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Evaluation of advanced anisotropic models with mixed hardening for general associated and non-associated flow metal plasticity

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ABSTRACT

The main objective of this paper is to develop a generalized finite element formulation of stress integration method for non-quadratic yield functions and potentials with mixed non-linear hardening under non-associated flow rule. Different approaches to analyze the anisotropic behavior of sheet materials were compared in this paper. The first model was based on a non-associated formulation with both quadratic yield and potential functions in the form of Hill's (1948). The anisotropy coefficients in the yield and potential functions were determined from the yield stresses and *r*-values in different orientations, respectively. The second model was an associated non-quadratic model (Yld2000-2d) proposed by Barlat et al. (2003). The anisotropy in this model was introduced by using two linear transformations on the stress tensor. The third model was a non-quadratic non-associated model in which the yield function was defined based on Yld91 proposed by Barlat et al. (1991) and the potential function was defined based on Yld89 proposed by Barlat and Lian (1989). Anisotropy coefficients of Yld91 and Yld89 functions were determined by yield stresses and *r*-values, respectively. The formulations for the three models were derived for the mixed isotropic-nonlinear kinematic hardening framework that is more suitable for cyclic loadings (though it can easily be derived for pure isotropic hardening). After developing a general non-associated mixed hardening numerical stress integration algorithm based on backward-Euler method, all models were implemented in the commercial finite element code ABAQUS as user-defined material subroutines. Different sheet metal forming simulations were performed with these anisotropic models: cup drawing processes and springback of channel draw processes with different drawbead penetrations. The earing profiles and the springback results obtained from simulations with the three different models were compared with experimental results, while the computational costs were compared. Also, in-plane cyclic tension–compression tests for the extraction of the mixed hardening parameters used in the springback simulations were performed for two sheet materials.

1. Introduction

One of the most important aspects of the constitutive laws dealing with finite element simulation of sheet metal forming is anisotropy. Anisotropy in sheet metals is mainly due to the noticeable alignment or preferred orientation of crystal-texture that is typically generated during the rolling process. Sheet metal anisotropy is commonly evident in both plastic yielding and flow, so that any material model should consider both aspects for a realistic simulation. Several micro- and macro-anisotropic models have been proposed for sheet metals in order to model the experimental behavior as accurately as possible. Hill's (1948) quadratic yield function may be noted as one of the most well-known yield criteria proposed as a generalization

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