Modelling of machining across length scales

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Keywords: Machining; Orthogonal turning; Conventional turning; Ultrasonically assisted turning

Abstract:

This study is a part of the on-going research at the Wolfson School of Mechanical and Manufacturing Engineering, Loughborough University, UK on multi-scale finite-element (FE) simulations of advanced machining processes. To date this has covered conventional machining operations over multiple length scales, as well as hybrid machining techniques, namely ultrasonically assisted machining (UAM).

Direct experimental studies of machining processes are expensive and time-consuming, especially when a wide range of machining parameters affects complex thermo-mechanical processes that govern a high-strain behaviour. Thus, the use of mathematical simulations and, in particular, FE techniques has gained prominence in the research community.

At the macroscale, efficient numerical models of three-dimensional oblique turning with and without vibration assistance reveal the underlying deformation mechanisms of intractable alloys (such as Ti-15-3-3-3 and Inconel 718) [1-3]. It is observed that UAM demonstrates noticeable advantages with reduced machining forces and damage in the machined alloy. Further numerical and physical experiments with thermal assistance show additional improvements in cutting metals [4].

With increased application of mechanical micromachining in manufacture of small-size components with complex geometries, the need for understanding mechanics of machining at the micro-scale is recognized. This has led to a demand for computationally accurate and efficient numerical models capable of predicting a small-scale material behaviour under conditions of high strains and high strain rates. Traditional FE analysis of machining problems is fraught with numerical stability problems, due to high distortion of finite elements in a primary deformation zone during the cutting process. Smoothed particle hydrodynamics (SPH) is a mesh-free computational method, which has been used to simulate multi-body problems. A hybrid modelling approach in micro-machinig of single-crystal metals with the use of SPH and continuum finite-element analysis is presented [5]. The model accounting for a transient deformation processes associated with dynamic impacts of the tool is implemented in commercial FE software. A recently proposed, enhanced model of a mechanism-based strain-gradient crystal plasticity theory, linking a microscale notion of dislocations to a mesoscale notion of plastic strain and strain gradient, is used to characterise the deformation behaviour of the single crystal. The model is used to gain insight into the effects of crystallographic anisotropy and cutting depth on the micro-machining response of single crystals.

Acknowledgements:

Funding from the Engineering and Physical Sciences Research Council (EPSRC) grant number: EP/K028316/1 is gratefully acknowledged.

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