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A practical two-surface plasticity model and its application to spring-back prediction

Myoung-Gyu Lee [a], Daeyong Kim [b], Chongmin Kim [c], M.L. Wenner [d], R.H. Wagoner [a], Kwansoo Chung [e,*]

[a] *Department of Materials Science and Engineering, 2041 College Road, Ohio State University, Columbus, OH 43210, USA*
[b] *Research and Development Division for Hyundai Motor Company and Kia Motors Corporation, 772-1, Jangduk-Dong, Whasung-Si, Gyunggi-Do 445-706, Republic of Korea*
[c] *Materials and Process Laboratory, R&D Center and NAO Planning General Motors, Warren, MI 48090-9055, USA*
[d] *Manufacturing Systems Research Laboratory, R&D Center and NAO Planning General Motors, Warren, MI 48090-9055, USA*
[e] *School of Materials Science and Engineering, Seoul National University, 56-1, Shinlim-Dong, Kwanak-Ku, Seoul 151-742, Republic of Korea*

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Abstract

A practical two-surface plasticity model based on classical Dafalias/Popov and Krieg concepts was derived and implemented to incorporate yield anisotropy and three hardening effects for non-monotonous deformation paths: the Bauschinger effect, transient hardening and permanent softening. A simple-but-effective stress-update scheme avoiding overshooting was proposed and implemented. Constitutive parameters were fit to 5754-O aluminum alloy using uniaxial tension/compression data. Spring-back predictions using the resulting material model were compared with experiments and with single-surface material models which do not account for permanent softening. The two-surface model improved such predictions significantly as compared with single-surface models, while the differences between two-surface simulations and experiments were insignificant.

Keywords: Two-surface model; Permanent softening; Bauschinger effect; Transient behavior; Overshooting; Sheet metal forming

* Corresponding author. Tel.: +82 2 880 8736; fax: +82 2 885 1748.
E-mail address: kchung@snu.ac.kr (K. Chung).

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1. Introduction

As a way to improve automotive fuel efficiency and environment impact, efforts are under way to replace conventional steels with aluminum, magnesium and high strength steel alloys. However, their often inferior formability and/or larger spring-back are technical obstacles to overcome. Spring-back is a critical factor in the quality of final products, making the designing of forming tools more difficult and expensive. One way to effectively overcome difficulties in proper tool design and process optimization for these advanced materials is to introduce accurate computational simulations, which require proper description of material deformation properties.

Since sheet spring-back is the elastic unloading response after complex, large-strain deformation paths such as those encountered in sheet metal forming operations (Wagoner et al., 2006), its accurate simulation requires a proper constitutive description incorporating complex behavior such as the (1) Bauschinger effect, (2) transient behavior (Laukonis and Wagoner, 1984; Chung and Wagoner, 1986; Doucet and Wagoner, 1987; Doucet and Wagoner, 1989; Kim et al., 2003) and (3) permanent softening (Geng and Wagoner, 2002; Geng et al., 2002; Chun et al., 2002a). As schematically illustrated in Fig. 1, the reverse loading curve following deformation shows a smaller magnitude of yield stress (Bauschinger effect). It then either rapidly converges to the original curve (transient behavior without permanent softening) or it eventually parallels the original curve (permanent softening).

Two main approaches have been used to describe the reverse loading behavior: one based on kinematic hardening (shifting of a single-yield surface) and the other involving multiple yield surfaces (Khan and Huang, 1995). The former model is based on linear kinematic hardening models proposed by Prager (1956) and Ziegler (1959) to describe the Bauschinger effect. To add the transient behavior, the linear model was modified to nonlinear models by Amstrong and Frederick (1966) and Chaboche (1986) by introducing

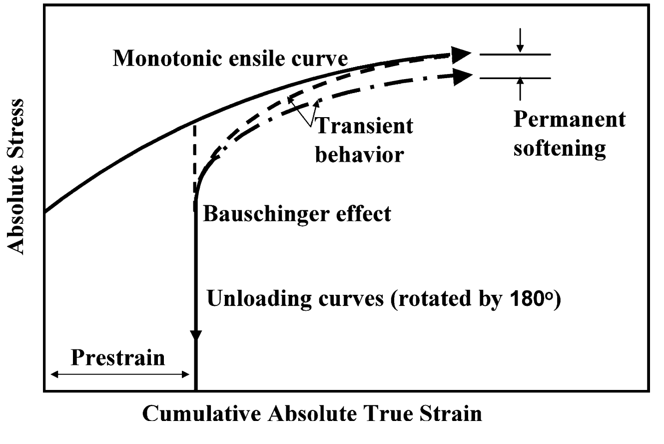

Fig. 1. A schematic unloading curve after pre-(tensile) strain to illustrate the Bauschinger, transient and permanent softening behavior (the bottom halves of unloading curves are plotted by rotating 180° so that they are moved up to the top).