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The use of volume of solid (VOS) approach in simulating metal cutting with chamfered and blunt tools

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ABSTRACT

A new volume of solid (VOS) method is proposed for simulating metal cutting applications. The method utilizes the Eulerian finite element formulation along with a numerical scheme to calculate volume of solid fractions in empty elements or cells. The method is shown to overcome problems with existing finite element formulations and may easily track and model the unconstrained flow of the material at free boundaries. As a sample application, the method is used to study the effect of introducing a chamfer angle to the tool or using a blunt (worn) tool on some of the process variable and on the cutting forces both in the cutting and thrust directions. The results of the VOS method are compared to similar results obtained using the arbitrary Lagrangian–Eulerian approach and to experimental results that were performed for one sharp and two chamfered tools.

1. Introduction

Metal cutting is considered to be one of the most complicated manufacturing processes. Even though the basic mechanics are almost the same for all metal cutting operations, each case is considered different due to the complexity that comes from the dependency of the process on many geometrical factors and material properties. Most of the research done in metal cutting used to be based on experimental work but since the advancements of the finite element method (FEM) and numerical simulations in the last few decades there has been more work on studying the machining process by means of numerical analysis. Compared to experiments, presenting accurate results from numerical simulations is still considered a challenging task due to the coupling of high temperatures and high strain rates, and the difficulty in modeling the friction and the contact between the chip and the tool. Due to the large plastic work and high friction, massive amounts of thermal energy are generated causing the temperature to rise in the metal and the tool. This means that an accurate numerical simulation must consider appropriate heat transfer analysis along with the deformation and stress analyses [1–3].

The main finite element approaches used in solid mechanics are the Lagrangian and the Eulerian formulations. The natural choice in metal forming applications, including machining, is the Lagrangian approach because the mesh is attached to the material points and undergoes the same deformation. In metal cutting this takes care of an important issue which is the unconstrained material flow on the free boundaries during the formation of the chip throughout the machining process. This eliminates the need for a priori assumption for the shape of the chip at steady state stages. This is important since the shape of the chip is highly dependent on the friction coefficient between the chip and the tool, the cutting speed and the shape of the tool (rake angle, chamfered, blunt,…etc.) [1,4–6]. The most common way to simulate metal cutting with Lagrangian formulation is to use a nodal separation method in conjugation with a failure criterion [7–11]. In this approach, the line of separation at the cut depth is defined prior to the analysis and the failure criterion is applied to the nodes/elements along that line. As the tool advances through the metal, the nodes starts to detach in front of the tip of the tool based on the failure criterion. Usually the separation aspect of the analysis is modeled in a similar fashion to an elastic–plastic crack propagation problem. One of the drawbacks of this approach is that the material separation happens at a small distance in front of the tool tip rather than at the tip itself [8–10]. This is actually an unrealistic approach since such cracks are not observed in actual cutting of ductile materials. Additionally, the process will be modeled with discrete jumps of the crack tip from one node to the next one which requires a very fine mesh in order to minimize the error of the material deformation history results at the vicinity of the tool tip. Although this might be reasonable in some cases where the distance between the tool tip and crack tip is too small, it can only perform well for tools with finite nose radius and fails in applications with chamfered or blunt tools [1,4]. With chamfered and blunt tools, there exists a dead metal zone under the chamfered length or the curved radius that cannot be modeled properly with nodal separation methods. In addition to that, one must pay attention to the unzipped nodes along the parting line since the line might be pushed out of its

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