented chip. After that the simulations were submitted.

3.1 Chip shape comparison

In Fig. 2 and 3 respectively are compared chip shapes for different values of feed. As it is clear from both figures, within both feed rates the tool has a tendency to produce segmented chip.

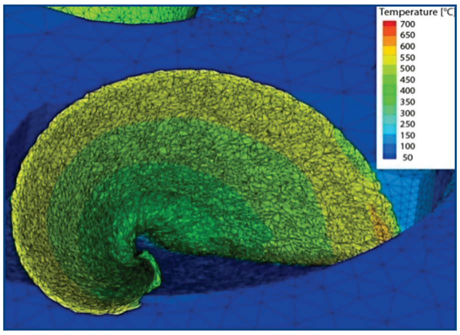

Figure 2. *Chip shape for f_{rev} = 0.08 mm.rev^{-1}*

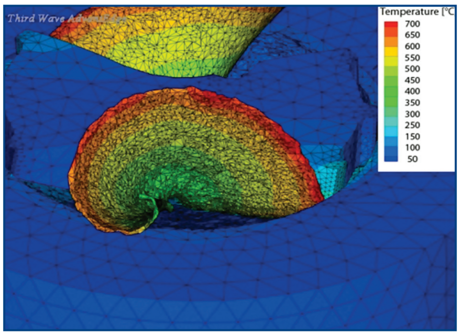

Figure 3. *Chip shape for f_{rev} = 0.12 mm.rev^{-1}*

When we compared temperature field distribution, it obvious when the feed f_{rev}= 0.12 mm.rev^{-1} is used the chip has higher temperatures within last third of its volume. This fact is with agreement with theory, because when higher feed rates are employed the higher forces are generated and as consequent the temperature increases.

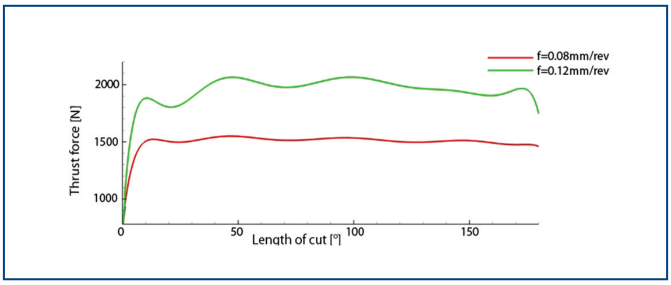

Figure 4. *Thrust force comparison*

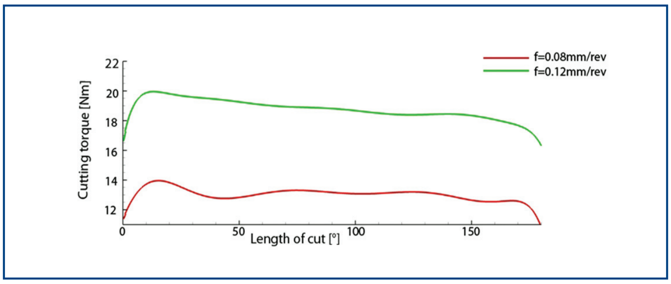

Figure 5. *Cutting torque comparison*

3.2 Cutting force comparison

On graph in Fig. 4 is shown comparison of thrust force vs length of cut for f_{rev}= 0.08 mm.rev^{-1}, $F_{f0.08}$=1500 N. It must be noted that in this graph and all graph which will follow the length of cut represents the magnitude of drill rotation within simulation. The magnitude of 180° was evaluated in preliminary tests, where the influence of length of cut on chip formation and cutting forces were studied. Graph in Fig.5 represents thrust force for f_{rev}= 0.12 mm.rev^{-1}. Exactly $F_{f0.12}$=2000 N. If we compared values of thrust forces (see formula 1)

$$\frac{F_{f0,08}}{F_{f0,12}} = 0,75 \qquad (1)$$

$$\frac{F_{f0,08}}{F_{f0,12}} = 0,75 \qquad (2)$$

with values of feed (see formula 2) we can observe that correlation between these two parameters are almost linear. In the case of cutting torque the situation is almost the same. This can be explained by higher volume of chip when f_{rev}= 0.12 mm.rev^{-1} is employed. In other words, although the cutting forces are higher the higher heat dissipates in to higher volume of chip and thus the increase in temperature is not so significant to thermal softening effect appeared in greater manner. As the result the material of the workpiece maintains its mechanical properties and thus the cutting forces increases with increase of feed rate. This claim is supported by temperature field distribution in Fig. 3, 4 respectively, where the temperatures within 2/3rd of chip volume is the same for both values of feed. However this claim will be compared with experimental measurement.

4. Results from experiments

The experiments were carried out on vertical milling center MCV 750A with continuous regulation of spindle speed. The cutting forces were measured by 4-component piezoelectric dynamometer Kistler. The measured data were post processed in software LabView 8.4. The physical prototype of solid twist drill was produced in Hofmeister, s. r. o .

4.1 Chip shape comparison

In Fig. 6, 7 respectively are compared chip shape predicted by the AdvantEdge 3D and the chip produced by real solid twist drill. As can be seen from Fig. 6, the drill produced segmented chip as the software predicted. Of course the simulation was not able to catch waves on outer part of the chip due to some amount error, which every numerical simulation has, but this can be overlooked, because the fact that chip is segmented is more important. Because it satisfy good the chip removal an stable cutting forces within process. The situation is the same for f_{rev}= 0.12 mm/rev. See Figs. 8,9.

Figure 6.
Real chip f_{rev} = 0.08 mm/rev

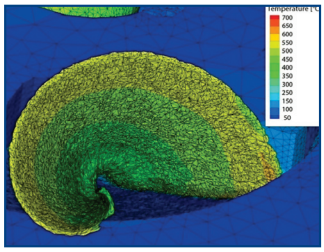

Figure 7.
Segmented chip f_{rev}= 0.08 mm/rev

Figure 8.
Real chip f_{rev} = 0.12 mm/rev

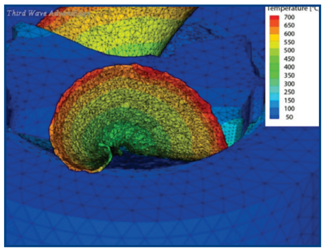

Figure 9.
Segmented chip f_{rev} = 0.12 mm/rev

From the results stated above we can make conclusion, that AdvantEdge 3D software has good chip shape prediction. The decision which value of feed rate is more suitable is a matter of future research, because it's necessary to provide tool life testing.

4.2 Cutting force comparison

In Figs. 10, 11 the graphs showing thrust force comparison for different feed rates f_{rev}= 0.08; 0.12 mm.rev^{-1} respectively are shown. If we compared the magnitudes of thrust force which was measured within experiments, we can see the same relative increase, as it was in the case of predicted value of thrust force. This can lead to conclusion that software AdvantEdge 3D is able to predicted the relative increase in thrust force with good accuracy.

If make the same comparison for cutting torque Mc, see graphs in Fig. 12, 13 respectively we can see that the situation is same as

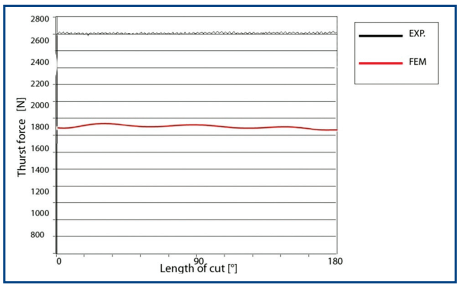

Figure 10. *Thrust force comparison for feed f_{rev} = 0.08 mm/rev*

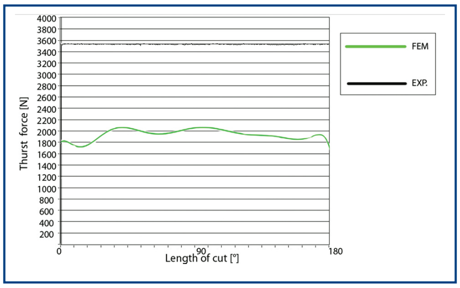

Figure 11. *Thrust force comparison for feed f_{rev} = 0.12 mm/rev*

in the case of thrust force. But when we compared the absolute values of predicted cutting forces, we can see that the difference between predicted and measured thrust force ranges from 46% to 50%, while the difference in cutting torques are lower, exactly 20 % to 22 %. This is very strange because we must take into account that both characteristics came from same simulations. The high difference in thrust forces can be explained, by the fact that the hardness of the real workpiece was higher due to heat treatment, than in computational model of the workpiece. Exactly the in simulation the hardness was about 53HRC, while the hardness of the real workpiece was 55±5HRC. Therefore this inaccuracy, which cannot be removed because due to nature of heat treatment and hardness measurement, can make this big difference between magnitudes of thrust force.

However this doesn't explain why the difference is not so big in the case of cutting torque Mc. The explanation can be found when

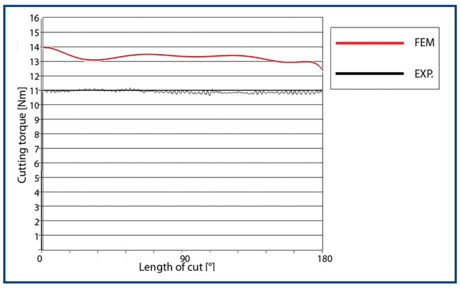

Figure 12. *Cutting torque comparison for feed f_{rev} = 0.08 mm/rev*

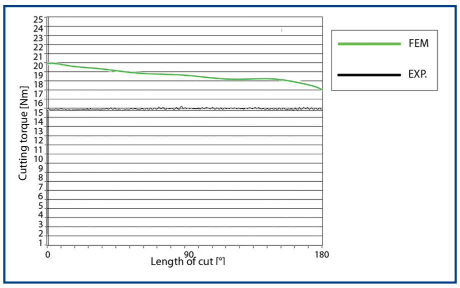

Figure 13. *Cutting torque comparison for feed f_{rev} = 0.12 mm/rev*

we realize that the cutting torque is generated by cutting force F_c which acts in tangential direction on beam, which lengths varies from 0 to $\frac{Dc}{2}$, where the D_c is the diameter of the solid twist drill. Generally the component of F_c is greater than component of thrust force F_f. In a consequence the higher temperatures are generated within primary cutting zone and therefore the thermal softening effect can occur in this area. Especially, when we take in to account dry cutting conditions. As the results the difference in hardness decreases for the case of cutting torque.

Conclusions

In this paper the using of FEM which was implemented in commercially available software package AdvantEdge 3D was presented. The simulations were focused on drilling in to tool steel AISI D3. The results were compared with experimentally measured data. The main observed parameters were:

- Chip shape;
- Thrust force F_f;
- Cutting torque M_c.

By comparison stated above parameters the main conclusions of this paper can be summarized as follows:

- The AdvantEdge 3D software predicts chip chape with good accuracy and this prediction can used in design of solid twist drill;
- The AdvantEdge 3D software predicts relative increase in cutting forces with good accuracy and this prediction can used in design of solid twist drill;
- The difference in absolute values of cutting forces can be explained by higher hardness of the experimental workpiece;
- The difference in hardness is significant in the case of thrust force F_f and ranges between 46-50%;
- The difference in hardness is not significant in the case of cutting torque M_c, where the difference 20–22% can be addressed to error in numerical simulation;
- The lower error for the case of cutting torque can explained by decrease of hardness between real and computational workpiece due the thermal softening effect within primary cutting zone.

Acknowledgments

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