A dislocation density-based multiscale simulation model for ultra-precision cutting process

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Abstract

In ultra-precision cutting of polycrystalline metals, the influence of microstructural transformation on the cutting performance is prominent because of the trans-scale variation of the undeformed cutting thickness from macro-scale to micro-scale. This work presented a multiscale coupling framework for revealing surface deformation and microstructural evolution behaviours in ultra-precision machining steel and copper. The proposed framework is composed of a 3D dislocation dynamic (3D-DD) model with a finite element analysis (FEA) model through optimizing a dislocation density-based (DDB) constitutive equation. The statistical features of dislocation density captured by demonstrating the dislocations nucleation, interactions and annihilation processes in the 3D-DD model were applied to calibrate the critical coefficients of the DDB model. On that basis, an FEA multi-step ultra-precision machining model was developed to reveal the surface appearance and microstructure characteristics, including chip formation, grain size, and dislocation density distributions, etc., under the tested cutting conditions, which provided comparable workpiece dimension and cutting parameters in both model and time scales with experiments. The present framework has been validated by comparing with the classic Johnson-Cook (J-C) model simulation results (stress-strain distribution and cutting force) with good consistency. The machined surface grains size drastically refined into submicron during the ultra-precision cutting process. Results showed the grain refinement mechanism was dynamic recrystallization in severe plastic deformation. Meanwhile, significant grain refinement phenomena have been found in the primary shear zone, second shear zone, and machined surface zone, which were affected by the feedrate and cutting speed. Finally, the present studies were compared with experimental findings utilizing the single point diamond turning tests for validation purpose, and a good consistency was exhibited.

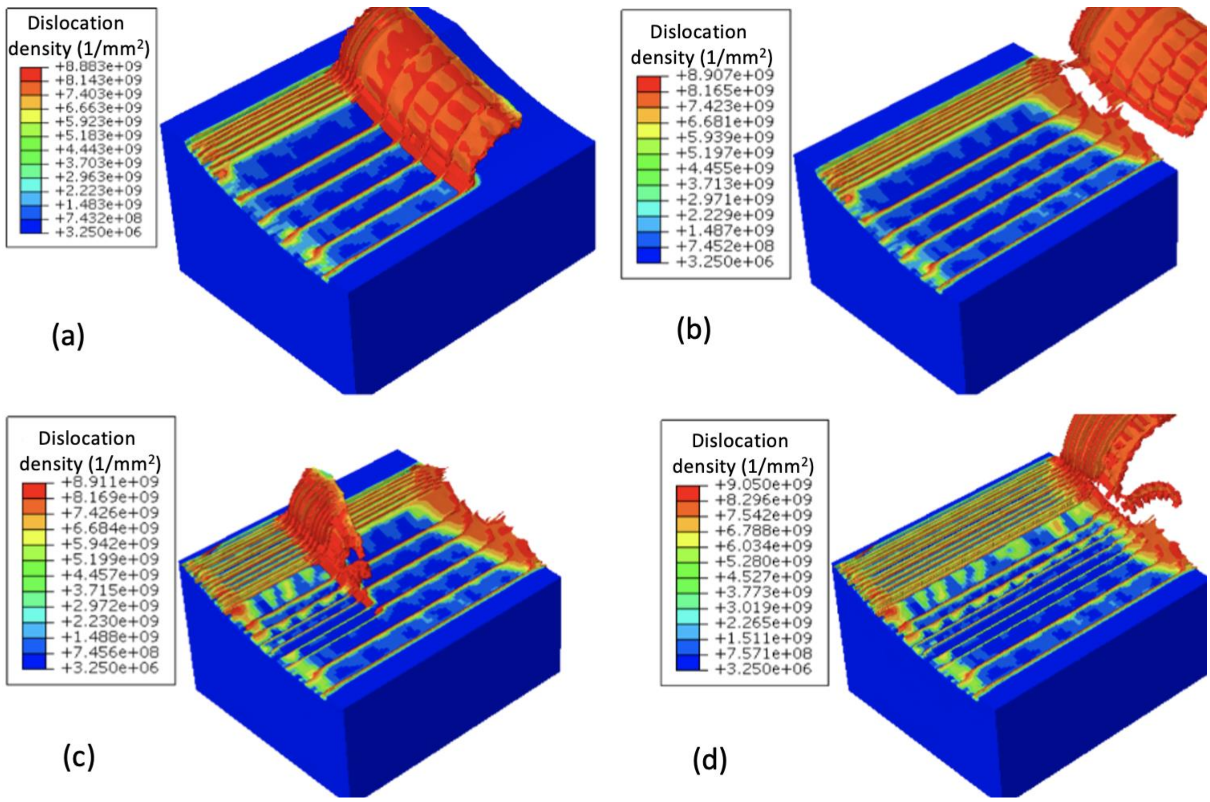

Figure 1: Dislocation densities distribution in two-step ultra-precision cutting steel.