Accepted Manuscript

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PII: S0890-6955(18)30217-7
DOI: 10.1016/j.ijmachtools.2018.06.004
Reference: MTM 3358

To appear in: *International Journal of Machine Tools and Manufacture*

Received Date: 21 February 2018
Revised Date: 18 June 2018
Accepted Date: 22 June 2018

A physics-based single crystal plasticity model for crystal orientation and length scale dependence of machining response

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Abstract

Crystal plasticity model with physics-based dislocation kinetics and hardening relations is presented in this work. The model is applied to simple shearing of machining to determine the shear angle by work minimization that is similar to the Merchant's principle. Model reveals crystal orientation dependence of cutting specific pressure during machining of single crystals in addition to the machining parameters such as friction coefficient, uncut chip thickness, rake angle, temperature, and cutting speed. The length scale dependence of machining forces is linked to the physical length of the shear plane which is treated as a limit for the mean-free-path. A unified approach is developed for the first time to account for a wide range of strain rates for machining process. Taylor-based rate insensitive model is also implemented and applied to the same problem. Taylor-based model captures the four-fold symmetry of the force patterns yet with incorrect prediction of force peak locations. The physics-based model predicts the values of cutting forces and its pattern more accurately than the Taylor-based rate-insensitive model. The significantly better results are obtained because of the treatment of stress on the shear plane in full tensor form, the strain hardening and its anisotropy, and the effect of temperature and strain-rate by the physics-based model.

Keywords: single crystal machining, crystal plasticity, physics-based modeling, micro machining, workpiece anisotropy, machining size dependence

Nomenclature

α rake angle of the cutting tool

β friction angle between cutting tool and chip

$\boldsymbol{\sigma}^c$, $\{\boldsymbol{\sigma}^c\}$ Bishop-Hill stress tensor and its vectorized form

$\boldsymbol{\sigma}$ Cauchy stress tensor on the shear plane

χ_z^a dislocation interaction matrix between slip systems z and a

ΔF thermal activation energy required for slip

ΔG activation energy required for slip

$\dot{\gamma}^a$ slip rate of slip system a

$\dot{\varrho}^a$ evolution rate of dislocation density on slip system a

$\dot{\varrho}^a$ evolution rate of total dislocation density on slip system a

$\dot{W}_c$ cutting power

$\dot{W}_f$ friction power

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