A meshfree multiscale approach to modeling ECAE

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Macroscale mechanical properties (e.g., strength, ductility, fatigue resistance, etc.) of metals and alloys are closely linked to the grain sizes and orientations at the microscale. Equal channel angular extrusion (ECAE) and in general, severe plastic deformation (SPD) processes are metal forming techniques that significantly improve bulk properties of metal and alloys by inducing ultra-fine grain refinement via application of large plastic strains. In ECAE, this is achieved by extruding a specimen around a 90° corner which generates severe shear strains. Optimization of the processing parameters to achieve the desirable bulk properties motivates a high-fidelity simulation framework capable of capturing the physics at multiple scales. In this contribution, we introduce a multiscale framework for modeling ECAE of copper. At the *macroscale*, an enhanced maximum-entropy (max-ent) based meshfree method is used for simulation of severe plastic deformations. Compared to finite elements and other meshfree methods, this method offers better robustness with respect to mesh-distortion related issues, as well as an updated-Lagrangian setting with significantly improved stability. The latter is particularly important due to the large plastic strains involved in ECAE. At each macroscale material point, we introduce the notion of grains via a Taylor model at the *mesoscale* that captures discontinuous dynamic recrystallization – in particular, nucleation and migration – at the polycrystal level. Further, each grain in the Taylor model is modeled with finite-strain crystal plasticity at the *microscale*. The Taylor model is fitted to a fully-resolved Monte-Carlo Potts based recrystallization model and offers comparable accuracy despite significantly reduced computational costs. To our best knowledge, this setup is the first truly multiscale framework for simulation of ECAE. The novelty of the proposed framework lies in: *(i)* the computationally feasible integration of a macroscale meshfree method with high-fidelity recrystallization and plasticity models at the sub-macroscales, and *(ii)* the ability to simultaneously predict the strain and stress distributions, grain refinement, and texture evolution during ECAE. The proposed framework is of a general construct and has a wide variety of applications including other SPD processes (e.g., rolling, high-pressure torsion, etc.) and metals/alloys (e.g., aluminum, magnesium, etc.)