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Prediction of Anisotropy of Textured Sheets Based on a New Polycrystal Model

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Abstract

In this paper, the new single crystal yield criterion developed by Cazacu et al. [1] is used to study the effect of the initial texture on the anisotropy in plastic properties of metal sheets. The directional dependence of the yield stresses and Lankford coefficients in uniaxial tension is calculated for polycrystalline sheets with textures described in terms of a Gaussian distribution of misorientations with scatter width increasing from zero (single crystal) to 45º. It is shown that the same fidelity in predictions is obtained for an ideal texture and for textures with misorientation scatter width up to 25º. Furthermore, irrespective of the number of grains in the sample, Lankford coefficients have finite values for all loading orientations. Therefore, using this new single crystal yield criterion for the description of the plastic behavior of the constituent grains, the polycrystalline behavior can be predicted with accuracy, and at a very low computational cost. Most importantly, once the single crystal behavior is known, no additional calibration or macroscopic mechanical tests are needed in order to predict the effect of different texture components on the polycrystalline behavior.

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Keywords: New crystal plasticity model; Texture; Yield stress anisotropy; Lankford coefficients

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1. Introduction

Description of the plastic deformation of textured polycrystalline materials using advanced analytical orthotropic yield criteria that capture with accuracy the anisotropy in mechanical response of the metal in bulk have led to significant advances in metal technology. Examples of yield criteria for textured polycrystalline materials that are defined for three-dimensional loadings include Hill [2], Barlat et al. [3], Cazacu and Barlat [4-6], Barlat et al.[7]. At present, in crystal plasticity calculations of polycrystalline behavior it is assumed that plastic deformation of the single crystal is accommodated by slip parallel to preferred planes and directions. The criterion for activation of slip is Schmid law [8]. While increasingly complex homogenization schemes have been proposed (e.g. see review paper of Tome and Lebensohn [9]), use of such models for solving large-scale boundary value problems is still limited, mainly due to the prohibitive computational cost. Recently, Cazacu, Revil, and Chandola [1] developed an analytical yield criterion for cubic single-crystals. This yield function is C^2 differentiable for any three-dimensional stress states, and it accounts for the symmetries of the cubic crystal. In this paper, using this new yield criterion for describing the plastic behavior of the constituent crystals, we investigate the effect of texture on the plastic anisotropy of strongly textured polycrystalline metallic sheets. Specifically, we predict the anisotropy in uniaxial yield stresses and Lankford coefficients (r-values) in metallic sheets containing common texture components observed experimentally such as Goss, Cube, and Copper.

It is to be noted that estimates of Lankford coefficients (r-values) are of interest to metallurgists and designers. This is motivated by the fact that the mechanical anisotropy of polycrystalline sheets, as manifested in the variation of the Lankford coefficients with the uniaxial tension direction, is a first-order parameter in applications such as deep-drawing. Calculations are presented for sheets with ideal textures as well also for textures described in terms of a Gaussian distribution of misorientations with scatter width up to 45º. The predicted results for a cube-textured sheet are also compared to the estimates of yield stress and strain-rate ratios obtained using the Taylor-Bishop-Hill (TBH) approach and reported in Leqeu et al [10]. While both approaches predict the same trends, only the proposed model predicts finite values for the Lankford coefficients for the rolling and transverse direction. Moreover, the accuracy of the prediction is the same irrespective of the number of grains considered in the sample. The low computational cost involved in obtaining the polycrsytal behavior makes the proposed approach based on the single-crystal model [1] more readily applicable to large-scale metal forming operations.

2. Constitutive Model

2.1. Single-crystal constitutive description

Using rigorous theorems of representation for tensor functions, Cazacu, et al. [1] developed a three-dimensional yield criterion for each class of the cubic system (see [1]). Here, we present the criterion developed for the hextetrahedral, gyroidal, and hexoctahedral cubic classes. It is worth noting that most of the face centered cubic metals (e.g. copper; aluminum) belong to these crystal classes.

In the coordinate system, Oxyz associated with the <100> crystal axes, the single-crystal yield criterion of Cazacu et al. [1] is expressed as:

$$\frac{729}{27-4cn_1^2}\left\{\begin{array}{l}\left[\frac{1}{2}\left(\sigma_x'^2+\sigma_y'^2+\sigma_z'^2\right)+m_2\left(\sigma_{xy}'^2+\sigma_{xz}'^2+\sigma_{yz}'^2\right)\right]^3\\ -c\left[n_1\sigma_x'\sigma_y'\sigma_z'-n_3\left(\sigma_z'\sigma_{xy}'^2+\sigma_x'\sigma_{yz}'^2+\sigma_y'\sigma_{xz}'^2\right)+2n_4\sigma_{xy}'\sigma_{xz}'\sigma_{yz}'\right]^2\end{array}\right\}=Y_{100}^6, \tag{1}$$

In Eq. (1) $\boldsymbol{\sigma}'$ is the Cauchy stress deviator, Y_{100} is the yield limit in uniaxial tension along any of the <100> crystal directions, m_2, n_1, n_3, n_4 are anisotropy coefficients, and c is a material parameter that describes the relative importance of the cubic invariants of the stress deviator on yielding (for more details concerning the methodology used to develop the mathematical expression for the cubic invariants of the stress deviator, the reader is referred to