MODELING OF ANISOTROPIC HARDENING AND GRAIN SIZE EFFECTS BASED ON ADVANCED CRYSTAL PLASTICTIY MODELS

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1. Introduction

The quality of the optimization of metal forming processes strongly depends on material models used. In addition, determination of the model parameters is commonly the most time consuming part and can be very expensive, due to the needed experimental data. As the models are getting more and more complex, the number and complexity of the required experiments is increasing continuously as well. In the sheet metal forming context, these requirements are even more pronounced, because of the anisotropic behavior of the sheet materials. In general, 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, e.g. the HAH model [1]. Hence, determination of the macroscopic model parameters based on virtual experiments is a very promising strategy to overcome these difficulties and to reduce the number of real experiments to a minium. For this purpose, in the framework of this study, following topics are covered:

- Investigation of the influence of the grain size on the hardening behavior
- Modeling of the Bauschinger effect at the grain level
- Prediction of the anisotropic behavior (yield locus) based on crystal plasticity simulations

2. Material models and numerical modeling techniques

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 the presented work, an efficient coupling of a physically based phenomenological crystal plasticity model - including an implementation of the backstress and grain size effects - and the FFT-spectral solver of the code DAMASK [2] is proposed. For the aluminum alloy AA5356 the influence of the grain size on the yield stress is shown in Figure 1 (left).

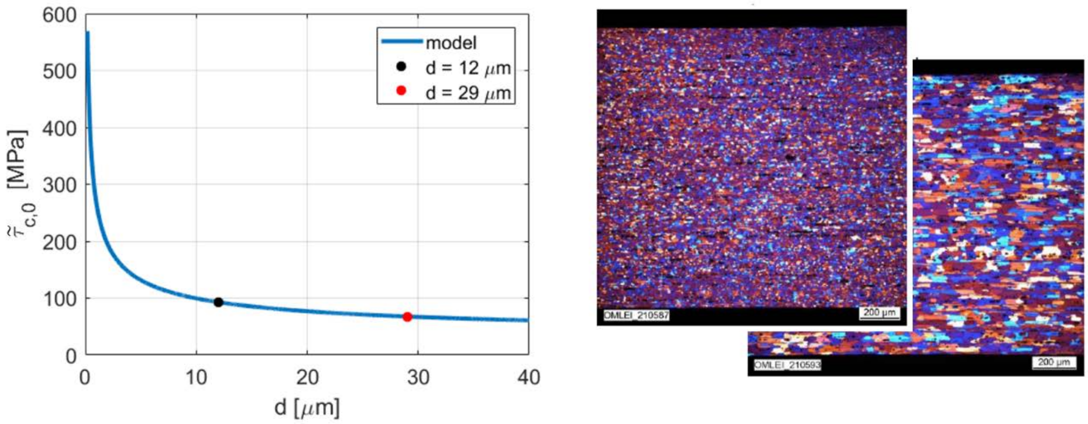

Figure 1: Yield stress as a function of the grain size (left); Micrographs for two different grain sizes: $12\mu m$ and $29\mu m$ (right).

The grain size effect is based on a Hall-Petch relationship. The initial critical resolved shear stress as well as the saturation stress are modified as follows:

$$\tilde{\tau}_{c,0}^{\alpha} = \tau_{c,0}^{\alpha} + k_1 \frac{1}{\sqrt{d}} \tag{1}$$

$$\tilde{\tau}_{sat}^{\alpha} = \tau_{sat}^{\alpha} + k_2 \frac{1}{\sqrt{d}} \tag{2}$$

where d is the grain size and k_1 and k_2 parameters fitted on tensile tests with grain sizes shown in Figure 1. A further aspect considered in this study is the Bauschinger effect. Similar to the macroscopic nonlinear Armstrong-Frederick type, a backstress model (see eq. 3 and 4) at the slip system level is implemented [4] in DAMASK. Predictive capabilities of the model for a tension-compression load case are shown in Figure 2.

$$\dot{\tau}_b^{\alpha} = c\dot{\gamma}^{\alpha} - \eta\left|\dot{\gamma}^{\alpha}\right|\tau_b^{\alpha} \tag{3}$$

$$\dot{\gamma}^{\alpha} = \dot{\gamma}_0^{\alpha}\left|\frac{\tau^{\alpha}-\tau_b^{\alpha}}{\tau_c^{\alpha}}\right|^{\frac{1}{n}} sgn(\tau^{\alpha} - \tau_b^{\alpha}) \tag{4}$$

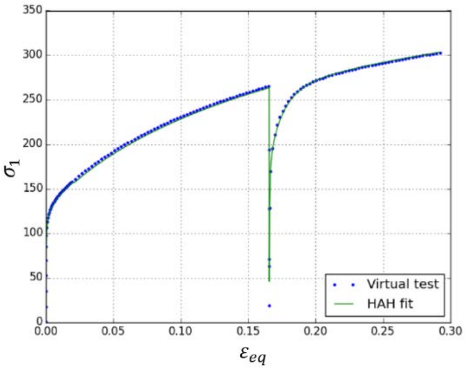

Figure 2: Modeling of the Bauschinger effect for the aluminium alloy AA5182.

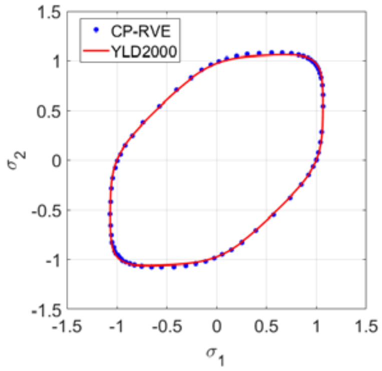

Figure 3: Comparison of the fitted YLD2000-2d model and CP-model prediction for AA6016-T4.

Modeling of the anisotropic behavior based on CP-simulations and the macroscopic model is shown in Figure 3 [4]. In this context it is worthwhile to mention that for the CP-simulations only the yield curve and the ODF has been used to predict the anisotropic behavior, whereas fitting of the YLD2000-2d model on experimental data requires three tensile tests at different directions as well as the equi-biaxial tension test.

3. Conclusions and Outlook

It can be concluded that an efficient coupling of crystal plasticity models and the FFT-spectral solver leads to a significant reduction of the amount of real experiments needed to calibrate macroscopic models. CP-modeling can be used to model anisotropic hardening more accurately by considering the backstress, similar to well-established macroscopic kinematic hardening models. Further, due to the time efficient spectral solver used in the computation of the RVE models, detailed modeling of the microstructure is possible. Performing of experiments with pre-strained material in tension and equi-biaxial stretching are subject of the ongoing work. These experiments will enable a validation of the CP-models for more general loading paths.

References

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