Research of Distribution of Temperature Field in Process of Shaping

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***Abstract*—The cutting is an important machining technology, in which is belong to nonlinear large deformation, involving material nonlinear, geometry nonlinear and original bug, the thermal energy coupling question, and the nonlinear boundary condition, and so on. For the processing of metal cutting, using the large-scale commercial finite element theory, the coupling finite element model is established the consideration metal orthogonal cutting thermal energy based on the hot elastoplasticity finite element method. Analyzing the scrap processing simulation and so on swarf separation criterion, auto-adapted grid key aspects. Depending on the established the finite element model, it obtained the distribution laws of the temperature field and displacement field. The study results can give a theoretical basis for selecting the cutting tool shape, preferable surface. The research will develop the new cutting tool material, at the same time reduce the experimental cost.**

***Index Terms* - plaining, shaping machine, large displacement, temperature field, numerical simulation, process of shaping**

I. INTRODUCTION

With the development of modern machinery manufacturing technology, it is an important factor to how to for improve the cutting quality and reduce the cost cutting for competitive strength. Using of cut processing, it can obtain the ideal workpiece shape, size and surface roughness by removal the excess material layer in surface. In order to improve processing products quality, especially the cutting productivity and processing quality for cutting of the precision and ultra-precision, it was require study in deeply of cutting mechanism. The technology development of numerical simulation makes it possible to the mechanism of cutting.[1-15]

Shaping machine cut the workpiece which fixed to the machine tool platform, by using cutter of movement back and forth, and it is used for shaping relatively minor pieces. Shaping machine is so named because its shape is like a cow-head, being designed for cutting various planes, formed surface and key way of workpiece, as a general rule, the machine is suitable for single piece or small batch production. The ram head make happing and planning tool to movement back and forth in the processing of working. The main movement of small and medium shaper of shaping machine mostly adopts the crank rocker Mechanism to drive. So transfer speed of he ram is non-uniform. Hydraulic transmission system is used to large-scale shaping machine, its ram will remain basically in the state of uniform motion in a straight line, but the speed of the spare travel is greater than speed of working stroke. The product efficient is relatively low because spare travel is not cutting of the workpiece with single-edge planer tool in the processing of cutting. Its basic parameter is the maximum length of shaping and planning, the types of shaping machine including common, copying, and Mobile, etc. The planer tool move away straight and level of back and forth by the ram in ordinary shaping machine, the blade adapter can turn a corner in the vertical plane, either feeding by hand, then workpiece and work platform together intermittent move in intermittent horizontal or vertical. It is suitable for plane surface, groove or dovetail groove and so on. Profiling shaper machine add a copying mechanism in ordinary shaping machine, it is used for the forming surface, such as turbine blades, and so on. The ram and the slide body are also shift in machine body (horizontal type) or column (vertical type) for portable-type shaper machine, it is suitable for local plane of king size work piece.[16-29]

In order to study the laws of metal flow and distribution of temperature field in the deformation the region during the planning, the finite element model was established for planning. The numerical simulation method of finite element analysis of is suitable for elastic-plastic large deformation problems, such as temperature-dependent material properties and large strain rate, and so on. It can predict the changes of cutting force and the distribution of cutting temperature after cutting, and optimize the cutting parameters to achieve the control of the cutting process.[30-32]

II. HARD ALLOY

Hard alloy is a powder metallurgy products, in which is produced from high hardness, metal carbide powder with high melting point, and Ni etc bonded together with high sintering temperature.

The characters of hard alloy are as follows:

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The greater the proportional of carbide in the carbide, the larger the hardness. The smaller the size of carbide particle, the bigger the total volume of carbide particle. The smaller the thickness of bonding layer, Which is equivalent to the relative reduction the metal of bonding layer, its hardness down, flexural strength down too.

The hardness, wear resistance and heat resistance of hard alloy is higher than the high-speed steel, its high thermal hard up to about 1000 , However, its bending strength and brittleness are lower, less able to absorb the shocks load. The ability of impact strength is a little poor.

In present, for the machining of hard alloy, complex carbides as matrix materials. Mainly includes three types are as follows:

1) The Hard alloy of WC-Co class, code YG, the hard carbide material is WC and the binder is Co.

2) The Hard alloy of WC-TiC-Co class, code YT, the hard carbide material is WC and the binder is Co.

3) The Hard alloy of WC-TiC-TaC (NbC)-Co class, code YW, the hard carbide material is WC and the binder is Co. Also name general hard alloy, and it is a wide range of uses in many fields, Have been partially replaced by YT and YG category of hard alloy. For various grades of code, the more the amount of cobalt, the better the toughness, and it applied to rough machining. The more the amount of carbon, the higher red-hardness, the poorer the toughness and it applied to finishing machining.

III. CUTTING THEORY

The cutting process will generate heat, the two-dimensional simulation model as an example

$$\lambda\left(\partial^2 T/\partial x^2 + \partial^2 T/\partial y^2\right) + Q = C_\rho\left(u_x \partial T/\partial x + u_y \partial T/\partial y\right) \quad (1)$$

Where $T = T(x, y)$ is temperature distribution, λ is Thermal conductivity, C_ρ is specific heat; Q is heat generation rate. It can be calculated by the equivalent stress and equivalent strain rate, Q is given by

$$Q = \bar{\sigma}\dot{\bar{\varepsilon}} / J \quad (2)$$

Where J is mechanical equivalent of heat.

For a small range of plastic strain, the vector of strain is described by the following equation

$$\dot{\varepsilon}_{ij}^{th} = \alpha_{ij}\dot{T} \quad (3)$$

Where $\dot{\varepsilon}_{ij}^{th}$ is the change rate of thermal strain tensor, α_{ij} is the thermal expansion coefficient, $\dot{T}$ is the change rate of temperature.

Without the considering the influence of temperature, the relationship between tress-strain is given by

$$\dot{\alpha}_{ij} = D_{ijkl}(\dot{\varepsilon}_{kl} - \dot{\varepsilon}_{kl}^{th}) = D_{ijkl}(\varepsilon_{kl} - \delta_{kl}\dot{T}) \quad (4)$$

The equation of the total incremental strain vector is given by

$$d\varepsilon = d\varepsilon_p + d\varepsilon_e + d\varepsilon_T \quad (5)$$

Where $d\varepsilon$ is the total strain increment, $d\varepsilon_p$ is strain plastic increment, $d\varepsilon_e$ is elastic strain increment, $d\varepsilon_T$ is thermal strain increment.

The total strain：

$$\varepsilon = \varepsilon_P + \varepsilon_e + \varepsilon_T \quad (6)$$

Where ε is the total strain, ε_p is plastic strain, ε_e is elastic strain, ε_T is thermal strain.

The stress-strain constitutive equation is denoted as：

$$d\sigma = D_{ep}(d\varepsilon - d\varepsilon_T) + d_T \quad (7)$$

Hence, the expression for the strain increment can then be writed by

$$\begin{cases} d\varepsilon_T = \left(\alpha + (dD^{-1}/dT)\sigma\right)dT \\ dD_T = \dfrac{D\dfrac{\partial\bar{\sigma}}{\partial\sigma}\dfrac{\partial H}{\partial T}dT}{H_T^{'} + \left(\dfrac{\partial\bar{\sigma}}{\partial\sigma}\right)^T D\dfrac{\partial\bar{\sigma}}{\partial\sigma}} \end{cases} \quad (8)$$

For material model of workpiece, without consideration of elastic deformation in the first deformation zone, workpiece material model simplified incompressible elastic-viscoplastic material. The flowing stress of material was described by the yield criterion Von Mise. When the material stress state is in plastic state, the equivalent stress is always a constant value, the formula is expressed as.

$$\bar{\sigma} = \sigma_s \quad (9)$$

It can also be expressed as：

$$\left(\sigma_1^2 - \sigma_2^2\right)^2 + \left(\sigma_2^2 - \sigma_3^2\right)^2 + \left(\sigma_3^2 - \sigma_1^2\right) = \sigma_s^2 \quad (10)$$

Where $\bar{\sigma}$ is equivalent stress, σ_s is material yield stress, σ_i is the ith main principal stress (i =1, 2, 3).

As the metal-cutting will produce large amounts of heat, workpiece material must comply with thermal softening model for strain hardening, equivalent stress-strain curves showed that the strain (thermal strain) will occur the phenomenon of strain softening, after the strain hardening. The workpiece materials was found mobility in process of thermal softening, its properties also showed the trend of instability.

IV. ANALYSIS THE PLANING MODEL

A. FE model for planing

The process was simulated and calculated for metal by finite element method. Analysis the contact between tool and chip, the impact of Materials large deformation and deformation rate on the calculation, between the chip and workpiece, as well as the separation criteria based on stress and so on.

The model of two-dimensional elastic-plastic metal-cutting thermo mechanical coupled finite element was established by large deformation-large strain theory, incremental theory, and updated Lagrangian.

For planning processing, as the thickness of the workpiece is much larger than the thickness of its processing, the problem is a plane strain problem in process of analyzing workpiece machining, two-dimensional finite element model is shown in Figure 1.

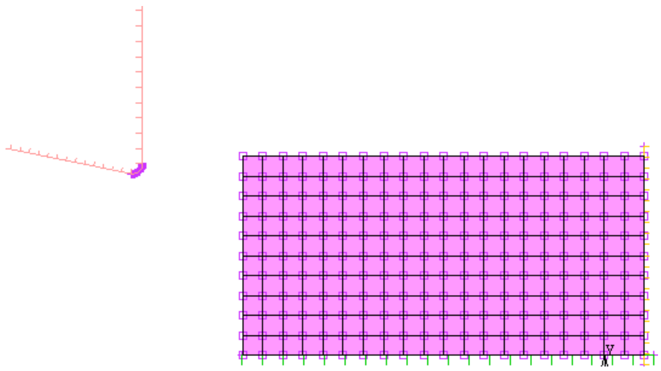

Figure 1. Finite element model of plaining

As shown in Figure 1, in order to more effectively analysis of cutting process, the assumptions is following:

1) Cutting process only produces a continuous chip after stable stage.

2) Tool is the rigid body, there is no deformation, but considering the temperature impact.

3）Workpiece material is elastic- viscoplastic material.

B. Initial and boundary conditions

The initial cutting temperature is 20 ℃ for the rigid Tool. The displacement is fixed for nodes in X and Y direction in bottom workpiece. There is convection and thermal radiation heat transfer between the free surface of the workpiece and the surrounding environment, here, it exists contact heat transfer between workpiece and tool, in the same time, due to plastic deformation and the friction caused generates heat, so the temperature of workpiece is raised in the process of cutting.

C. Workpiece model

The workpiece geometric parameters of the model are as follows:

Its length is 40 mm, thickness is 1mm, the thickness for cutting is 0.141mm, and due to the cutting layer thickness is much smaller than the thickness of the workpiece. So the type of stress is plane strain state. Workpiece material is 45 steel.

σ_b =600Mpa

σ_s =350Mpa

υ =0.3

E=212 Gpa

The hardness= 299HBS

ρ =7.8X103Kg/m^3

D. Cutter model

The material is alloy steel YT15, its parameters are as follows:

The thermal conductivity of cutter is 121.4W/(m.k)

Heat capacity of material is 460J/(Kg.K)

Thermal conductivity is 33.5 W/(m.K)

E=515Gpa

Bending strength is 1.13Gpa

υ =0.22

The hardness is 91HRA

The speed of cutting is 1500 mm/s

Feed depth is 0.1 mm/r

The main angle of tool is 45°

The backing-off angle of tool is 6°

The frication coefficient is 0.4

The convective heat transfer coefficient is 0.02 W/(m^2·℃)

The temperature of environment is 20℃.

The distance of cutting is 10 mm.

V. ANALYSIS THE RESULTS

A. Analysis of displacement field

Considering the friction that was caused by tool of rake face and backing-off angle and workpiece. The temperature change in tool was caused by the temperature change within workpiece and the placement of workpiece. The state in stable cutting was chosen as research object.

Based on the establishment of thermal coupled finite element model, accordingly the results of analysis by the calculation, the process of a chip stable region as the research object, so the displacement distribution in X direction is shown in Figure 2.

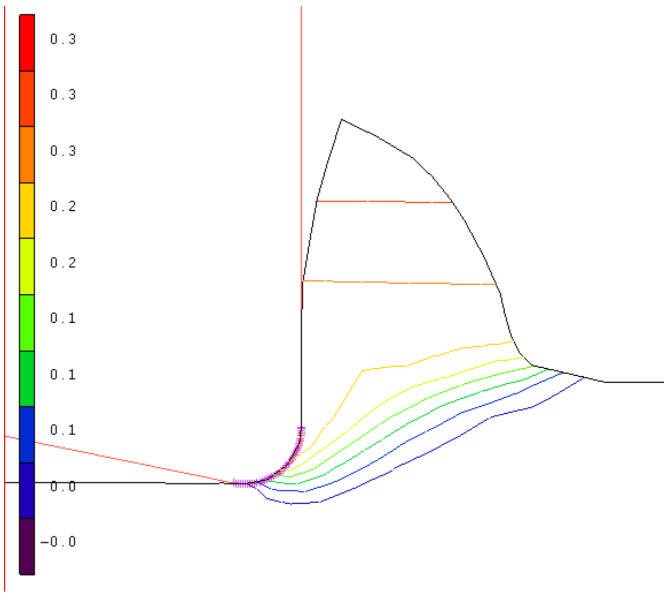

Figure 2. Displacement distribution in x direction in deformation zone

Figure 2 shows that the contour lines of the displacement in the x direction, base on Figure 2, it can show that contour distribution is the more dense near the boundary of zone between blade and the contact deformation, the distribution of contour lines of displacement is relatively sparse away from the cutting area of the metal, This is mainly reasons that the metal cutting process is a continuous process of deformation. Rigid tool do a straight line reciprocating movement, the greater the metal deformation, the greater the displacement in the process the cutting. On the contrary, the smaller the metal deformation, the smaller the displacement in the process the cutting.

Displacement distribution in Y direction is shown in Figure 3.

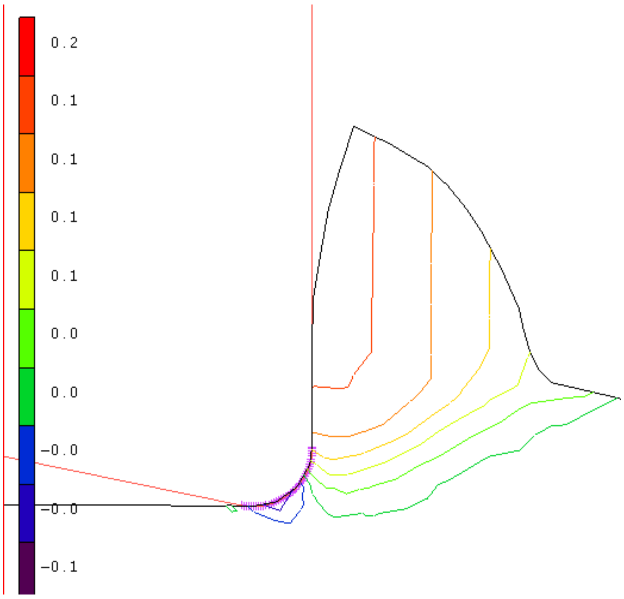

Figure 3. Displacement distribution in Y direction in deformation zone

Figure 3 shows that the contour lines of the displacement in the Y direction, base on Figure 3, it can show that the distribution in the Y direction is similar to the distribution in the X direction. Also should satisfy the demand of the laws. The greater the metal deformation, the greater the displacement in the process the cutting. On the contrary, the smaller the metal deformation, the smaller the displacement in the process the cutting.

In the deformation zone in the same, displacement cloud in Y direction is shown in Figure 4.

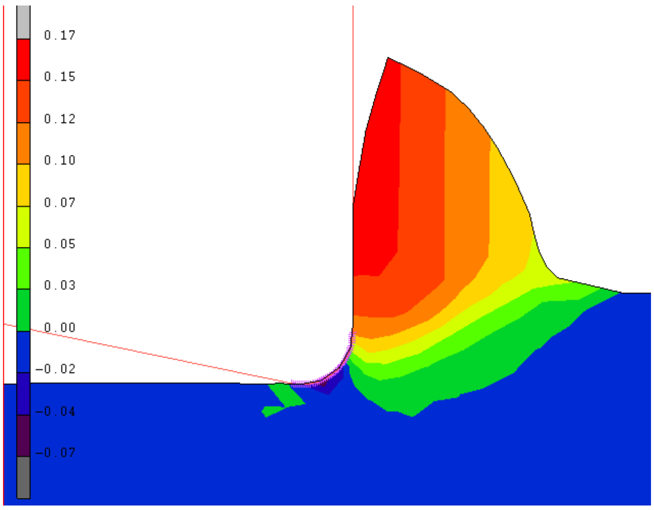

Figure 4. Displacement cloud in Y direction in deformation zone

Figure 4 shows that the displacement cloud in Y direction in deformation zone, as shown in Figure 4, there is maximum displacement in contact zone of the end land.

The curve of displacement in X and Y direction is shown in Figure 5.

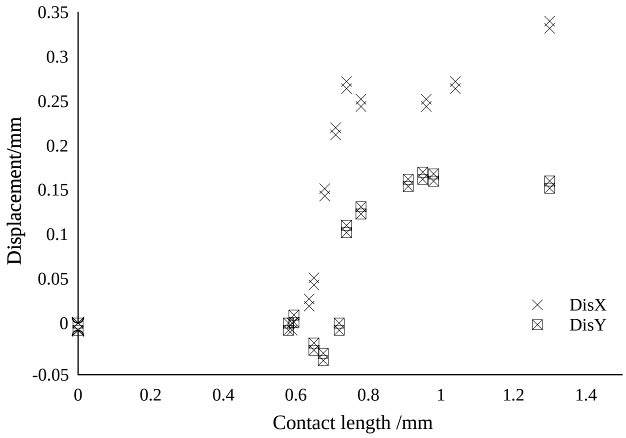

Figure 5. Displacement curve

Figure 5 shows that the displacement curve in X and Y direction in deformation zone, from Figures 1 to 5, it shown that the displacement changed is little, in the same time, and the error of displacement is small in the course of cutting in X and Y direction.

B. *Analysis the temperature field*

According to the characteristics of displacement distribution in deformation zone, it can gain the same location in the FE model, its temperature cloud is shown in Figure 6.

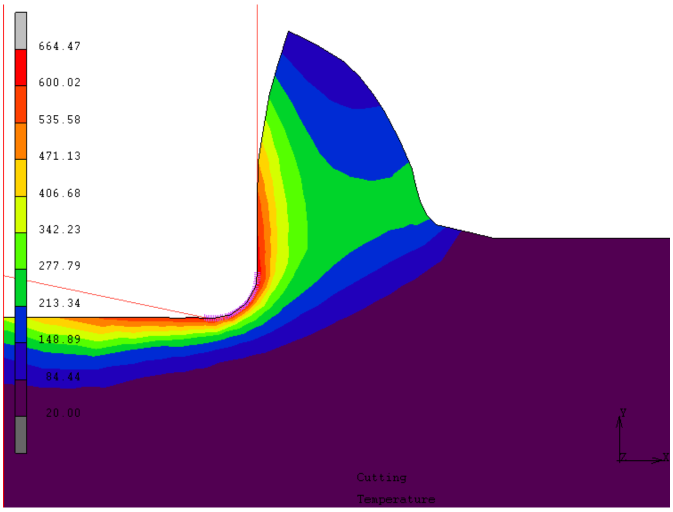

Figure 6. The cloud of tempereture in deformation zone

Figure 6 shows that the cloud of temperature in deformation zone, due to the presence of friction, the local temperature significantly increased the phenomenon for the workpiece in the cutting process. The analysis of Figure 6,it can shown that the temperature ranges from 20 °C to 664.40 °C atha amplitude fluctuated greatly, and its fluctuations regional is a continuous movement. The closer the distance metal from the cutting layer, the higher the temperature in workpiece in deformation zone.

The temperature distribution in deformation is shown Figure 7.

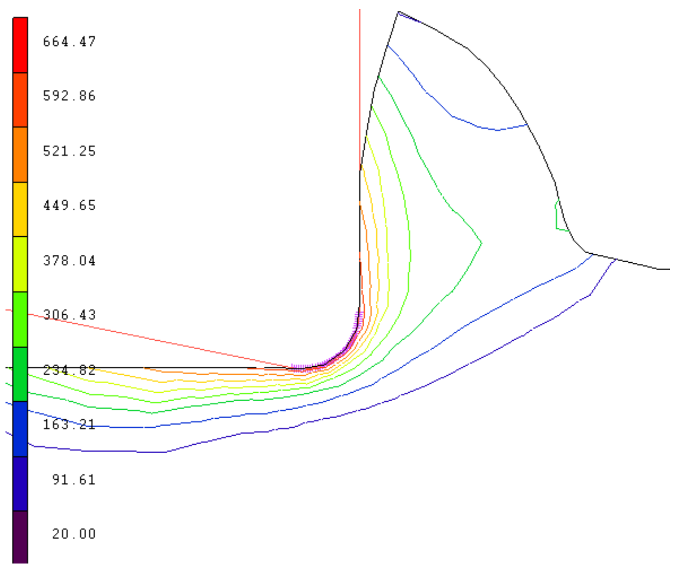

Figure 7. The distribution of temperature in deformation zone

Figure 7 shows that the distribution of temperature in deformation zone, base on Figure 3 and Figure 2, it can show that the distribution temperature is similar to the distribution of displacement.

The distribution of temperature in boundary within the deformation zone is shown Figure 8.

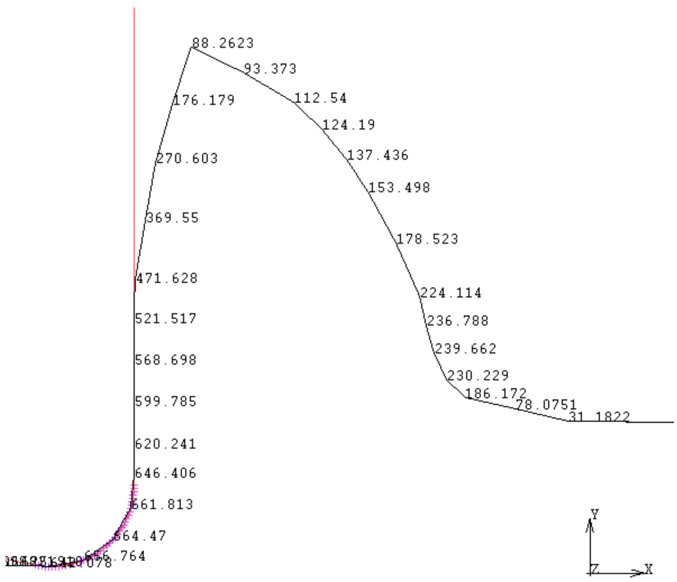

Figure 8. The distribution of temperture numerical in boundary within deformaton zone

Figure 7 shows that the distribution of temperature numerical in boundary within deformation zone, there is peak of temperature 664.47 °C in the boundary of cutting. The distribution curve of temperature in deformation zone is show in Figure 9.

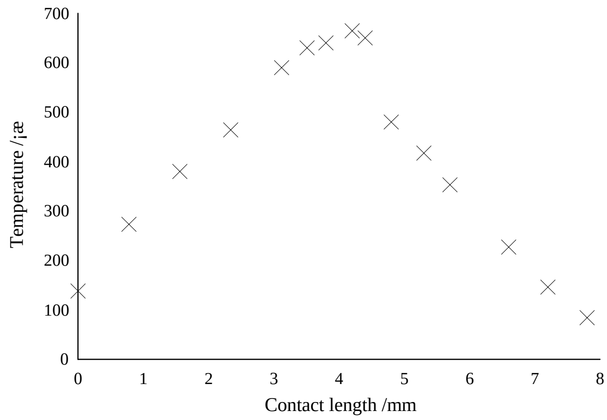

Figure 9. The distribution of temperture in boundary within deformaton zone

The fluctuations cutting temperature is mainly caused by local energy dissipation in process of cutting, however, the internal temperature distribution of materials mainly relied on plastic deformation to make its magnitude. From Figure 6-9, they indicate the distribution temperature, because it is relatively concentrated areas for plastic deformation and friction heat, there is maximum temperature with 664.47 ℃, in which lie in local deformation region and the blade area nearby the point of tool.

VI. Conclusion

Assumed that the premise of the state of plane strain, metal-cutting model was analyzed by finite element theory, analysis of influence of cutting forces and the internal temperature changes during cutting, and the conclusions is as following:

Taking into account large strain, large strain rate and temperature and other factors on the impact of material parameters in the finite element model of metal-cutting. Therefore, the results are more precise using the finite element method over than other analytical methods. For the processing of continuous chip, there are characteristics of high-temperature, high-speed forming for machining, its local temperatures will inevitably affect the performance parameters of various materials, and so it can ultimately affect the process of the workpiece machining.

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