

# 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 ( $10^0\text{s}^{-1}$  to  $10^6\text{s}^{-1}$ ), 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 ( $1.0\text{s}^{-1}$ ),  $T_0$  is the room temperature,  $T_{\text{melt}}$  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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