Finite Element Simulation of Whirling Temperature of Titanium Alloy Based on DEFORM

LIU Shunhua

Tianjin University of Technology and Education No.1310, Dagu South Road, Hexi District, Tianjin, 300222, China

Abstract: ***Using DEFORM-3D software as a platform, a 3D cutting finite element model was established for the machining process of titanium alloy whirlwind milling with three elements. The effects of cutting speed, feed rate and radial depth on the cutting temperature were analyzed. The results showed that the cutting speed had the greatest influence on the cutting temperature, the axial feed rate and the radial cutting depth.***

Keywords: Software-DEFORM, titanium alloy, whirling, cutting temperature

1. Introduction

Titanium alloy products have good corrosion resistance and outstanding mechanical properties in the aerospace, chemical, medical and other fields are widely used in processing, cutting force, tool wear serious, low processing efficiency. Cutting temperature is an important parameter in the process of metal cutting process, affecting the surface quality of the workpiece, tool wear and life span. Simply rely on experimental means, not only time-consuming and laborious to increase production costs, and the cutting process of cutting force and cutting temperature is difficult to obtain accurate [1].

DEFORM-3D is a system based on finite element theory, metal plastic forming and process simulation. It can acquire important data such as cutting force, cutting temperature and tool wear at a certain cutting time [2]. Based on the DEFORM-3D software, the TC4 titanium alloy workpiece is simulated with the finite element numerical value whirlwind milling under certain cutting parameters. And the cutting temperature of each cutting tool is compared and analyzed. Which provide a theoretical basis for optimization of machining parameters.

2. Establishment of Simulation Model

2.1 Whirling Cut

Whirling is mounted on the cutter multi-tool, With the help of the cutter around the workpiece high-speed rotation and workpiece rotation of the composite movement to perform the processing, as shown in Figure 1.The cutting tools are clamped on the whirling ring at the radius R_T and rotate at the angular velocity ω_T .the workpiece with the radius R_w rotates at the angular velocity ω_W inside of the depth of cut. The rotation speed of the workpiece is very slow and the rotation speed of the tool is high. The axis of rotation of the cutter head has an angle of inclination for the workpiece axis of rotation equal to the thread angle of the thread. Each time the workpiece is rotated, the milling cutter moves a pitch along the workpiece axis, and the whole thread can be machined. In whirling process, the rotation center of the milling cutter is revolved with the radius of the eccentricity and the rotation center of the workpiece as the center. Figure 2 depicts the curvature of the center of rotation of the milling cutter during the two previous cutting operations. From the geometric relationship can know,

$$a_2 = \frac{2\pi \times n_\omega}{z \times n_t} \tag{1}$$

Where z is the number of tools on the milling cutter, n_ω is workpiece speed,

n_t is tool speed. The cutting speed of the tool v_t is:

$$v_t = \pi D_T n_t \times 10^{-3} m/\min \tag{2}$$

$$f_t = v_t \cdot n(mm/\min) \tag{3}$$

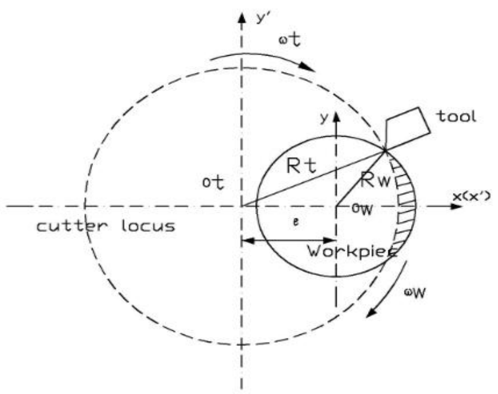

Figure 1: Actual in whirling

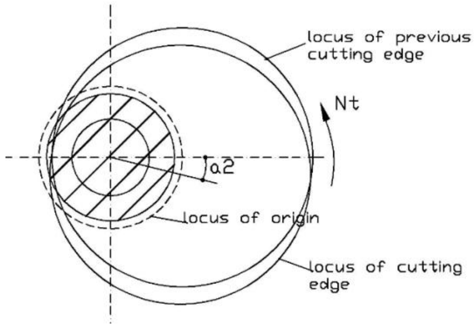

Figure 2: Cutting model of whirling

2.2 Tool and workpiece material selection

DEFORM-3D has a wealth of material library, and can be customized according to the material properties. Tools and artifacts are extracted from the model library that comes with the software. In this paper, the tool material is WC and the workpiece material is Ti-6Al-4V.

2.3 Elastic - plastic stress model

Elastic modulus E and Poisson's ratio are the characteristic parameters of elastic deformation stage of workpiece material. After the plastic deformation stage, the change of material properties is analyzed according to the flow stress model. Johnson-Cook flow stress model, simple in form, adapted to describe stress-strain relationships of metals at large deformation rates [3]. The expression is as follows:

$$\sigma = (A + B\varepsilon^{n})\left[1 + C\ln(\frac{\varepsilon}{\varepsilon_0})\right]\left[1 - \left(\frac{T - T_r}{T_m - T_r}\right)^{m}\right] \quad (4)$$

Where σ is flow stress of workpiece material, ε is plastic strain of workpiece material, A、B、n、C、m is the coefficient of the material itself, respectively, the yield stress intensity, strain hardening constant, strain hardening index, strain rate strengthening parameters, temperature strain rate sensitivity.

T is deformation temperature, T_m is melting point of the material, T_r is room temperature, ε_0 is reference strain rate.

2.4 Heat conduction model

The heat transfer equation of cutting [4] is

$$\lambda\ (\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2}) - \rho c(\mu\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y}) + Q = 0 \quad (5)$$

Where λ is thermal conductivity, T is temperature, ρ is material density, c is specific heat capacity of material, μ、v respectively move the heat source in x and y out of the velocity component, Q is heat generation rate per unit volume. And there,

$$Q = \frac{M\omega_h\omega_P'}{\rho} \quad (6)$$

Where M is thermal equivalent, ω_h is the ratio of plastic deformation work to heat energy, usually is 0.9, ω_P' is plastic strain rate. The frictional heat equation between the rake face of the tool and the chip, the flank face and the machined surface is,

$$Q_f = F_T V_T \quad (7)$$

3. Simulation Parameters Setting

In the simulation test, according to the physical and mechanical properties of TC4 titanium alloy parameters (see Table 1) set the corresponding DEFORM simulation parameters. In the finite element simulation of metal cutting, the cooling effect is achieved by setting the heat transfer coefficient. In the definition of the workpiece surface and the outside heat exchange, the ambient temperature is set to 20 °C. The heat transfer coefficient is 0.02 N / sec / mm / C, Lubricating effect by setting the knife - chip friction coefficient to achieve, in view of the titanium alloy cutting sticky knife is the phenomenon, take knife - chip friction coefficient of 0.8, In order to prevent the occurrence of non-qualified units to ensure the accuracy of the simulation process used in the adaptive set to 4, the number of grid 35000. The workpiece Size Ratio field is set to 7 and the grid size is set to 40000. In the simulation control, considering the calculation accuracy and efficiency, set the number of simulation steps to 1000 steps, save the calculation data every 25 steps, the cutting termination angle is 15 °.In addition to using tool wear calculation with Usui mode to set the tool wear, according to the experience values were taken a, b is 0.0000001 and 855.

Table 1: Titanium alloy TC4 physical and mechanical performance parameters

T°C	Elastic Modulus/GPa	Yield Strength/MPa	Poisson's ratio	Thermal expansion coefficient(m/K)	Thermal conductivity (m/K)
20	113	930	0.307	7.89	5.44
100	—	—	—	7.89	6.7
200	—	—	—	9.01	8.79
300	—	—	—	9.3	10.47
400	—	—	—	9.24	12.56
500	—	—	—	9.39	14.24
600	—	—	—	9.4	15.49

4. Analysis steps and boundary conditions

Finite element simulation of whirling, the cooling effect is achieved by setting the heat transfer coefficient, the ambient temperature is set to 20 ° C, the heat transfer coefficient is set to 0.02 N / sec / mm / C. The workpiece Size Ratio item is set to 7. The calculation precision and the calculation efficiency are considered synthetically, set the memory increments to 25 steps to store them once, for a total of 10,000 steps. Other boundary condition parameters for the DEFORM-3D simulation of the whirling are shown in Table 2.

Table 2: Boundary Conditions

Boundary conditions	sets
Ambient temperature	20℃
Convective Heat Transfer Coefficient of Workpiece and Air	9N/sec/mm/℃
Emissivity of the workpiece	0.75
Work - heat conversion efficiency	0.9

5. Simulation Scheme and Analysis of Whirling

According to the factors that affect the cutting force, the paper chooses three factors, feed rate, radial cutting depth and cutting speed. Each factor takes into account three different levels. The simulation model data is shown in Table 3.

Table 3: Simulation model data

	f_z mm/rev	Cutting depth/mm	Cutting speed/ v_t （m/min）	Whirling ring speed/rpm
A	0.05	0.5	40	500
B	0.1	1	100	1000
C	0.15	1.5	150	2000

Table 4: Program and results

	v_t （m/min）	Depth/mm	f_z (mm/rev)	Temperature simulation results（℃）
1	40	0.5	0.05	570
2	40	1	0.1	627
3	40	1.5	0.15	710
4	100	0.5	0.1	819
5	100	1	0.15	828
6	100	1.5	0.05	843
7	150	0.5	0.15	946
8	150	1	0.05	977
9	150	1.5	0.1	1040

Select the tip of the arc a few observations, as shown in Figure 3, you can find the closer to the arc vertex, the higher the temperature, the farther away from the arc fixed point, the lower the temperature. From the temperature distribution can be seen, the highest cutting temperature appears in the tool - chip contact surface on the tip of the arc near the local area, and it is in accordance with the fact that the cutting edge of the tool tip is the largest in the actual machining of the cyclone milling, and that the plastic deformation and the tool flank face are large.

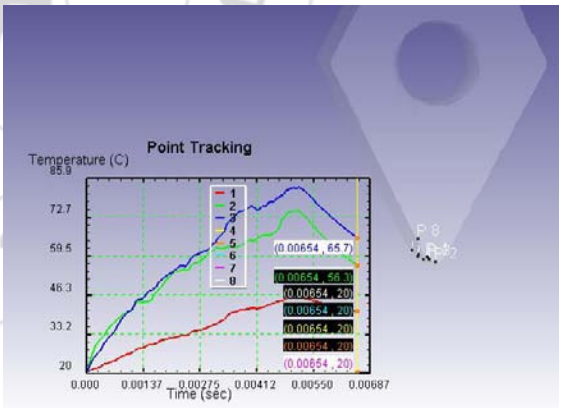

Figure 3: The Temperature Distribution of Cutting Edge of Tool

Figure 4 shows the comparison of the simulation values of each model. From the simulation results, it can be seen that when the workpiece parameters and the process parameters change, the maximum temperature value in the cutting appears obvious change. If maintain the maximum cutting thickness constant, with the cutting line speed increases, the processing temperature will rise.

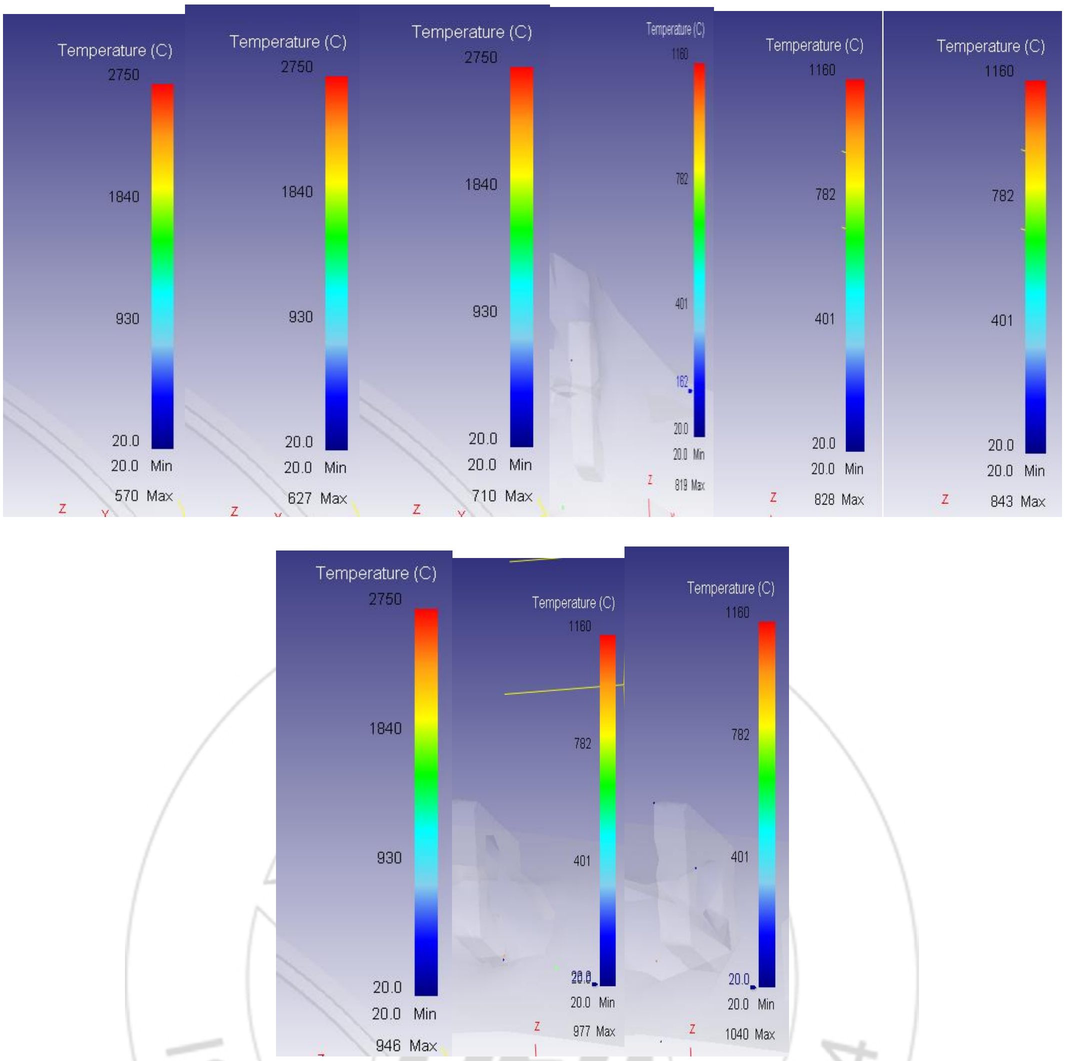

Figure 4: The maximum temperature of each scheme

The factors of the temperature changes in the situation shown by the graph, as shown in Figure 5,6,7.

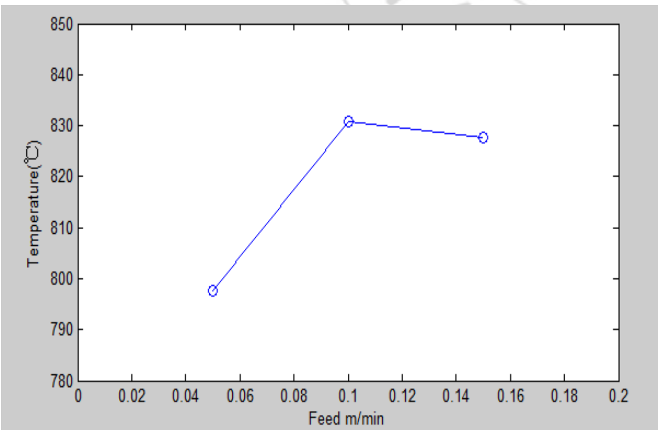

Figure 5: The relationship between feed rate and cutting temperature

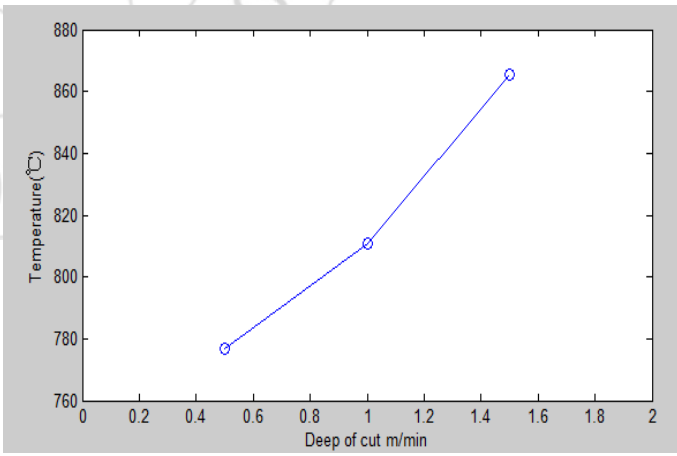

Figure 6: Radial depth of cut and the relationship between cutting temperature

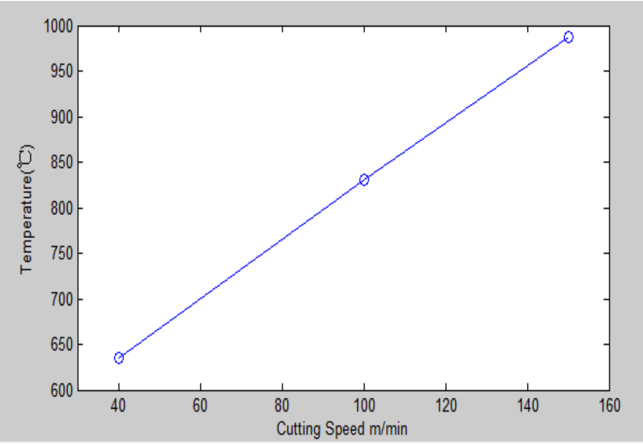

Figure 7: The relationship between cutting speed and cutting temperature

It can be seen from Table 4, the cutting temperature of the cutting tool with the feed, radial cutting depth and cutting speed increases, but the tool axial feed the greatest impact on temperature, followed by radial cutting depth, and finally cutting speed. In whirling cut, the tool feed along the workpiece axis is small relative to the speed of the whirling ring and is almost negligible. Because the milling cutter speed is high to facilitate cutting, radial cutting depth selection is generally small. High speed corresponding to the speed of exclusion of chips, a lot of heat has not yet passed into the chip, making the tool - the workpiece contact area of the cutting temperature increases. Therefore, in whirling cut, the cutting speed has the greatest effect on temperature. Radial cutting increases, the length of contact between the tool and the workpiece increases, heat dissipation conditions improve, the radial depth of cut is relatively small.

6. Acknowledgement

In order to study the influence of cutting parameters on the cutting temperature of titanium alloy during the cyclone milling process, using DEFORM finite element software. In this paper, the simulation results, the following main conclusions,

1) In whirling tool cutting force suffered by the two directions, the tip of the arc at the highest temperature can be introduced as the cutting edge of the cutting edge to participate in cutting an important part.
2) Through simulation analysis, it can be seen that the cutting speed has the greatest influence on the cutting temperature, followed by the axial feed, and the radial cutting depth has the least effect on the cutting temperature. In whirling cut ,in the control of cutting temperature to improve the processing efficiency requirements, the choice of a larger radial depth of cut, feed and a smaller cutting speed.

References

[1] Huang Jianlong, Yue Yun. Simulation of Dry Turning Temperature for 30CrNiMo8 Based on DEFORM - 3D. 2011,49(9),56-60.
[2] Xu Qingshan, Guo Xuhong, Wan Dongdong. Finite element simulation of ADI cutting force based on DEFORM - 3D. Mechanical design & manufacturing. 2013(2), 35-38.
[3] ZUO Jian - min, HU Yan - yan, and WANG Mu – lan. Finite Element Simulation and Analysis of Ti6Al4V Chip Forming Based on JC Model. Machine Tool & Hydraulics. 2009,37(11),7-10.
[4] Wang Sudong. Finite element simulation of titanium alloy cutting process based on DEFORM - 3D. Equipment Manufacturing Technology. 2009(12),30-32.

Author Profile

Liu Shunhua is reading the M.S. degrees in Mechanical Engineering from Tianjin University of Technology and Education.