Proceedings of the 5th WSEAS International Conference on Telecommunications and Informatics, Istanbul, Turkey, May 27-29, 2006 (pp452-456)

Analysis and Computation of Mechanical Action of Residual Stress in Milling

WANG LITAO , WANG HONGFENG ,YE HUAN
Department of Mechanical Engineering, Anhui University of Technology and Science, Wuhu.China,241000

Abstract: Given proprieties of tool-workpiece materials, the experimental model of milling stress measurement is set as boundary condition for finite element analysis during milling process. The residual stress is the main reason of workpiece deformation. It is analyzed and computed using the finite element method. The idea of living and dead element is employed to model the material removal process while considering the impact effect when tool cutting workpiece. A small time step is used while the tool is contacting with workpiece to improve the accuracy of the simulation. The simulation results conform with experimental results.
Keywords: Residual Stress, Milling Force, Finite Element Analysis, Impact Effect, Stress Wave Effect, Birth-death Element

1 Introduction

It is important to model the residual stress induced by metal cutting. This is a complex problem in machining engineering. It involves the machine property, the stability and intensity of fixture system, the state of blank, and the reaction between workpiece and working environment, etc. There are some convincing results achieved on this problem in the last years. However, it is possible to make use of the progress in the related fields to get more useful results for more complex applications.The integrated design requirement for mechanical products, especially for aeronautic products, is advanced with the development and improvement of equipments and design ideas in recent years. Workpieces with large aluminum alloy structure are used widely in modern aviation products because of the light density, high ability of bear weight, the property of resisting decay and meeting the whole requirement. As deformation widely exists in milling, it is important to improve machining precision by controlling and even eliminating the deformation. The residual stress is the main physical reason that induces machining deformation.The formation mechanism and law of the residual stress of a kind of aviation material, 7075-T7451, are studied. The residual stress induced by the force and heat of milling is mainly in the finished layers of the workpiece as a result of the tool's action during milling. The residual stress is tension in the exterior layers and compressive stress in the interior layers. The existing of residual stress affects negatively on the dimension and performance of the workpiece. Finite element model for two- dimensionals milling is build up in ANSYS, and the removal of materials is simulated with the living and dead element. The distribution law of residual stress induced by milling force in the finished surface

●The research is supported by National Science Foundation of China, Provincial Science Foundation of Anhui, Key Project of Science Foundation of Education Department of Anhui Province, and Anhui Provincial Science Foundation for Outstanding Young Scholars

is analyzed. The elastic and plastic deformation of the chip and the finished surface induced by milling force leads to the formation of residual stress in the surface layer. In this paper the distribution law of the residual stress of the given material during machining is simulated using FEA techniques to provide clues to eliminate the deformation of the workpiece.

2 Milling Model

The characteristic of milling is that the process is discontinuous, and the state of the milling force in the process is very complex. The model shown in Fig.1 is the model of the milling force

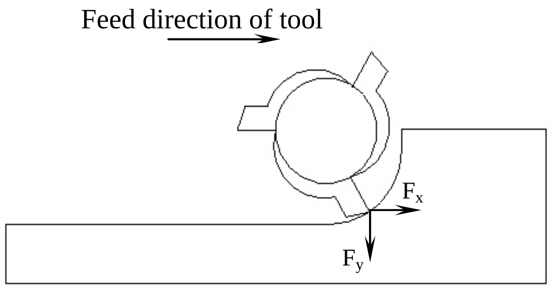


Fig.1 The model of milling in engineering

for a spiral milling cutter with three teeth.To simulate the process with FEA method, some assumption are made by considering the practical problem: The effect of temperature and strain rate are ignored for the formation of the residual stress and the law of its distribution according to the opinion of Sasahara and Obikawa[1]. The tool is assumed to be rigid and sharp all the time. The viscous and viscouso-plastic deformations of the workpiece meterials do not happen during milling. Mises regulation is met when there is plastic deformation. Bauschinger effect is not existing when the workpiece is loaded and unloaded repeatedly. It is assumed to be a plane strain problem because the milling layer is much thinner than workpiece length. The removal of material is simulated with the alive and dead finite element

3 Finite Element Model of Milling

3.1 Preprocessing

The milling force that is measured in experiments is set as input for finite element analysis of the milling. The workpiece material is 7050 -T7451. The tool diameter isφ25, the rake angle is 16°, the clearance angle is 27°, and the helical angle is 39°. The entity of the mesh is the plane quadrangle which is stabile in computation and the result has high precision. The workpiece is 1000mm long and 450mm high. It is divided into 260 elements, and the 3 uniform layers on the top of the workpiece is set as chip, and the bottom is set as base which is divided 10 layers which are getting thicker and thicker gradually from top to bottom[2]. The result is shown in Fig.2.

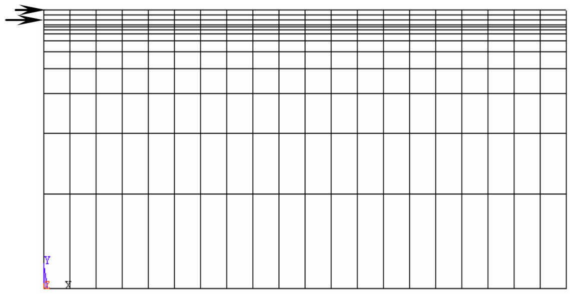


Fig.2 the finite element model of the workpiece to be machined

3.2 Modeling of the Moving Load

3.2.1 The Impact Load

The modeling process is divided into two steps, one is transition state and the other is steady state because it was shown in the experiment and simulation that there is a sudden change of the milling force while the tool is cutting into the workpiece. The mechanic characteristic of the transition state is related with the tool's spiral angle, as shown in Fig.2

3.2.2 The Steady Cutting Force

It is assumed that the finite element model is steady in the main process of the simulation. Two-directional milling force that is obtained from milling force model acts on the predefined separation surface in the way of a thread load, and goes forward along the surface. The length of a step is the length of an element. The milling force acts on the current element and the force on the former element is assigned to be zero for loading and unloading. After all the elements are finished, the force magnitude on the last element is assigned to be zero, and another sub-step is computed to obtain the distribution law of the residual stress.

3.2.3 Material Removal

It is important for the computation result whether or not to consider the chip layer during the process of modeling. The process and the chip are all dynamic. It is very difficult and very time-consuming to re-mesh dynamically and to reset boundary condition in the process of computation. So the alive and dead technique in finite element method is used to kill these elements that undergo milling force, and these elements will have no effect on the following computation. Both the efficiency and the precision of the computation are guaranteed using this method. The finite element model after all the load steps and the removal of material have been finished is shown in Fig.3.

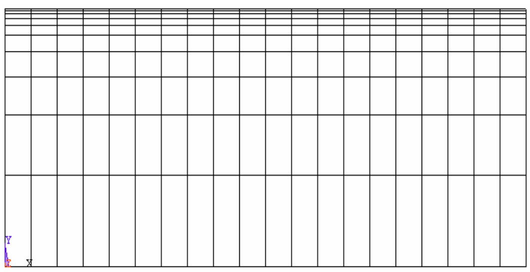
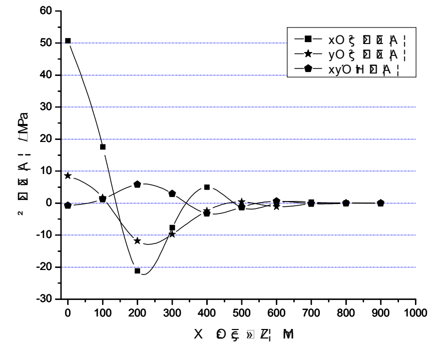


Fig.3 finite element model of milled workpiece

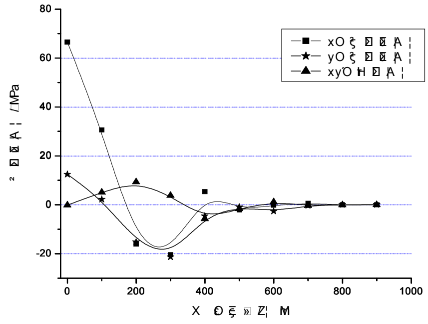
4 Computational Results

It is well-known in metal cutting theory[3]~[5] that the resources of the residual stress in the finished surface layer are cutting force, machining plastic deformation and cutting heat.

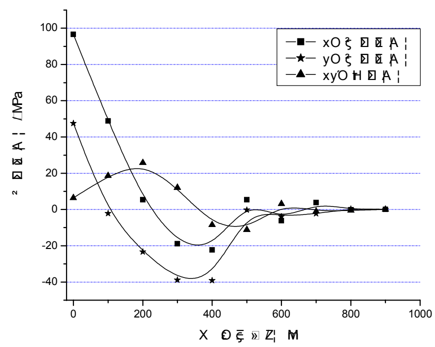
The residual stress obtained using finite element method in this paper is due to the two former elements, and cutting heat is not considered. Four group parameters corresponding to residual stress distribution along longitude of the basis workpiece and one group parameter corresponding to the residual stress in the x direction distribution are shown in Fig.4 and Fig.5.



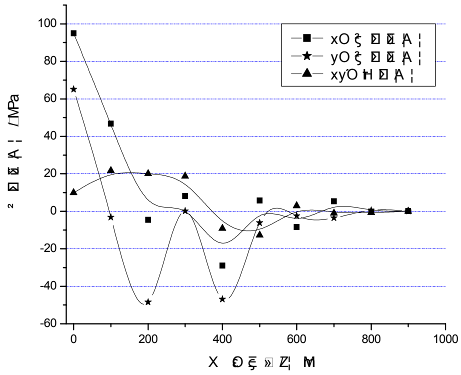
a)



b)



c)



d)

Fig.4 The residual stress distributing along ordinate of the basis workpiece

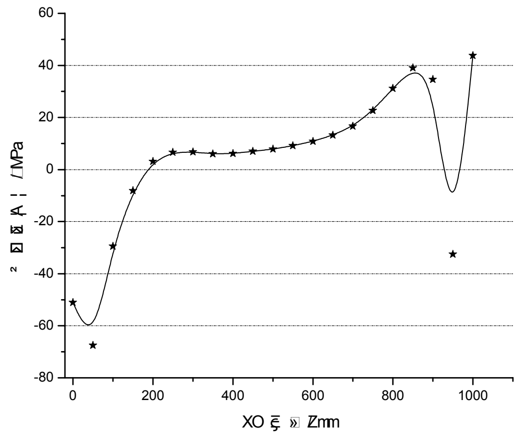


Fig.5 The residual stress distributing along machined surface of workpiece

The milling parameters in the Fig.4 are: a) milling thickness is 3mm, spindle rev. is 3000r/min, feed speed is 400mm/min, milling width is 15mm; b) milling thickness is 4mm, spindle rev. is 2500r/min, feeding speed is 400mm/min, milling width is 15mm;c) milling thickness is 4mm, spindle rev. is 3000r/min, feeding speed is 300mm/min, milling width is 12.5mm; d) milling thickness is 5mm, spindle rev. is 3000r/min, feeding speed is 350mm/min, milling width is 10mm; The milling parameters in the in Fig.5 are: milling thickness is 5mm, spindle rev. is 2500r/min, feeding speed is 300mm/min, milling width is 15mm. In Fig.4, the distribution trend of the residual stress inosculate well with the result shown in other reference[6]. There is residual stress in surface layer, and it gets almost zero beyond the range. The practical distribution law of residual stress in the surface layer is shown in Fig5. The periods that tool cuts into and out workpiece are sensitive stages of stress. The effect of impact causes the period of tool cutting into workpiece to be a sensitive stage of stress. As for the period of tool cutting out workpiece, we propose that there is a “stress wave effect” in this period. When the generation of the stress along with the motion of the tool is broken by the workpiece boundary, the stress concentrates near the boundary, and increases speedily at that time.

5 Conclusion

The distribution law of the residual stress in the finished surface during milling process has been analyzed and computed using elastic and plastic finite element techniques in the paper. The effect of tool impact and material removal on residual stress is considered simultaneously. To explain the results of the simulation, “stress wave effect” is proposed. The stress wave effect can not only reflect the residual stress distribution characteristic but also interpret the physical phenomena of machining. It is important for the research of the machining deformation[7] and other related problems. It is also give some clues to eliminate the machining deformation in engineering.

References:

[1] H.Sasahara, T.Obikawa and T. Shira kashi. FEM Analysis of Cutting Sequenence Effect on Mechanical Characteristics in Machined Layer. Journal of Materials Processing Technology 62(1996), pp448-453

[2]WANG Litao. Application skills of ANSYS— a general finite element analysis software package, Journal of Anhui University of Technology and Science (Natural Scien-

ce),Vol.18 No.3(2003),p18~p21

[3] Mahmoud Shala, Christian Kerk, Taylay Altan. Process modeling in machining,Part □ :determination of flow stress data. International Journal of Machine Tools & Manufacture, 41(2001),p1511~p1534; Part □:Validation and applications of the determined flow stress data. International Journal of Machine Tools & Manufacture, 41(2001), p1659~p1680

[4] ALBERT J.SHIH AND HENRY T.Y.YANG. Experimental and Finite Element Prediction of Residual Stresses Due to Orthogonal Metal Cutting, International Journal for Numerical Methods in Engineering, Vol.36, 1993, pp1487~1507

[5] ALBERT J.SHIH. Finite Element Analsis of Orthogonal Metal Cutting Mechanics, Int.J.MachTools Manufact,1996,Vol.36,No.2, pp255~273

[6]Hu Huanan. Investigation on Theoretical Prediction and Control of the Residual Stress in Machined Surface[A dissertation for degree of Doctor]. South China University of Techn-ology,1993.5

[7]Wang Litao. Study on Residual Stress and Distortion Theory of Aeronautic Frame Structure in the Milling [A dissertation for degree of Doctor]. Zhejiang univ. 2003.1