International Journal of Research in Engineering and Science (IJRES)
ISSN (Online): 2320-9364, ISSN (Print): 2320-9356
www.ijres.org Volume 2 Issue 10 ǁ October. 2014 ǁ PP.42-49

Simulation and Analysis of 45 Steel Cutting Force On Turning Cutting Process Based on ABAQUS

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Abstract:*Based on function of the large deformation analysis module of ABAQUS system,the orthogonal cutting process of 45 steel was simulated and analyzed by using FEM software. Using the failure criterion of Johnson - Cook realize the separation of the chip and workpiece, using the adaptive meshing technique(ALE), and the phenomenon of the hourglass control and post-processing.The influences of cutting parameters on cutting force were analyzed and discussed. It was found that simulation results were to be in good agreement with the experimental data.*

Key words- *cutting force, Johnson-Cook model, ABAQUS, ALE*

I. Introduction

With the development of science and technology, people put forward higher requirements for metal cutting technology, so more urgent requirements for efficiency, high precision cutting technology. In this environment, finite element simulation of metal cutting technology is also obtained the very big development, the low cost, more convenient and intuitive simulation technology has a great reference value to the actual machining.

On the research of cutting mechanism of cutting force and power consumption of computers. For cutting tools, machine tool and fixture design, to formulate the reasonable cutting dosage, optimize the tool geometric parameters, has very important significance. In the automation production, but also through the cutting process and cutting force to monitor tool working status, broken like a knife, wear and tear, etc.

II. Two-dimensional finite element modeling

2.1 Geometric model

The Y15 tool’s materials is carbide , which is defined as a rigid body,.limiting the freedom of the Y direction, speed applied to the left in the direction of the reference points out. Workpiece’s material is 45 steel ,which is better stability of the simplified integral four-node coupled to reduce the temperature of the displacement unit. The sides and bottom of Workpiece are constrained, and the boundary temperature of the Workpiece and tool are room temperature. Various models will be introduced one by one in the following. Tool and Workpiece parameters in Table 1 and the specific heat, thermal conductivity and expansion coefficient of the Workpiece are with temperature change,and there is no longer enumerate.

Tab.1 Material properties of the workpiece and tool

Material properties	Workpiece	Tool
Materials	45 steel	Carbide
Density（g/mm^3)	7850	9700
Modulus of elasticity（Gpa）	210	206
Poisson's ratio	0.269	0.27
Specific heat（J/kg.° C）	---	251.2
Conductivity(W/m.k)	---	33.5
Coefficient of thermal expansion	---	6.5E-6

2.2 Material constitutive model

To simulate the cutting process properly, it is necessary to introduce a classical model called J-C material model [9] to describe the material behavior that is usually presented with an equation (1) below.

$$\sigma = \left[A + B\varepsilon^n\right]\left[1 + c\ln\left(\frac{\dot{\varepsilon}}{\dot{\varepsilon}_0}\right)\right]\left[1 - \left(\frac{T - T_r}{T_m - T_r}\right)^m\right] \tag{1}$$

where σ is the equivalent flow stress, ε is the equivalent plastic strain, $\dot{\varepsilon}$ is the equivalent plastic strain rate, $\dot{\varepsilon}_0$ is the reference equivalent plastic strain, *T* is the workpiece temperature, T_m and T_r is the temperature of the material melting and room, respectively. *A*, *B*, *C*, *n* and *m* are constitutive constants. The material strain, strain rate hardening and the thermal softening phenomenon are taken into account in this J-C law.; Table 2 shows the various constant values used to simulate the characteristics of the JC 45 steel workpiece material model.

Tab.2 Johnson-Cook behaviour law parameters of 45 steel

Materials	*A*（*Mpa*）	*B*（*Mpa*）	*n*	*c*	*m*	*PDZ*	*Melting temperature*	Transition temperature
45	496	434	0.307	0.0084	0.804	0.25	1492	500

2.3 Friction model

Durring metal cutting process, the state of tool rake face friction is very complex.Usually, the friction atea of the rake face is divided into bond area and the friction slide area .The frictional state of bond area is related to the critical shear stress of the material .The sliding area can be approximated that a constant value for the coefficient of friction can be represented by the following formula(2):

$$\tau_c = \min(\mu\sigma_n, \quad \tau_s) \qquad (2)$$

Where: τ_c is the shear stress of the sliding contact surface ; μ is the coefficient of friction; σ_n is the pressure on the contact surface; τ_s is the critical yield stress of the material.

2.4 Cutting separation criteria

Currently, the chip separation criteria for metal cutting finite element simulation mainly have two types which are geometric and physical criteria, but for these two criteria have not yet reached a unified standard.Then the physical separation criteria is more meaningful,and so this study uses the Johnson-Cook fracture criterion to achieve separation of the chip and the workpiece: When the separation layer unit strain reaches the set value, that considers material failure and the corresponding unit is removed.

III. Simulation Results Analysis

3.1 Experimental Parameters

The cutting simulation using five sets of data, specific simulation parameters as shown in Table 3.

Table 3 Experimental parameters YT15 cutting 45 steel

Tool geometry						Cutting the amount of			
Main tool rake angle	Main tool clearance angle	Vice posteri or horn	Tool main angle	Vice-an gle	Cutter blade angle	Back engagem ent	Feed	Spindle speed	Sets
15	8	8	75	5	-4	1.5	0.14	320	1
20	8	8	75	5	-4	2	0.2	560	2
10	8	8	75	5	-4	2	0.2	560	3
5	8	8	75	5	-4	2	0.2	560	4
5	8	8	75	5	-4	2	0.2	320	5

The data which we can get from Table 3, this variable are mainly primary rake angle, back engagement of the cutting edge, feed rate and cutting speed,.And the second、third and four sets of data are to study the main tool rake angle. The following were the results of each set of data for analysis.

3.2 Five sets of cutting simulation results

(1) When the rake angel is 15 °, the back engagement of the cutting edge is 1.5mm, the feed rate is 0.14mm / r, the spindle speed is 320r / min ,the below picture is captured and the cutting forces change graphs with time .

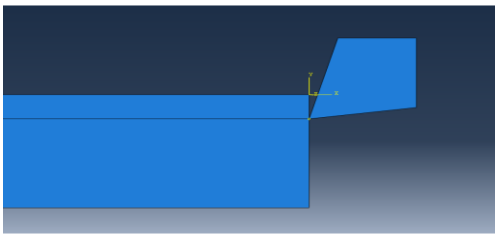


Fig.1.1 The first set of data model

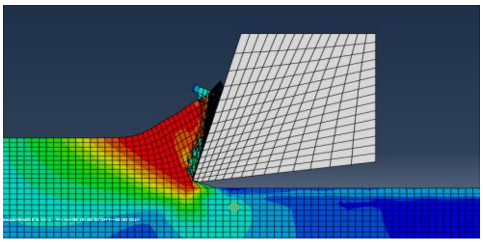
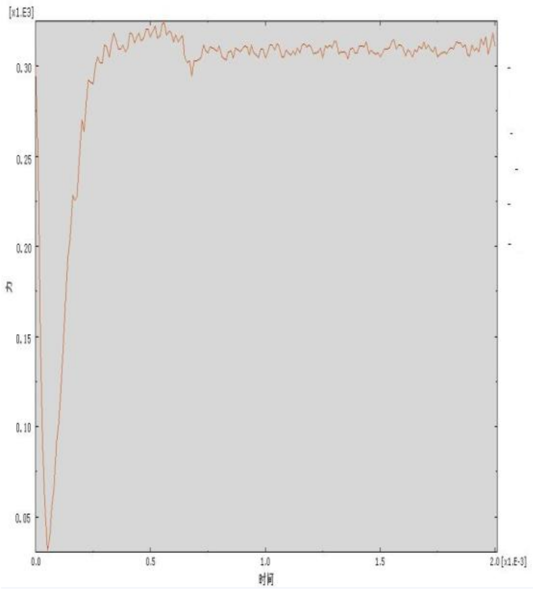


Fig.1.2 The first set of data simulation screenshots



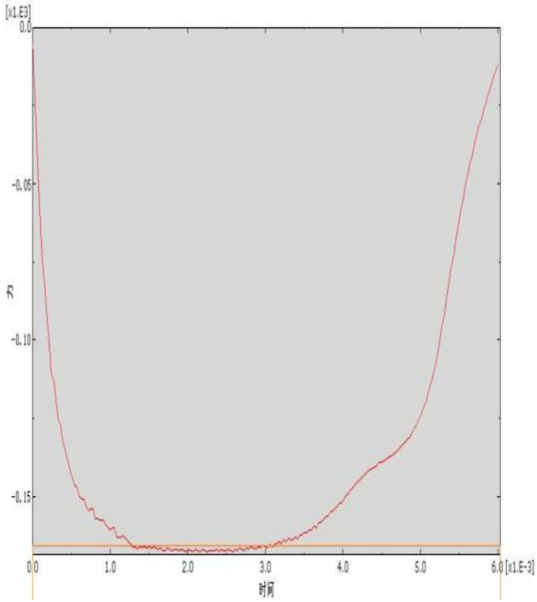
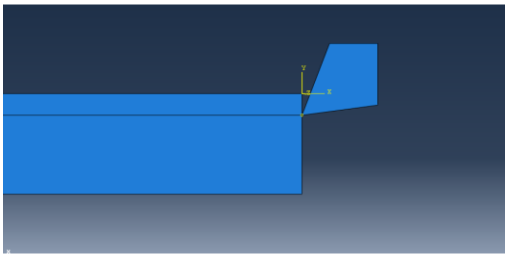


Fig.1.3 The first set of data tangential force diagram Fig.1.4 The first set of data output axial force diagram

(2) When the rake angel is 20 °, the back engagement of the cutting edge is 2mm, the feed rate is 0.2mm / r, the spindle speed is 560r / min ,the below picture is captured and the cuttiing forces change graphs with time .



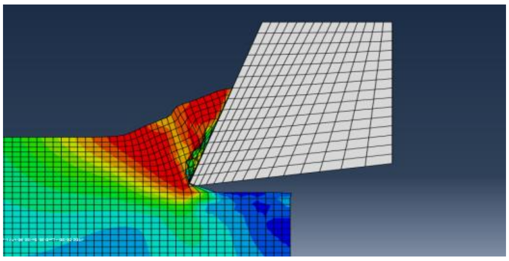
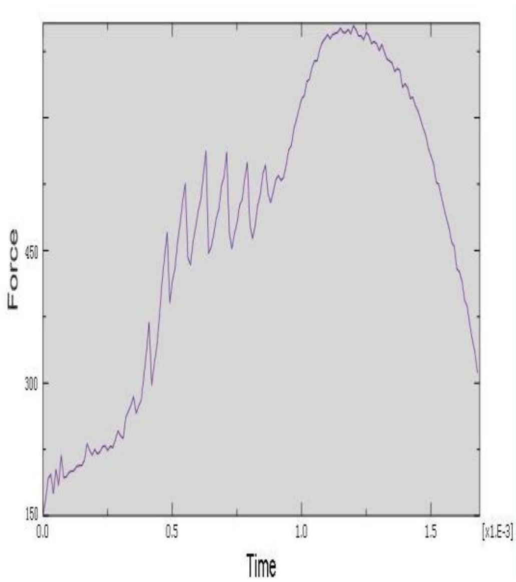


Fig.2.1 The second set of data model Fig.2.2 The second set of data simulation screenshots



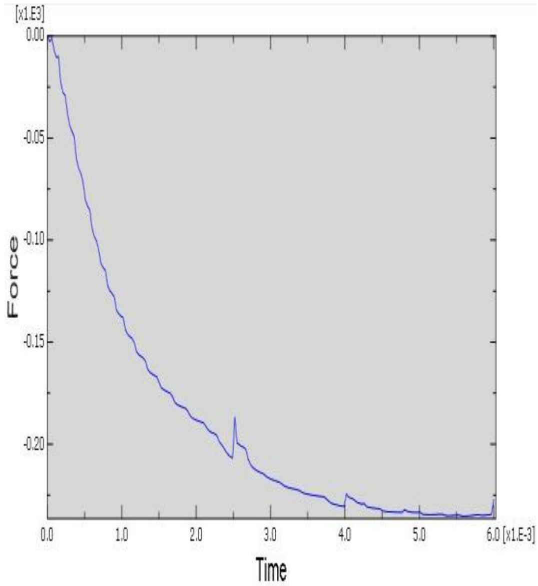


Fig.2.3 The second set of data tangential force diagram Fig.2.4 The second set of data axial force diagram

(3) When the rake angel is 10 °, the back engagement of the cutting edge is 2mm, the feed rate is 0.2mm / r,

the spindle speed is 560r / min ,the below picture is captured and the cuttiing forces change graphs with time .

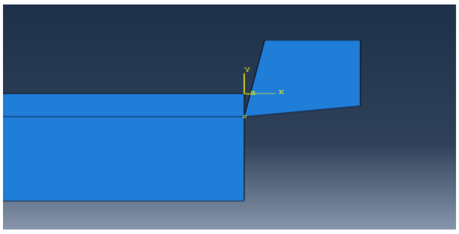


Fig.3.1 The third set of data model

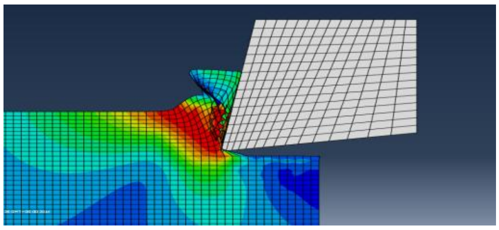


Fig.3.2 The third set of data simulation screenshots

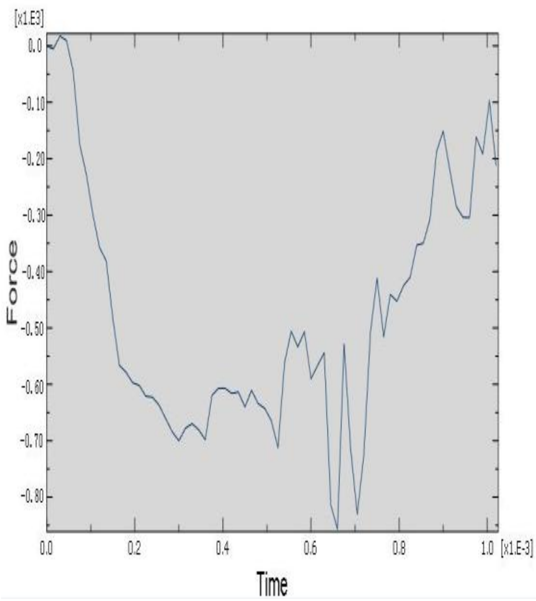


Fig.3.3 The third set of data tangential force diagram

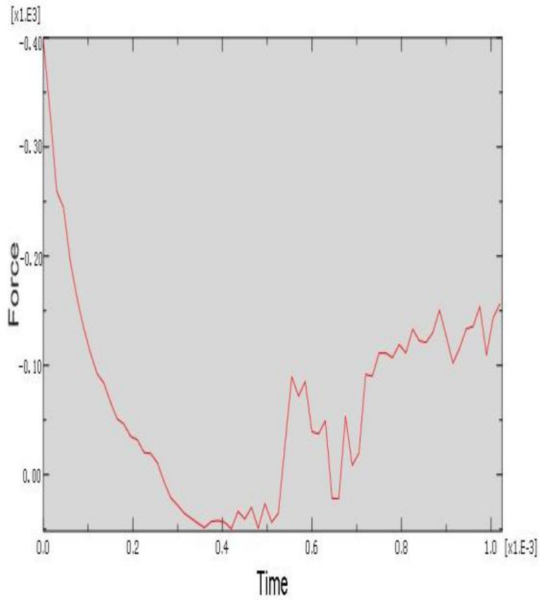


Fig.3.4 The third set of data output axial force diagram

(4) When the rake angel is 5 °, the back engagement of the cutting edge is 2mm, the feed rate is 0.2mm / r, the spindle speed is 560r / min ,the below picture is captured and the cuttiing forces change graphs with time .

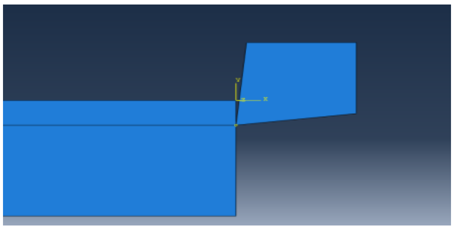


Fig.4.1 The fourth set of data model

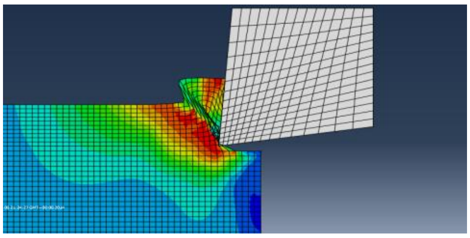
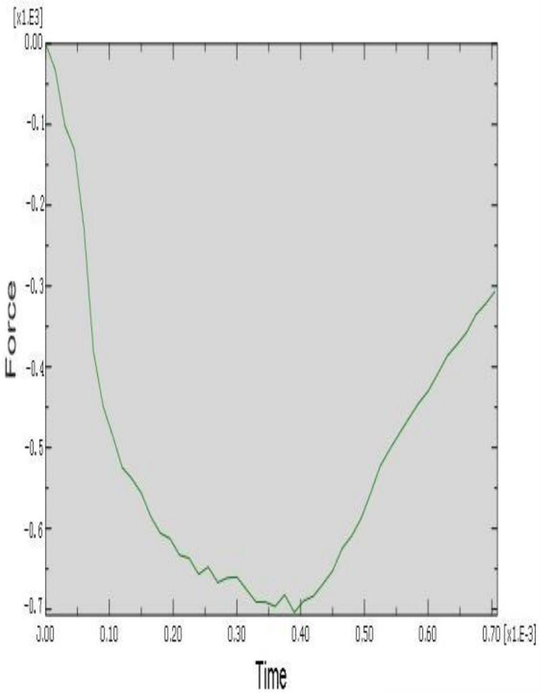


Fig.4.2 The fourth set of data simulation screenshots



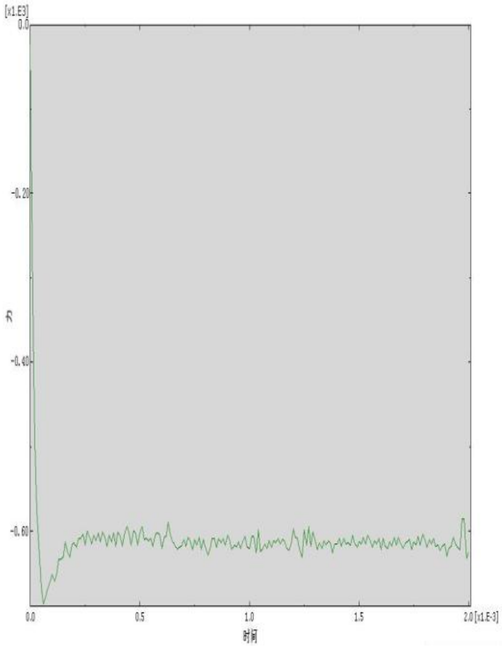
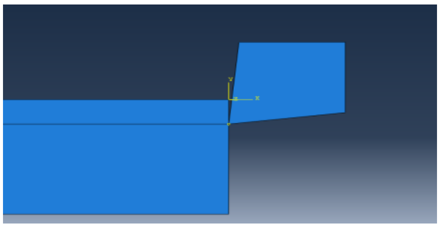


Fig.4.3 The fourth set of data tangential force diagram   Fig.4.4 The fourth set of data axial force diagram

(5) When the rake angel is 5 °, the back engagement of the cutting edge is 2mm, the feed rate is 0.2mm / r, the spindle speed is 320r / min ,the below picture is captured and the cuttiing forces change graphs with time .



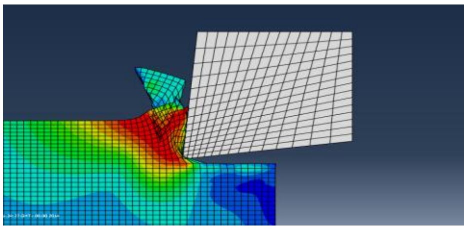
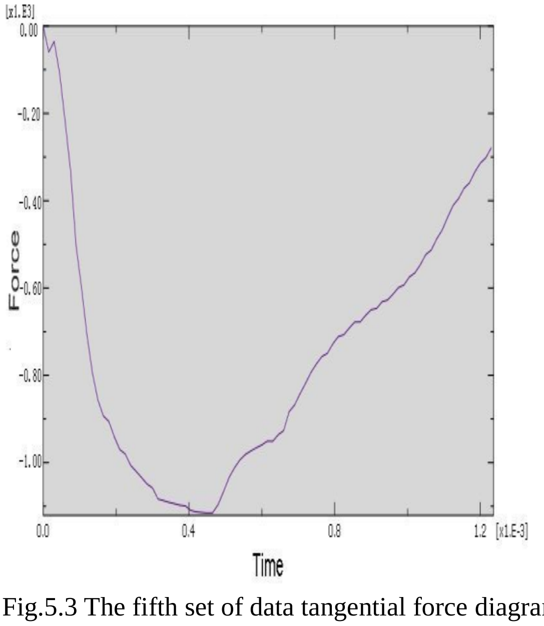


Fig.5.1 The fifth set of data model   Fig.5.2 The fifth set of data simulation screenshots



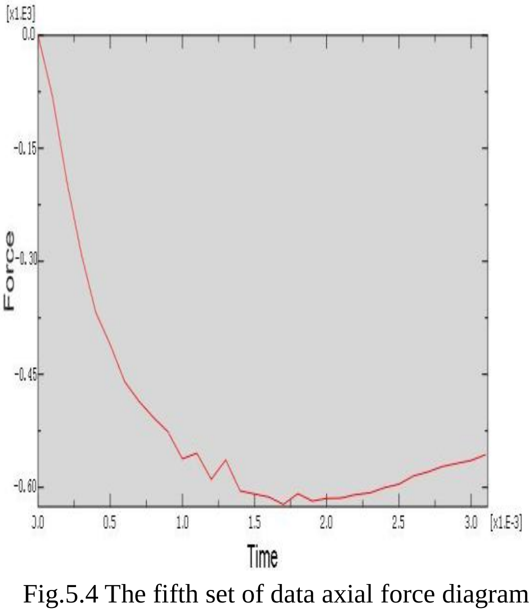


Fig.5.3 The fifth set of data tangential force diagram   Fig.5.4 The fifth set of data axial force diagram

3.3 Data Summary

Summarized above five sets of data, you can get Table 4

Table 4 ABAQUS cutting simulation

Tool geometry	Cutting condition			Force		
Main tool rake angle	Back engagement	Feed	Spindle speed	Tangential Force	Axial force	
15	1.5	0.14	320	360	185	1
20	2	0.2	560	450	240	2
10	2	0.2	560	660	340	3
5	2	0.2	560	900	590	4
5	2	0.2	320	878	597	5

The following conclusions can be drawn from the table,

(1) By comparing the fourth and fifth set of data and images can be roughly seen that when the X-axis suffer different cutting speeds ,the force is about 800N ~ 900N fluctuations .When time reachs 0.4E-3 seconds points, the force of the tool has a large fluctuation.Because the speed of the finite element is defined between the time 0 to the time of 0.4E-3 increased from 0mm / s to to achieve the required speed, so the 0.4E-3 time about a sudden fluctuation of the speed does not exist in the actual situation .So this curve can be ignored, and at the end of the curve has a tendency to increase the force by which the speed is reduced to zero from the maximum relevant. So comparing the effective range of several curves is in the middle of a period of time. So cutting speed has little effect on the cutting force, which cutting speed decreasing by about 5%, increase cutting force of about 1%.

(2)By comparing the back engagement of the cutting edge and the feed of the curve under the cutting force can be seen that the tool in the vertical direction, i.e. (Y-axis) is almost constant force, small fluctuations; The cutting force in the X-axis also appear a great fluctuations at the beginning of near the moment, which is related to this definition of the speed and curves.The reasons has been described in previous conclusion , so here will not talk any more.as can be seen by the graph ,with back engagement of the cutting edge and feed rate increasing, the cutting force increased. Since this does not use a control variable cutting simulation method, this part control conclusion change status does not do a detailed analysis.

(3)By comparing curves of the cutting forces under different rake angle can be seen that the tool (Y-axis) in the vertical direction of the force changed little, but in the X-axis cutting force varies greatly, from 5 ° and 20 °,the cutting force almost change doubled.As can be seen by the graph that when rake angle increases, the cutting force also increases.

IV. Conclusions

Through the study of the principle of the machining, analyzing the common Johnson - Cook constitutive model, then establish a suitable for turning processing simulation model. By means of equivalent deformation layer theory,then the simulation model to simplify again and eventually come to a two-dimensional orthogonal cutting model.

When meshing, because automatic separation can not be achieved in ABAQUS node ,so it must prejudge cutting layers and cutting paths, and establish the underlying chip and the initial contact which has been machined surface on the pre-cut path.Then when mapped meshing,the bottom of the chip and the suface which has been machined are equal in the length and number of unite, and the establishment of a fully coupled overlap each other at each node. When selecting unit, because the tool is rigid which does not consider material deformation, so only calculate heat transfer. The workpiece is a large plastic deformation of rigid body, but also considers more strong thermal coupling.

In determining the material model, in order to fully reflect the workpiece material at different cutting speeds and lead to different constitutive relations,so according to the material manual, to get more real material qualities. In order to ensure that the unit of external model is removed, the rest is still able to consider contacting,and then the Contact Type must be set to Surface toSurf and Eroding (ESTS).

Parameter range:

Spindle speed: 320r / min - 560r / min; Feed: 0.14mm / r - 0.2mm / r; back engagement of the cutting edge: 1.5mm - 2mm; rake angle: 5 ° --20 °.

Simulation study the following conclusions:

(1)In the first shear region and gradually form a maximum equivalent stress zone. The stress flow in the layer of the chip as the tool advances , and always has been in the position of the shear layer.

(2)Main cutting force from the beginning to the formation of cutting chips to steady state has been in the process of change. The general trend : start rising rapidly, gradually entering the steady state, the cutting force began to decline, and ultimately remained stable.

(3)As the cutting speed increases, the cutting force decreases; cutting temperatures start to rise, then fall, and slowly stabilized.

(4)With the cutting depth increases, the cutting force becomes larger.

(5)When the rake angle is increased from 5 degrees to 20 degrees, the cutting force is reduced.

These results demonstrate that this cutting simulation is consistent with the fact,and the simulation process parameter settings and model optimization are reasonable. From one side to reveal a finite element analysis as a versatile tool for future in-depth study has laid a solid foundation.

V. Acknowledgements

The authors would like to thank the financial support from Scientific Research Innovation Fund of Shanghai University of Engineering Science (No. EI-0903-14-01004) and the school’s lab conditions to this research.

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Annotation

In all of the cutting force curve diagram,there are three groups of simulation experiments which are carried out under the condition of the Chinese model of ABAQUS,so the font type in the x and Y Axis is chinese.