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Study on three dimensional cutting simulation under different cooling conditions

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ABSTRACT: In order to improve the cutting temperature in the cutting process, adverse effects of the cutting tool and the workpiece, it is better to join the cooling factors in the cutting to achieve a better cutting effect. In this paper several common cooling methods (cold air, high pressure water jet, cold and warm air atomizing jet, cutting fluid) are used. A series of comparative analysis is done by simulation, such as analysis of the chip shape, chip formation, cutting force, temperature and surface stress at different cooling cutting conditions. Through the comparison, it is found that the cooling effect of cold and warm air is the best.

Keywords: Cooling, ABAQUS, Heat transfer, Simulation

I. INTRODUCTION

In the manufacturing process, the machining precision of the cutting, ultra high speed cutting and good surface quality of thin and hard processing materials processing and other advantages, have been widely used, prompting people to each of the high-speed cutting system of ring section. Cooling is one aspect of it [1]. Cooling problem is very important, it has a great influence on the quality of the workpiece and the life of the tool [2].

At present, the common cooling methods in high speed machining are cutting fluid cooling, air cooling, tool coating, or other means, such as cold wind, and the most widely used cutting fluid cooling [3]. Cutting fluid is divided into cutting oil and water soluble cutting fluid, its basic role is cooling, lubrication, cleaning, rusting and so on. However, with the development of society and put forward the strategy of "sustainable development", the people of industrial activities on the environment and the health effects of more and more attention, application of cutting fluid cooling and lubricating mode has been strictly limited[4].

A. Iturbe, E. Hormaetxe, A. Garay and P. J. Arrazola investigated the suitability of replacing conventional cutting fluids by liquid nitrogen together with MQL, for industrial application when machining Inconel 718. They founded cryogenic and MQL machining improves the machining performance for short machining times in comparison with dry and MQL machining, but tool lives achieved with cryogenic+MQL machining for long term turning operations, are much shorter than the ones obtained in conventional machining, and long below the tool life requirements established by the industry [5]. G. S. Su, Y. K. Guo, X. L Song and H. Tao discussed effects of high-pressure cutting fluid with different jetting paths on tool wear in cutting compacted graphite iron and proved that high-pressure cutting fluid jetting along rake face can reduce the flank wear and chipping and adhesive wear is the main mode of tool wear on rake and flank face when no cutting fluid in used in machining of CGI [6]. M. R. Sankar and S. K. Choudhury considered experimental study and modeling of machining with dry compressed air, flood and minimum quantity cutting fluid cooling techniques, discovering that as the pressure air increases, the cutting fluid flow rate decreases and MQCF is one of viable economic and eco-friendly alternative machining to FC and DAC [7].

This thesis focuses on the methods of environmental protection cooling (cold air jet atomization, cold air, high pressure water jet and coolant) were studied, simulating the cutting process under different cooling conditions of the application of ABAQUS software, the cutting temperature, cutting force, chip morphology, stress analysis and discussion, to provide reference for the selection optimization of cooling conditions in the actual production.

II. MODEL BUILDING

2.1 Material Constitutive Model

A 3D FE-model of longitudinal turning of aluminum alloy 7050-T7451was developed. The cutting speed is directed in the y-direction whereas the feed is directed in the x-axis and the thrust is directed in the z-direction. The tool domain is initially meshed with 9138 elements. The workpiece was initially meshed with 6000 elements having a cutting length of 0.12m. Mesh density windows are used in order to locally mesh areas of high interest with higher density such as the shear zone.

Besides the mesh density, the material model of the work material and the contact model are crucial for the prediction of temperatures, stresses and sliding velocities of the chip. Therefore, the submodels are described in the following.

In high temperature, strain rate and strain intensity should be strong, the frequent elastic-plastic deformation in the cutting process, therefore, consider these factors affect the flow stress of material is very important, the most widely used Johnson-Cook model, the model can reflect the dynamic changes of material flow stress. The well-established constitutive equation used in metal cutting is the Johnson Cook Material model, taking strain hardening, strain rate hardening and thermal softening into account, see the followingequation [8]:

$$\sigma=\left(A+B\varepsilon^{n}\right)\left(1+CIn\frac{\dot{\varepsilon}}{\dot{\varepsilon}_{o}}\right)\left(1-\left(\frac{T-T_{r}}{T_{m}-T_{r}}\right)\right)^{m} \qquad (1)$$

Where is initial yield stress, A is strain hardening constant,$B$is work hardening index, n is work hardening index, C is coefficient depending on strain rate, softening coefficient, m is softening coefficientmelting temperature, T_m is melting temperature room temperature, T_r is room temperature , $\dot{\varepsilon}$ is reference strain rate.

2.2 Contact Friction Between The Tool And The Chip

Based on the different friction types, the interface between the tool and the chip could be divided into two different zones, i.e., the stick zone and the slip zone. In the stick zone, which was close to the tool tip, the chip pressed the working surface of the tool and the cutting temperature increased rapidly. The heat dissipation in this zone was slow and the chip was plastically deformed. The root of the chip tightly contacted the tool surface. When the cutting force exceeded the maximum shear stress of the workpiece, the material underneath the chip was torn and the friction in this area was the internal friction of the surface layer. Whereas, in the area away from the tip, due to the faster heat dissipation, either the cutting temperature or the cutting stress was much lower than that at the tip. The cold-working hardening of the material occurred after the deformation. Correspondingly, the friction in this area was the slip friction between the tool and the chip. The type of the friction that the element node was assigned to was determined by comparing the friction shear stress τ_f with the maximum shear stress τ_s . If $\tau_f > \tau_s$, the node was in the stick zone. Otherwise, it was in the slip zoom.

$$\begin{cases} \tau_f = \tau_s & \tau_f \geq \tau_s \\ \tau_f = \mu\sigma_n & \tau_f < \tau_s \end{cases} \quad (2)$$

where τ_f is the friction shear stress of the material, stress, τ_s is the maximum the node, and σ_n is the normal stress at node, and μ is the friction coefficient.

III. SELECTION OF COOLING CONDITIONS

The cooling factor is determined by the heat transfer coefficient of ABAQUS. The surface heat transfer coefficient of different heat transfer process is quite different, such as the natural convection heat transfer coefficient of air pseudo 5~25W/ (m^{2}. K), forced convection heat transfer coefficient is 20~100 W/ (m^{2}. K).The natural convection heat transfer coefficient of water is 2X10^{2}~10^{3} W/ (m^{2}. K), and the forced convective heat transfer coefficient is as high as 10^{3} ~1.5X10^{3} W/ (m^{2}. K).The heat transfer coefficient of cutting fluid can reach 50~1.5X10^{4} W/ (m^{2}. K).The forced convection heat transfer coefficient of the cooling medium is 80 W/ (m^{2}. K) [9], high pressure water jet cooling heat transfer coefficient of about 1000W/ (m^{2}. K) [10]. According to the difference of the heat transfer process, and combined with the actual needs of the simulation analysis, make cold wind cutting when the heat transfer coefficient of 80W/ (m^{2}. K), low temperature air atomizing jet cooling heat transfer coefficient 4X10^{4}W/ (m^{2}. K), the number of heat transfer system of high pressure water jet cooling is about 1000 W/ (m^{2}. K).The thermal coefficient is up to 50~1.5X10^{4} W/ (m^{2}. K)for cutting fluid. Analyzing of different cooling methods (low temperature cold air, water jet cooling, low temperature atomizing jet cooling, cutting fluid) has cooling effect on the cutting performance of different materials for metal cutting.

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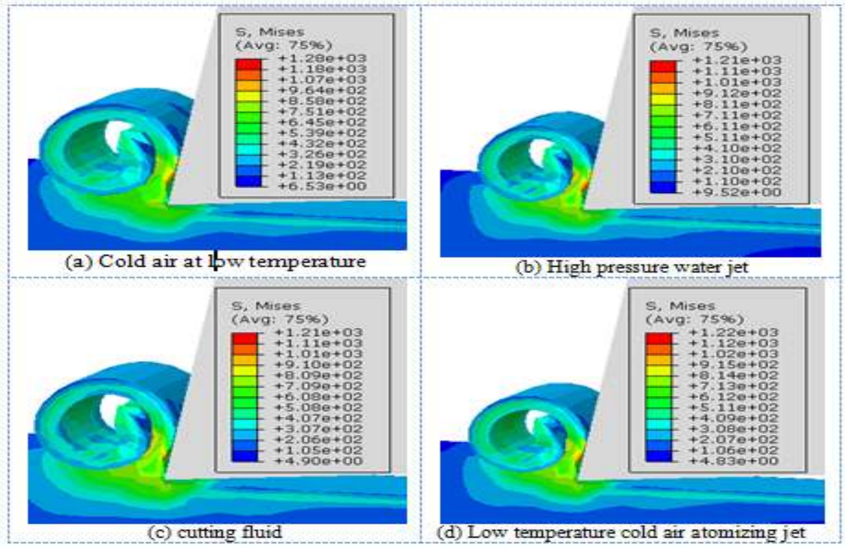
IV. ANALYSIS OF SIMULATION

4.1 Comparison Of Cutting Patterns

The cutting state of the turning is mainly in the shape of strip chip and saw tooth chip, the three elements of cutting and the material, and so on. In this paper, the change of chip formation and chip formation speed under different cooling conditions are discussed.



(a) Cold air at low temperature (b) High pressure water jet (c) cutting fluid (d) Low temperature cold air atomizing jet

Fig.1. Chip morphology and stress distribution under different cooling conditions

The cooling factor has little effect on the chip formation and the formation speed. In the selection of cooling conditions, the cooling factors on chip morphology and formation rate is not much affected .From the overall stress, the cooling condition has great influence on the stress of the cooling condition, the temperature is reduced, the thermal softening effect is weakened, and the stress is increased. As can be seen from the above, the higher the cooling coefficient, the smaller the stress and the lower the cooling coefficient, the greater the stress. The higher the cooling coefficient, the overall stress situation has improved.

4.2 Influence of different cooling conditions on cutting force

Cutting force is one of the important physical phenomena in the metal cutting process, which directly affects the quality of the workpiece, tool life, power consumption of the machine tool. The factors that affect the cutting force are the power size of the device itself, the type of the processed material, the type of the tool and the different parameters of the blade.

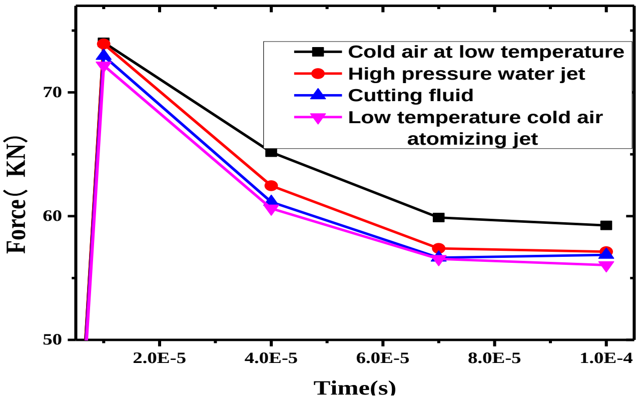
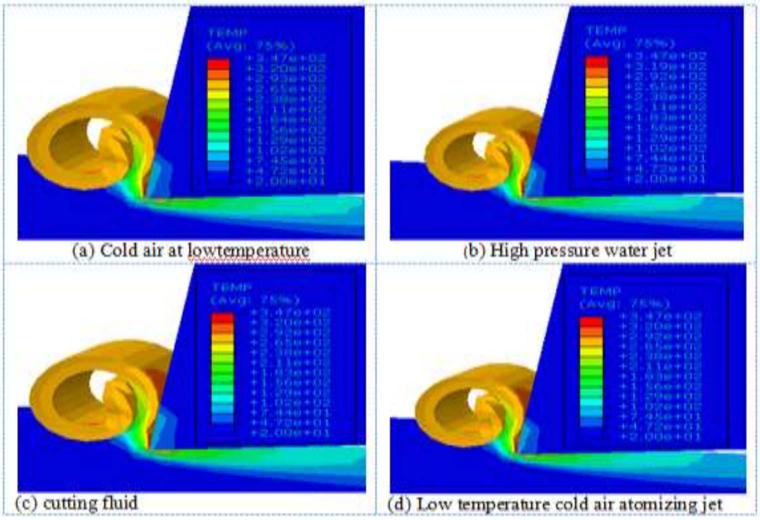


Fig.2. Changes of cutting force under different cooling cutting conditions

The cutting force curve is a good response to the cutting force in the cutting process, the cutting force gradually increases to a stable. The cutting force varies greatly in different cooling conditions, the low temperature cold air and high pressure water jet cutting force is the lowest, the low temperature cold air atomizing jet cutting force is the highest. The greater the cutting force, the more serious the tool wear

4.3 Comparison of temperature change in cutting process

Cutting temperature is mainly affected by cutting parameters, tool geometry, workpiece material, tool wear and cutting fluid. High cutting temperature is the main cause of tool wear, which would limit the productivity increase. Cutting temperature would reduce the processing accuracy, so that the surface has been processed to produce residual stress and other defects.



(a) Cold air at lowtemperature (b) High pressure water jet (c) cutting fluid (d) Low temperature cold air atomizing jet

Fig.3. Temperature variation under different cooling conditions

Influence of different cooling conditions on temperature, especially for the effect of the tool chip contact surface temperature of the chip and cutting, the temperature change in this area often leads to the tool and chip adhesion, serious tool wear and a series of adverse effects and reducing the temperature of the area can directly improve the cutting process. In the analysis of the above steps, the tip temperature is intercepted under different cooling conditions, respectively 970.257K, 982.108K, 989.023K, 981.817K, the temperature is very high, but relatively in low temperature air atomizing jet cooling condition, the temperature is the lowest point. Without any comparison of cooling conditions of dry cutting temperature (981.077K), it shows that the influence of cooling conditions the temperature is not great.

4.4 The change of the stress of a point on the surface of the work piece

Residual stress is that when the object has no external factors, there is a balance between the internal and external factors. The reason is that a part of the deformation of the workpiece is bound to be restrained, and the residual stress is caused by the no uniform deformation.

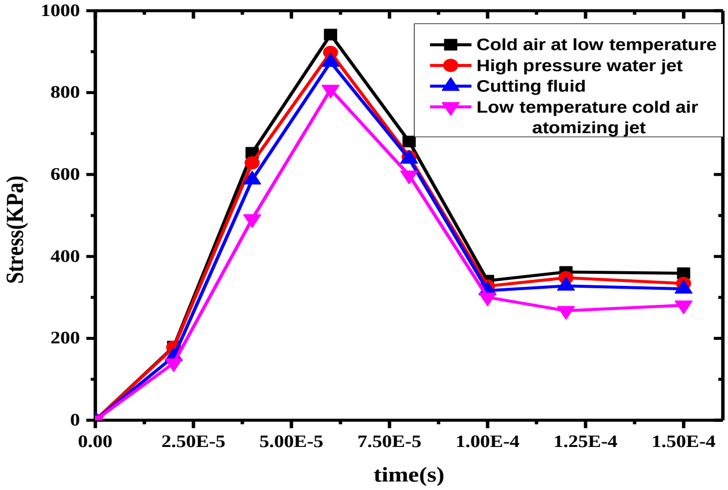


Fig.4. The change of stress at a point on the machined surface

The stress of the processed surface increases first and then decreases, finally tends to be stable, that is, the residual stress. Different cooling conditions on the machined surface fit in with the change of stress, but relatively speaking, it can be seen from the figure, because the whole process of stress change in the stress magnitude is too large, the stress curves are almost identical, but there are certain differences.

V. CONCLUSION

This paper mainly analyzes under the different cooling conditions (low temperature air, water jet cooling, Cryogenic Mist Jet Cooling, cutting fluid), chip formation and chip formation speed, cutting force, temperature and change of a point of stress. The conclusions are as follows:

(1) Different cooling conditions had little effect on chip formation and chip formation speed, but the whole of the workpiece should have great impact force. Higher the cooling coefficient, lesser the stress, it can improve the surface quality of the workpiece and tool life.

(2) Cutting force is more sensitive in the different cooling conditions to the cutting form and chip formation rate. Cutting force of cold air and high pressure water jet is the lowest, low temperature cold air atomizing jet cutting force is the highest.

(3) By cooling, the temperature of chips and cutting tools are decreased in different degrees. By comparison, the influence of cooling conditions on the temperature is not great.

(4) The change of the stress of a point on the surface of the workpiece is in accordance with the stress change of the cutting process, but because of the stress change of the whole process, the stress amplitude is too large, the stress curve is almost identical, but there are some differences.

In the selection of several different cooling conditions, the condition of the low temperature atomizing jet cooling is better than other cooling effects.

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