Three-Dimensional Finite Element Modeling of Drilling Burr Formation
Part I: Modeling

Sangkee Min
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Abstract— A 3-dimensional finite element model of drilling burr formation was proposed. A conventional twist drill was used and assumed to be a rigid body. Stainless steel (AISI 304L) was modeled for the workpiece material. An incremental plasticity model with associated flow rule and isotropic hardening rule was used to describe a plastic behavior of the workpiece. Due to the rapid speed of process, strain rate dependency of the material was modeled and adiabatic thermal assumption was made.

Introduction

The essence of metal cutting in reality is removal of material from workpiece. How to model this concept is the biggest challenge in the finite element modeling of metal cutting. In the most cases, this concept is simulated either by separation of elements or by removal of elements in the finite element model.

The chip separation criteria are related to the separation of elements that are mostly adopted in two-dimensional orthogonal cutting. Even though they used different measures for the chip separation criteria [1], the way the criteria applied was the same. The parting line between the workpiece and chip was predefined and the chip was formed when the element near the parting line meets a separation criterion.

In 3-dimensional finite element modeling of drilling, it is very difficult to define a parting line and arrange elements along this parting line because material in front of drill deforms as the drill advances and at any instance, this causes the parting line to be redefined. Instead, elements close to the drill tip were removed when all the material points in an element meet a failure criterion [2]. In this research, this scheme was used to simulate material failure.

Finite element modeling

1. Workpiece modeling:
    a. Quadrilateral brick elements for the workpiece because they give better convergence rate for equivalent accuracy. The semi-infinite elements for the outer perimeter of the workpiece were used, Figure 1.

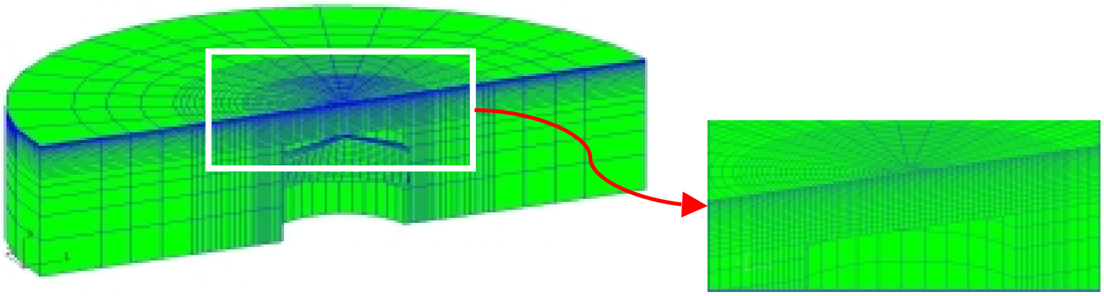

Figure 1. Finite element model of the workpiece

    b. Incremental plasticity using von Mises yield surface and associated flow rule were used to model the plastic behavior of the material. All the material properties were assumed to be isotropic.

$$d\underline{\varepsilon}^{pl} = d\lambda \frac{\partial F}{\partial \underline{\sigma}} \qquad F(\underline{\sigma},\bar{\sigma}) = 3J_2 - \bar{\sigma}$$

where F is the von Mises yield surface, $d\lambda$ is an arbitrary proportional constant, $\bar{\sigma}$ is the yield stress and J_2 is the second deviatoric stress invariant.

    c. The strain rate dependency of material properties was modeled using the overstress power law because material properties, especially yield stress, vary at high strain rate (strain rate in drilling ranges from 10^3 to 10^5).

$$\dot{e}^{pl} = D\left(\frac{\bar{\sigma}}{\sigma^0} - 1\right)^p$$

where D, p are material parameters and σ^{o} is the static yield stress.

2. Drill modeling: A conventional twist drill was used, Figure 2 and Table 1. The drill was assumed to be a rigid body and have a sharp edge. Tool wear was not considered.

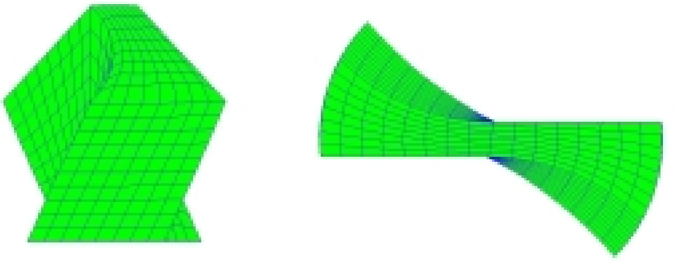

Figure 2. Finite element model of the conventional twist drill

Point angle	Helix angle	Diameter	Number of flutes
135^{o}	25^{o}	4 mm	2

Table 1. Drill geometry

3. Process modeling:
   a. Heat is mostly generated by inelastic strain. Since a drilling process is an enclosed process which involves high strain rate, heat cannot be dissipated through the workpiece. Hence, an adiabatic thermal assumption was made.

$$r^{pl} = \eta\,\underline{\sigma}\,\underline{\dot{\varepsilon}}^{pl}$$

$$\rho c(\theta)\dot{\theta} = r^{pl}$$

   where r^{pl} is the heat flux that is added into the thermal energy balance, η is the factor that defines the amounts of inelastic strain turning into heat, ρ is the material density, c is the specific heat.

   b. Material failure was assumed to occur when the damage parameter, ω, the ratio of the incremental equivalent plastic strain to the equivalent plastic strain at failure exceeds 1. Once an element satisfied the failure criterion, and then it becomes inactive in the remaining calculations [3].

$$\omega = \sum\left(\frac{\Delta\bar{\varepsilon}^{pl}}{\bar{\varepsilon}_{f}^{pl}}\right) \geq 1$$

   c. Built-up-edge and chip formation were not considered due to the complexity of the problem.

Process parameters from experiments that generate a uniform burr and a crown burr were chosen.

References

[1] Guo, Y., “Finite Element Modeling of Drilling Burr Formation”, M.E. Dissertation, University of California, Berkeley, Department of Mechanical Engineering, 1997

[2] Min, S., Dornfeld, D.A., Shyu, B., Kim, J., “Finite Element Modeling of Burr Formation in Metal Cutting”, Submitted to Fourth CIRP International Workshop, Modeling of Machining Operations, TU Delft, Netherlands, 2001

[3] Hibbit, Karlsson, and Sorenson, Inc., *ABAQUS/Explicit User’s Manual*, ver 5.8, Providence, RI, 1998