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Modeling of Anisotropic Hardening Based on Crystal Plasticity Theory and Virtual Experiments

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Abstract : Advanced material models involving several sets of model parameters require a big experimental effort. As models are getting more and more complex like e.g. the so called “Homogeneous Anisotropic Hardening - HAH” model for description of the yielding behavior in the 2D/3D stress space, the number and complexity of the required experiments are also increasing continuously. In the context of sheet metal forming, these requirements are even more pronounced, because of the anisotropic behavior or sheet materials. In addition, some of the experiments are very difficult to perform e.g. the plane stress biaxial compression test. Accordingly, tensile tests in at least three directions, biaxial tests and tension-compression or shear-reverse shear experiments are performed to determine the parameters of the macroscopic models. Therefore, determination of the macroscopic model parameters based on virtual experiments is a very promising strategy to overcome these difficulties. For this purpose, in the framework of multiscale material modeling, a dislocation density based crystal plasticity model in combination with a FFT-based spectral solver is applied to perform virtual experiments. Modeling of the plastic behavior of metals based on crystal plasticity theory is a well-established methodology. However, in general, the computation time is very high and therefore, the computations are restricted to simplified microstructures as well as simple polycrystal models. In this study, a dislocation density based crystal plasticity model – including an implementation of the backstress – is used in a spectral solver framework to generate virtual experiments for three deep drawing materials, DC05-steel, AA6111-T4 and AA4045 aluminum alloys. For this purpose, uniaxial as well as multiaxial loading cases, including various pre-strain histories, has been computed and validated with real experiments. These investigations showed that crystal plasticity modeling in the framework of Representative Volume Elements (RVEs) can be used to replace most of the expensive real experiments. Further, model parameters of advanced macroscopic models like the HAH model can be determined from virtual experiments, even for multiaxial deformation histories. It was also found that crystal plasticity modeling can be used to model anisotropic hardening more accurately by considering the backstress, similar to well-established macroscopic kinematic hardening models. It can be concluded that an efficient coupling of crystal plasticity models and the spectral solver leads to a significant reduction of the amount of real experiments needed to calibrate macroscopic models. This advantage leads also to a significant reduction of computational effort needed for the optimization of metal forming process. Further, due to the time efficient spectral solver used in the computation of the RVE models, detailed modeling of the microstructure are possible.

Keywords : anisotropic hardening, crystal plasticity, micro structure, spectral solver
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