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New polycrystalline modeling as applied to textured steel sheets

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Highlights

- New approach for modeling polycrystalline behavior
- Constituent grains modeled with recent single-crystal criterion
- Accurate prediction of r-values and yield stress anisotropy of textured steel sheets

Abstract

It has been long recognized that the preferred orientation of the grains, arising from processing of metallic materials, result in anisotropic plastic behavior. An accurate assessment of the resulting macroscopic plastic anisotropy is thus essential in predicting the mechanical performance of alloys. This paper presents a new approach for modeling polycrystalline behavior. A key aspect in the formulation is the use of the single-crystal yield criterion recently developed by Cazacu, Revil, and Chandola [1] for the description of the plastic properties of the constituent grains. The capabilities of the polycrystalline model in predicting the directionality of macroscopic tensile properties are illustrated by comparing the theoretical predictions with mechanical data on steel sheets of various textures. There is a good agreement between experimental and theoretical predictions.

Keywords: single-crystal yield criterion; polycrystal model; Lankford coefficients; textured steel sheets; metal forming.

1. Introduction

Controlling the mechanical behavior is essential when developing new materials. Substituting mechanical tests by simulation studies to evaluate the mechanical performance of alloys is highly desirable as it enables a significant reduction of resource allocation in the alloy design process. However, in order to get reliable results, the models need to accurately predict the mechanical behavior.

Description of the plastic deformation of materials which display strong texture components is particularly challenging. Generally, in industrial applications macroscopic analytic yield criteria are used (e.g. Banabic et al. [2]). Full three-dimensional macroscopic scale analytical yield criteria that are flexible enough to describe the effects of anisotropy on the forming behavior have been developed by Hill [3], Barlat et al. [4-5], Cazacu and Barlat [6-9] and Nixon et al. ([10]), etc. Crystal plasticity models build upon the knowledge of the statistical distribution of crystallographic orientations of the material considered (see also [11]-13]). The plastic deformation of the constituent grains is described by Schmid law, the regularized Schmid law [14], or the power-law viscoplastic regularization of the Schmid law [15]. Either Taylor's assumption of homogeneous deformation of all crystals (see [16]) or Sachs hypothesis of homogeneous stress (see also [17]), or more sophisticated grain-interaction models such as the self-consistent approach (see [18]); or Alamel model (e.g. see [19]) are used to obtain the overall plastic response of the polycrystalline material.

Very recently, Cazacu et al. [1] developed an analytical yield criterion for the description of the plastic behavior of cubic single-crystals. This yield function is C^2 differentiable for any three-dimensional stress states, and it is invariant with respect to any symmetry transformation belonging to the appropriate crystal class of the cubic system. It involves four anisotropy coefficients, and as such has flexibility in describing the directionality of the plastic properties of the single crystal. For example, it captures the different relative ordering of the yield stresses as a function of the crystallographic direction of loading in single crystal copper as compared to an aluminum single crystal (see [1]).

In this paper, a polycrystalline approach employing this new single-crystal criterion for the description of the plastic behavior of the constituent grains is presented (Section 2). The model predictions are compared to experimental data on textured steel sheets reported in the literature (Section 3). It is shown that using the approach presented both the plastic anisotropy in yield stresses and strain-rate ratios of textured engineering materials can be predicted with accuracy.