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Numerical and analytical modeling of orthogonal cutting: The link between local variables and global contact characteristics

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ABSTRACT

The response of the tool–chip interface is characterized in the orthogonal cutting process by numerical and analytical means and compared to experimental results. We study the link between local parameters (chip temperature, sliding friction coefficient, tool geometry) and overall friction characteristics depicting the global response of the tool–chip interface. Sticking and sliding contact regimes are described.

The overall friction characteristics of the tool are represented by two quantities: (i) the mean friction coefficient qualifies the global response of the tool rake face (tool edge excluded) and (ii) the apparent friction coefficient reflects the overall response of the entire tool face, the effect of the edge radius being included. When sticking contact is dominant the mean friction coefficient is shown to be essentially the ratio of the average shear flow stress along the sticking zone by the average normal stress along the contact zone. The dependence of overall friction characteristics is analyzed with respect to tool geometry and cutting conditions. The differences between mean friction and apparent friction are quantified. It is demonstrated that the evolutions of the apparent and of the mean friction coefficients are essentially controlled by thermal effects. Constitutive relationships are proposed which depict the overall friction characteristics as functions of the maximum chip temperature along the rake face. This approach offers a simple way for describing the effect of cutting conditions on the tool–chip interface response. Finally, the contact length and contact forces are analyzed. Throughout the paper, the consistency between numerical, analytical and experimental results is systematically checked.

1. Introduction

A salient issue in the modeling of machining is to reach a better perception of the relationship between local parameters (stress, strains, temperature, velocity fields, local friction characteristics) and global variables (overall friction characteristics, shear angle, chip morphology, forces, and contact length). Clarifying this connection is especially important for the validation of the physical concepts introduced into the modeling and for improving analytical models of machining.

The aim of this work is to investigate the relationship between local and global cutting parameters by developing a fruitful interplay between theoretical tools offered by numerical methods on the one hand and analytical formulations on the other hand. The relationship between local variables and global friction characteristics is analyzed in a first step. Then, the tool–chip contact length and the contact forces exerted on the tool are characterized.

The use of Finite Element methods for the analysis of orthogonal cutting has been initiated three decades ago [1,2]. Presently, most of simulations are relying either on Lagrangian formulations with automatic remeshing to avoid using a separation criterion [3,4], or on the Arbitrary Lagrangian Eulerian (ALE) technique [5,6]. Conversely, since the pioneered work of Merchant [7] dealing with perfectly plastic materials, a thermo-mechanical framework has been developed for the analytical modeling of cutting [8–11]. A foremost aspect of the present work is to establish a dialog between numerical modeling of machining that provides an efficient tool for analyzing local and global variables and analytical formulation that offers a clear synthetic perception of the phenomena studied.

The work material is taken to be a medium carbon steel 42CrMo4. The thermo-viscoplastic response of the material is modeled with a Johnson–Cook law. Material parameters are fixed, but interface properties are varied since the analysis of frictional effects is of particular concern.

In machining, the contact problem is generally modeled with phenomenological laws that include sticking and sliding contact regimes [12–18]. Important features of dry contact can be captured by using the Coulomb friction law. Sometimes, a modified Coulomb friction law has been adopted, which accounts for the saturation at a given value of the shear stress on the tool face. In the present

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