

Finite Element Simulation and Experiment of Chip Formation Process during High Speed Machining of AISI 1045 Hardened Steel

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Abstract—As an advanced manufacturing technology which has been developed rapidly in recent years, high speed machining is widely applied in many industries. The chip formation during high speed machining is a complicated material deformation and removing process. In research area of high speed machining, the prediction of chip morphology is a hot and difficult topic. A finite element method based on the software ABAQUS which involves Johnson-Cook material model and fracture criterion was used to simulate the serrated chip morphology and cutting force during high speed machining of AISI 1045 hardened steel. The serrated chip morphology and cutting force were observed and measured by high speed machining experiment of AISI 1045 hardened steel. The effects of rake angle on cutting force, sawtooth degree and space between sawteeth were discussed. The investigation indicates that the simulation results are consistent with the experiments and this finite element simulation method presented can be used to predict the chip morphology and cutting force accurately during high speed machining of hardened steel.

Index Terms—finite element simulation, high speed machining, serrated chip, chip formation, hardened steel

I. INTRODUCTION

As an advanced manufacturing technology which has been developed rapidly in more than last ten years, high speed machining can provide high efficiency of production and low cost, as well as improve the quality of machined surface. In addition, it can remove the difficult-to-cut materials with high hardness. High speed machining technology is widely applied in many industrial fields such as aeronautics and astronautics, automobile, mould, light industry, etc. One of the most important differences on cutting mechanics between high speed machining and conventional machining is that in high speed machining, a serrated chip is most often generated which affects nearly every aspect of high speed machining process, such as cutting force[1], cutting temperature[2], cutting tool wear[3] and life and machined surface quality[4]. Therefore, it is necessary to investigate and to predict the formation of serrated chip and the effect of chip morphology on vibration of cutting force, and their relationship with workpiece material and machining condition. At present, the published researches on prediction of serrated chip formation have focused on the theoretical modeling and the finite element simulation[5-6]. High speed machining is a strongly non-linear and complex contact

process. But these characteristics, especially the material constitutive relationship in high deformation condition are not fully considered by the existing methods. In addition, the simulation results of commonly used Deform-2D FE software are usually not consistent with the experiments because of their weak capability for non-linear problems. In this paper, a finite element method involving Johnson-Cook material model and fracture criterion was used to simulate the serrated chip formation during high speed machining using commercial FE software ABAQUS which can in principle handle such strongly non-linear problems and allow the definition of complex contact conditions. By using above method for FE simulation, the chip morphology during high speed machining of AISI 1045 hardened steel was accurately predicted and the effects of rake angle on the chip morphology and cutting force were discussed.

II. CHIP MORPHOLOGY SIMULATION

A. Material Model

For the simulation of chip morphology and cutting force, a Johnson-Cook model was used. This model is a strain rate and temperature dependent[7-8] visco-plastic material model which describes the relationship of stress, strain, strain rate and temperature. It is suitable for problems where the strain rate varies over a large range (10^0s^{-1} to 10^6s^{-1}), and the temperature changes due to plastic deformation caused by thermal softening. This model uses the following equivalent flow stress:

$$\sigma = [A + B(\bar{\epsilon})^n] \left[1 + C \ln \left(\frac{\dot{\bar{\epsilon}}}{\dot{\bar{\epsilon}}_0} \right) \right] \left[1 - \left(\frac{T - T_0}{T_{\text{melt}} - T_0} \right)^m \right] \quad (1)$$

Where $\bar{\sigma}$ is the equivalent stress, $\bar{\epsilon}$ is the equivalent plastic strain, $\dot{\bar{\epsilon}}$ is the plastic strain rate, $\dot{\bar{\epsilon}}_0$ is the reference strain rate (1.0s^{-1}), T_0 is the room temperature, T_{melt} is the melting temperature, A is the initial yield stress (MPa), B is the hardening modulus, n is the work-hardening exponent, C is a coefficient dependent on the strain rate (MPa), and m is the thermal softening coefficient. The Johnson-Cook parameter values used to simulate the behaviour of AISI 1045 workpiece are specified in Table I.

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An Analytical Study and Finite Element Modeling of Chip Formation in Metal Machining Process Qufei Xie,1993 Statistical and Computational Techniques in Manufacturing J. Paulo Davim,2012-03-06 In recent years interest in developing statistical and computational techniques for applied manufacturing engineering has been increased Today due to the great complexity of manufacturing engineering and the high number of parameters used conventional approaches are no longer sufficient Therefore in manufacturing statistical and computational techniques have achieved several applications namely modelling and simulation manufacturing processes optimization manufacturing parameters monitoring and control computer aided process planning etc The present book aims to provide recent information on statistical and computational techniques applied in manufacturing engineering The content is suitable for final undergraduate engineering courses or as a subject on manufacturing at the postgraduate level This book serves as a useful reference for academics statistical and computational science researchers mechanical manufacturing and industrial engineers and professionals in industries related to manufacturing engineering *Dynamic Methods and Process Advancements in Mechanical, Manufacturing, and Materials Engineering* Davim, J. Paulo,2012-07-31 Engineering and design are often a necessary steps for an industry to become effective Industry modeling can help to bridge the communication gap among engineers and system designers *Dynamic Methods and Process Advancements in Mechanical Manufacturing and Materials Engineering* examines the principles of physics and materials science for analysis design manufacturing and maintenance of mechanical equipments and systems Targeting researchers practitioners and academicians this volume promotes innovative findings in mechanical manufacturing and materials engineering **Light Metals—Advances in Research and Application: 2012 Edition** ,2012-12-26 *Light Metals Advances in Research and Application 2012 Edition* is a ScholarlyEditions eBook that delivers timely authoritative and comprehensive information about Light Metals The editors have built *Light Metals Advances in Research and Application 2012 Edition* on the vast information databases of ScholarlyNews You can expect the information about Light Metals in this eBook to be deeper than what you can access anywhere else as well as consistently reliable authoritative informed and relevant The content of *Light Metals Advances in Research and Application 2012 Edition* has been produced by the world s leading scientists engineers analysts research institutions and companies All of the content is from peer reviewed sources and all of it is written assembled and edited by the editors at ScholarlyEditions and available exclusively from us You now have a source you can cite with authority confidence and credibility More information is available at <http://www.ScholarlyEditions.com> Applied Mechanics Reviews ,1974 **Manufacturing Engineering and Process** Xiaoxiao Zhou,2012-04-25 Selected peer reviewed papers from the 2012 International Conference on Manufacturing Engineering and Process ICMEP 2012 April 21 22 2012 Kunming China **Manufacturing Automation Technology** Guang Lin Wang,Huifeng Wang,Jun Liu,2008-10-21 Selected peer reviewed papers from the 13th Conference of China

University Society on Manufacturing Automation July 22 24 2008 Harbin China CIRP Annals International Institution for Production Engineering Research,1993 *Finite Element Method in Machining Processes* Angelos P. Markopoulos,2012-08-04 Finite Element Method in Machining Processes provides a concise study on the way the Finite Element Method FEM is used in the case of manufacturing processes primarily in machining The basics of this kind of modeling are detailed to create a reference that will provide guidelines for those who start to study this method now but also for scientists already involved in FEM and want to expand their research A discussion on FEM formulations and techniques currently in use is followed up by machining case studies Orthogonal cutting oblique cutting 3D simulations for turning and milling grinding and state of the art topics such as high speed machining and micromachining are explained with relevant examples This is all supported by a literature review and a reference list for further study As FEM is a key method for researchers in the manufacturing and especially in the machining sector Finite Element Method in Machining Processes is a key reference for students studying manufacturing processes but also for industry professionals **Computational Methods in Materials Processing** American Society of Mechanical Engineers. Winter Annual Meeting,1992 **Advanced Materials and Manufacturing Technology II** Hun Guo,Tai Yong Wang,Dun Wen Zuo,Zi Jing Wang,Jun Li,Ji Xu,2016-05-20 Special topic volume with invited peer reviewed papers only **Metals Abstracts Index** ,1996 Advances in Materials Manufacturing Science and Technology XIII: Advanced manufacturing technology and equipment, and manufacturing systems and automation ,2009 Fundamental Issues in Machining American Society of Mechanical Engineers. Winter Annual Meeting,1990 *Mechanical Engineering, Materials Science and Civil Engineering* Jun Peng Shao,Xian Li Liu,2013-01-11 Selected peer reviewed papers from the 2012 International Conference on Mechanical Engineering Materials Science and Civil Engineering ICMEMSCE 2012 August 18 20 2012 Harbin China **Journal of Engineering for Industry** ,1996 Finite Element Analysis of Two-dimensional Chip Formation Process for Machining with Grooved Tool Inserts Ramesh Ramalingam,1996 **Manufacturing Science and Engineering** ,1995 *Manufacturing Science and Engineering 1995* ,1995 **Current Advances in Mechanical Design and Production III** Salah E. A. Bayoumi, Maher Y. A. Younan,1986

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