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 (10^2s^{-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:

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

Where $\bar{\sigma}$ is the equivalent stress, $\bar{\varepsilon}$ is the equivalent plastic strain, $\dot{\bar{\varepsilon}}$ is the plastic strain rate, $\dot{\bar{\varepsilon}}_0$ 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.

DOI: 01.IJPIE.02.01.572

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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 **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 **CIRP Annals** International Institution for Production Engineering Research,1993 **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 **Fundamental Issues in Machining** American Society of Mechanical Engineers. Winter Annual Meeting,1990 **Advances in Materials Manufacturing Science and Technology XIII: Advanced manufacturing technology and equipment, and manufacturing systems and automation** ,2009 *Finite Element Analysis of Two-dimensional Chip Formation Process for Machining with Grooved Tool Inserts* Ramesh Ramalingam,1996 **Progress in Advanced Manufacturing Technologies** Guang Lin Wang,Hui Feng Wang,Xiang Zhang,Bin Li,Ding Fang Chen,Yue Feng Li,2012-08-24 Special topic volume on Advanced Manufacturing Technologies **Manufacturing Science and Engineering 1995** ,1995 **Manufacturing Science and Engineering** ,1995 **Metals Abstracts Index** ,1996

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