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Spring-back evaluation of automotive sheets based on isotropic–kinematic hardening laws and non-quadratic anisotropic yield functions, part III: applications

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Abstract

In order to improve the prediction capability of spring-back in the computational analysis of automotive sheet forming processes, the modified Chaboche type combined isotropic–kinematic hardening law was formulated to account for the Bauschinger and transient behavior in Part I. As for the yield stress function, the non-quadratic anisotropic yield potential, Yld2000-2d, was utilized under the plane stress condition. Experimental procedures to obtain the material parameters of the combined hardening law and the yield potential were presented in Part II for three automotive sheets. For verification purposes, comparisons of simulations and experiments were performed here for the unconstrained cylindrical bending, the 2-D draw bending and the modified industrial part (the double-S rail). For all three applications, simulations showed good agreements with experiments. Simplified one-dimensional plane strain

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analytical and numerical methods were also developed here to better understand the spring-back in forming processes.

Keywords: Spring-back; Isotropic–kinematic hardening; Bauschinger effect; Transient behavior; Non-quadratic yield function; Unconstrained cylindrical bending; 2-D draw bending; Double-S rail

1. Introduction

Since aluminum sheets would improve the fuel efficiency with their lighter weight, significant efforts are being put forth to utilize aluminum alloy sheets for automotive applications. However, the inferior formability and large spring-back of aluminum sheets are major technical hurdles to overcome for their applications, besides high material costs. Introducing computational methods based on the finite element method (FEM) in the design stage to analyze the forming process of aluminum alloy sheets is one way to overcome those drawbacks, especially utilizing proper mechanical properties of aluminum alloy sheets.

In order to improve the prediction capability of spring-back in the finite element analysis, a combined isotropic–kinematic hardening rule based on the Chaboche model (Chaboche, 1986) as well as the non-quadratic anisotropic yield potential Yld2000-2d (Barlat et al., 2003) was developed in Part I (Chung et al., 2004). Experimental procedures to measure and parameterize the isotropic–kinematic hardening as well as the anisotropic yield stress potential were summarized in Part II (Lee et al., 2004) for three automotive sheets, AA5754-O, AA6111-T4 and DP-Steel. The combination type constitutive law was considered since it can account for the Bauschinger effect and the transient behavior during unloading. Ultimately, the better prediction capability in analysis would be useful in designing forming processes by properly compensating the spring-back.

In order to validate the prediction capability, especially for the spring-back, of the developed constitutive model, comparisons of simulations and experiments were performed here for the unconstrained cylindrical bending, the 2-D draw bending and the modified industrial part (the double-S rail). The unconstrained cylindrical bending test previously proposed as a benchmark problem at the NUMISHEET 2002 conference (2002) does not involve blank holders, therefore, it mainly shows the material difference effect with little process parameter effect. The 2-D draw-bending test proposed as a benchmark problem at NUMISHEET'93 (1993) involves two-dimensional blank holders so that it would show both effects of material difference as well as process parameters. The industrial panel shape idealized as a double-S rail has an extended S shape when viewed from the top as well as from the side and this would show the (local) spring-back at cross-sections as well as the (global) twisting.

Many researchers introduced FEM to predict the spring-back of 2-D formed parts. Kawaguchi et al. (1994) used FEM to analyze the spring-back of a cantilever beam. Mattiasson et al. (1995) and He and Wagoner (1996) investigated the spring-back of the 2-D draw bending benchmark problem. Duffett et al. (2002) and