Journal of Manufacturing Processes 31 (2018) 480–493

Contents lists available at ScienceDirect

Journal of Manufacturing Processes

journal homepage: www.elsevier.com/locate/manpro

# Surface residual stress in high speed cutting of superalloy Inconel718 based on multiscale simulation

YiHang Fan, Tao Wang, ZhaoPeng Hao*, XiaoYong Liu, Song Gao, RongLi Li

*School of Mechatronic Engineering, ChangChun University of Technology, ChangChun, 130012, China*

ARTICLE INFO

*Article history:*
Received 24 April 2017
Received in revised form
20 November 2017
Accepted 13 December 2017

*Keywords:*
Inconel718
Brittle phase particle
Multi-scale simulation
Residual stress

ABSTRACT

Inconel718 is one kind of nickel-based superalloy strengthened by body centered tetragonal $\gamma''$ and face centered cubic $\gamma'$ precipitation, which has a high yield strength, high corrosion resistance and oxidation resistance at high temperature. Alloying elements exist in the form of high hardness compounds, such as TiC, NbC and other interphase hard point. These high hardness compounds result in the presence of high cutting temperature, large plastic deformation, especially the generation of residual stress in the machined surface. In this paper, the multi-scale finite element model of Inconel718 is established, and the cohesive element is added into the brittle phase particles to conduct the cutting simulation process. The accuracy of the established model is verified according to the chip morphology and the cutting force. The formation mechanism and distribution law of residual stress in the machined surface is studied deeply. The results show that the simulation results of the multi-scale finite element model which adds the brittle phase particles are closer to the experimental results. The larger the size of the brittle phase particles is, the smaller the residual stress of the workpiece is. Along the depth direction of workpiece, the influence of the brittle phase particles on the residual stress is getting smaller and smaller. This study provides a theoretical basis and reference for the further optimization of Inconel718 cutting performance and surface integrity.

© 2017 Published by Elsevier Ltd on behalf of The Society of Manufacturing Engineers.

## 1. Introduction

Nickel-based superalloy Inconel718 has good fatigue resistance, creep resistance, oxidation resistance, and corrosion resistance. It has been widely used in the aerospace field. However, the nickel-based alloy is one kind of typical difficult-to-cut materials. The alloy elements exist in the form of high hardness compounds, such as TiC, NbC and other interphase hard point [1]. There exists high cutting temperature, large plastic deformation and residual stress in cutting process. As an important index of surface integrity, residual stress is the main factor affecting the performance of parts. The residual stress leads to deformation of the workpiece easily, which influences the mechanical properties and fatigue life of the workpiece [2]. Therefore, it is important to study how to estimate the size and distribution of the residual stress in the machined surface. There are mainly two kinds of methods to study the residual stress. There are experiment and finite element simulation method. The experiment equipments have high cost and the accuracy of experimental results is affected by measurement means, instrument, the size and shape of the workpiece. Therefore, the finite element analysis method get the favor of many scholars, because it can save the experiment cost, obtain the data which is difficult to measure in the experiment [3].

In 1970, Barash and Schoech [4] used a simple slip line (the trajectory of maximum shear stress at each point in plastic deformable body is called slip line, which is usually used to solve the rigid plastic plane strain problem) model and successfully predicted the residual stress in the workpiece surface. Liang and Su [5] established the prediction model of residual stress in orthogonal cutting process. This model, by applying the pre-stress in the cutting process, can evaluate the effects of cutting conditions and geometrical parameters on the residual stress. Ulutan et al [6] developed an analytical model which can comprehensive forecast the residual stress in cutting process. In the thermo-mechanical model of residual stresses, both the thermal field of the workpiece and mechanical cutting forces are coupled. The proposed model can reduce the computational time in the predictions of residual stresses. Ee et al. [7] used a thermal elastic-viscoplastic finite element model to evaluate the residual stresses remaining in a machined component. They improved the accuracy of the predicted residual stresses through a series of methods, such as using a modified Johnson–Cook material model, considering the thermomechanical coupling effect on

* Corresponding author.
*E-mail address:* hzp1911@163.com (Z. Hao).

https://doi.org/10.1016/j.jmapro.2017.12.011
1526-6125/© 2017 Published by Elsevier Ltd on behalf of The Society of Manufacturing Engineers.

**Nomenclature**

| | |
|---|---|
| $\overline{\sigma}$ | equivalent plastic stress |
| $\overline{\varepsilon}$ | equivalent plastic strain |
| $\dot{\overline{\varepsilon}}$ | equivalent plastic strain rate |
| $\dot{\overline{\varepsilon_0}}$ | reference strain rate |
| $T_0$ | room temperature(°) |
| $A$ | initial yield stress |
| B | hardening modulus |
| $\rho$ | material density |
| $vc$ | cutting speed |
| $\sigma$ | uniaxial stress |
| $a$ | crack length |
| $E$ | elastic modulus |
| $h_D$ | cutting thickness |
| $d_0$ | average width of adiabatic shear bands |
| $\xi$ | shear strain |
| $\eta$ | elastic strain energy |
| $\tau_0$ | the shear flow resistance |
| $L$ | serration distance |
| $H$ | chip thickness |
| h | saw height |
| $\tau_{max}$ | maximum shear stress |
| $k_s$ | damaged parameter |
| $\bar{\varepsilon}_s^{pl}$ | critical value of equivalent plastic strain |
| $C$ | strain rate dependence coefficient |
| $n$ | work hardening index |
| $m$ | thermal softening coefficient |
| $T$ | dynamic temperature of materials(°) |
| $T_{melt}$ | material melting temperature(°) |
| $\gamma_0$ | tool rake angle |
| VB | tool flank wear volume |
| $\psi$ | increased surface energy of crack propagation |
| $f$ | feed rate |
| $F_f$ | feed force |
| a | coefficient |
| b | constant |
| $\gamma$ | error |
| $d$ | adiabatic shear band width |
| $k_0$ | thermal conductivity |
| $\theta_0$ | initial temperature |
| $\alpha$ | thermal softening parameter |
| $\sigma_m$ | theoretical fracture strength |
| $\lambda$ | period of interatomic bonding force change |
| $\theta_s$ | shear stress ratio |
| $w_s$ | monotonically increasing state variables |
| $\dot{\bar{\varepsilon}}^{pl}$ | equivalent plastic strain rate |

deformation and so on. They studied the influence of sequential cuts, cutting conditions, etc., on the residual stresses through case studies. Guo and Liu [8] developed a thermo-elastic-viscoplastic explicit FEM model to predict effects of sequential orthogonal cuts on the mechanical state and cutting mechanisms in a machined layer. They found that residual stress distribution is shown to be significantly changed in sequential cuts. They also evaluated the influences of cutting forces, cutting temperatures, and clamping forces on the residual stress distribution. Lazoglu, et al. [9] proposed an enhanced analytic elasto-plastic model using the superposition of thermal and mechanical stresses on the workpiece. Theoretical residual stress predictions are verified experimentally with X-ray diffraction measurements. With the enhanced analytical model, accurate residual stress results are achieved. Özel and Ulutan [10] utilize 3-D finite element (FE) modeling to predict forces and machining induced stress fields. They conducted cutting trials and used X-ray diffraction technique to measure the residual stresses. The predicted stress fields were compared against measured residual stresses. They also investigated the effect of tool edge radius and coating on the predicted stress profiles. Their findings are useful in predicting machining induced surface integrity.

Outeiro et al. [11] investigated the effects of tool geometry, tool coating and cutting regime parameters on residual stress distribution in the machined surface and subsurface of AISI 316L steel with experimental and numerical methods. The results show that residual stresses increase with most of the cutting parameters, including cutting speed, uncut chip thickness and tool cutting edge radius. Furthermore, the uncut chip thickness seems to be the parameter that has the strongest influence on residual stresses. Outeiro et al. [12] hold the idea that the cutting procedure also affects the residual stress. They studied the effects of cutting sequence on the residual stress distribution in the machined surface of AISI 316L steel through experimental and numerical methods. Based on their findings, the residual stress distribution on the affected machined layers can be controlled by optimizing the cutting sequence. Nasr et al. [13] examined the effects of two workpiece thermal properties, specifically thermal conductivity ($k$) and thermal softening exponent ($m$), on machining-induced residual stresses. They found that for both properties, $k$ has mainly affected the thickness of the tensile layer, where higher $k$ resulted in thicker layers. It has also induced higher surface tensile residual stresses. On the other hand, higher $m$ (lower softening effects) has significantly increased the magnitude of surface tensile residual stresses, with almost no effect on the thickness of the tensile layer.

Umbrello et al. [14] considered that the accuracy of the material constitutive model is an important guarantee for the prediction of residual stress. Miguelez et al. [15] analyzed the effects of the thermo-mechanical coupling parameters on residual stresses. The roles of thermal expansion, of thermal softening are considered separately. They also discussed the geometrical effects such as the tool rake angle and the tool edge radius on residual stress. Sharman et al. [16] carried out a series of experiments to evaluate the effects of varying cutting tool material, geometry, wear level and operating parameters on surface integrity. They found that the largest influence on surface integrity was tool wear. Cutting with a worn tool resulted in high surface tensile stresses. High tensile stresses were also formed in the surface layer when cutting with a coated tool, while cutting with an uncoated tungsten carbide insert at the same operating parameters produced deep compressive stresses beneath a reduced tensile layer. Akhavan Niaki and Mears [17] developed a 3D finite element model to study the wear effect on machining-induced residual stresses. The results showed that the FE model works well in predicting residual stresses when using sharp tool however it was unable to predict the existence of compressive stresses beneath the cut-ting surface accurately with the worn tool. They thought that the primary reason is element deletion in the simulation and the consequent loss of contact at the surface between the workpiece and flank face of the tool.

According to the above literatures, it can be found that the current simulation of residual stress has two shortcomings: one is that the finite element model cannot reflect the true structure (internal of material contains brittle phase).The other is that there exists two kinds of failure mechanism in cutting Inconel718. The failure mechanism of brittle particles is brittle failure(brittle rupture), but the matrix of Inconel718 is plastic failure. The previous simulation models considered the Inconel718 as a homogeneous material. It ignored the brittle particles in the material.

In this paper, a high-speed cutting Inconel718 model with brittle phase particles is established, based on multi-scale simulation. The effect of the size and position of the brittle phase particles on the residual stress magnitude and distribution is analyzed. The reli-

Download English Version:

https://daneshyari.com/en/article/8048035

Download Persian Version:

https://daneshyari.com/article/8048035

Daneshyari.com