# Advanced constitutive modeling of AHSS sheets for application to springback prediction after U-draw double stamping process

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**Abstract.** The reduction of springback for a U-shaped channel using a double drawing process was investigated. In this test, the punch strokes of the 1st and 2nd stamping steps were controlled and each followed by unloading. The simulations were conducted using kinematic and distortional hardening models, which were implemented into a finite element (FE) code to describe the Bauschinger effect and its associated anisotropic hardening effects during strain path change. In addition to the usual mechanical characterization tests, in-plane compression-tension experiments were conducted on DP980 and TWIP980 to determine the constitutive parameters pertaining to load reversal. Experimental and FE simulated results of the channel shape were compared for both materials in order to understand the effect of anisotropic hardening under non-proportional loading on springback.

## 1. Introduction

Advanced high strength steels (AHSS) have replaced conventional steels for automotive parts to reduce the body weight and improve the crash performance. However, the higher strength and thinner design of the parts manufactured with AHSS sheets result in significant springback increase. Thus, tool adjustments for a springback-free design should be optimized based on trial-and-error, which usually increases the process design time and cost.

In order to understand and predict the mechanics of springback for AHSS, finite element (FE) approaches have been frequently used. An accurate prediction of springback based on FE simulation can significantly facilitate a successful achievement of the optimum tool design. In order to increase the reliability of the springback estimation using FE simulations, an accurate elasto-plasticity constitutive model must be used. Specifically, the Yoshida-Uemori (YU) constitutive model has been extensively used for springback simulation. It is based on a two-surface kinematic hardening approach and can predict most of the complex hardening behaviors under load reversal [1]. Recently, a new approach was proposed as an alternative to kinematic hardening, known as a homogenous yield function based, anisotropic hardening (HAH) model [2].

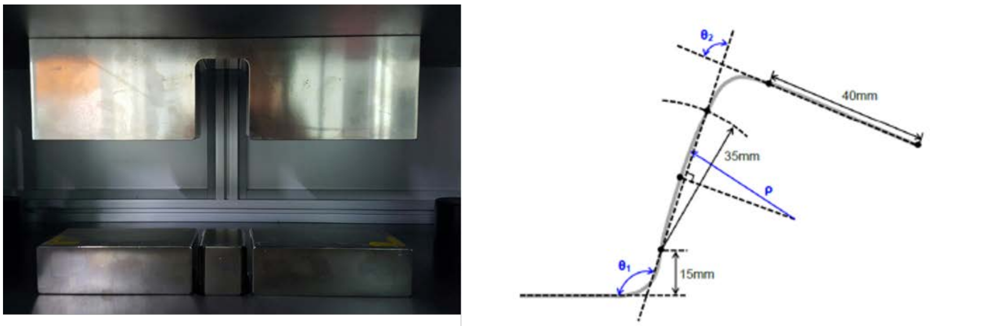
Automotive parts are generally produced using multi-stage forming processes in industry. In this case, since blanks undergo strain path change several times, it is difficult to simulate accurate predictions of springback with conventional constitutive descriptions. In this work, the U-draw double stamping process was investigated for two different AHSS sheets with various blank holding force (BHF) and strokes. Different types of hardening models were considered to predict springback in this work.

## 2. Experiment

To evaluate the performance of U-draw double stamping predictions, two AHSS sheet samples provided by POSCO were investigated; i.e., a dual-phase steel (DP 980) and a twinning-induced plasticity steel (TWIP 980), both of which with a nominal ultimate tensile strength of 980 MPa. The size of the sheet specimen was 350 (length), 45 (width) and 1.2 mm (thickness).

Continuous compression-tension (CT) tests were conducted to determine the hardening behavior during load reversal. The testing device was designed with an anti-buckling system where a constant normal force is applied to prevent sheet buckling during compression. The experimental data were calibrated by considering the effects of the clamping force and friction. All the tests were performed with a quasi-static, constant strain rate of $10^{-3}/s$.

For U-draw double stamping, an equipment recently modified, Fig. 1(a), was employed. The punch width was 50 mm and the clearance was 1.5 mm. The punch velocity and total stroke were set to 70 mm/min and 70 mm, respectively. For conventional (one stroke) U-draw bending, three different blank holder forces, BHF, (10, 25 and 50 kN) were selected but for double stamping, only the 1st stroke was varied (30, 50 and 70 mm). The BHF and 2nd stroke were fixed to 50 kN and 70 mm, respectively. An oil, BW-70PSB, was used for lubrication. The method of springback measurement is illustrated in Fig.1(b). There are three black dash lines, which are defined unambiguously: bottom line, middle line (sidewall region) and upper line (flange region). Based on these three lines, the springback indicators $\theta_1, \theta_2$ and $\rho$ were calculated using MATLAB.




(a) (b)

**Figure 1.** (a) U-draw stamping apparatus, (b) springback measurement

## 3. Constitutive model

The Swift hardening law was adopted for isotropic hardening. In addition, to consider the elastic modulus degradation when sheets are unloaded after prior deformation, the chord modulus concept [3] was considered. A non-quadratic yield function, Yld2000-2d [4], was employed to describe the plastic anisotropy of the sheet metals during forming.

### *3.1. Isotropic-kinematic hardening: Yoshida-Uemori model*

The Yoshida–Uemori (YU) model is based on a nonlinear, two-surface, kinematic hardening law. In this study, the YU model was combined with Yld2000-2d to investigate the effect of both the yield surface and hardening on the springback. In the following paragraph, a summary of the YU model is presented, but the details of the model can be found in [1]. The relative kinematic motion $(\boldsymbol{\alpha}_*)$ of the yield surface is

$$\boldsymbol{\alpha}_* = \boldsymbol{\alpha} - \boldsymbol{\beta} \quad (1)$$

$$\overset{\circ}{\boldsymbol{\alpha}}_* = \mathrm{C}\left[\left(\frac{\mathrm{a}}{\mathrm{Y}}\right)(\boldsymbol{\sigma} - \boldsymbol{\alpha}) - \sqrt{\frac{\mathrm{a}}{\bar{\alpha}_*}}\boldsymbol{\alpha}_*\right] \dot{\mathrm{p}} \quad (2)$$

where $\boldsymbol{\alpha}$ is the back stress tensor and $\boldsymbol{\beta}$ is the center of the bounding surface. From Eq. (1), the evolution of $\boldsymbol{\alpha}_*$ is assumed to be given by Eq. (2). $\dot{\mathbf{p}}$ is the effective strain rate and $\mathbf{C}$ a material constant controlling the kinematic hardening rate. ($\circ$ ) stands for time derivation with an objective rate. Y is the size of the yield surface.

*3.2. Distortional anisotropic hardening: HAH model*

In this work, the HAH model was also coupled with Yld2000-2d to represent the anisotropy under linear strain paths. The HAH yield condition can be expressed as

$$\bar{\sigma}(\mathbf{s}) = \left[\phi^q(\mathbf{s}) + f_1^q \left|\hat{\mathbf{h}} : \mathbf{s} - |\hat{\mathbf{h}} : \mathbf{s}|\right|^q + f_2^q \left|\hat{\mathbf{h}} : \mathbf{s} + |\hat{\mathbf{h}} : \mathbf{s}|\right|^q\right]^{\frac{1}{q}} = \sigma(\bar{\varepsilon}) \tag{3}$$

where $\phi(s)$ can be any homogeneous anisotropic yield function of first degree, and $\hat{\mathbf{h}}$ is the microstructure deviator, which is associated with the deformation history in a continuum sense. The superscript "^" implies a normalized value, ":" denotes the double dot product, $\mathbf{s}$ is the stress deviator and q is a constant exponent. The detailed HAH formulation was reported in [2].

## 4. FE simulation

For the YU model, the parameters were determined using a nonlinear least-square method in MATLAB to fit both the monotonic and reverse stress–strain curves obtained from the compression-tension test. In the HAH model, the Swift hardening coefficient were obtained by fitting the monotonic flow curve. In order to determine the anisotropic hardening parameters, a single element FE simulation was performed iteratively under compression-tension loading to determine the optimized hardening coefficients, $k_i$

For the FE simulations, the 2D draw-bending springback model proposed in the Numisheet'93 benchmark was considered. ABAQUS/explicit was employed for the forming process simulations and ABAQUS/implicit for springback analysis. The element type was a 4-node shell element with reduced integration (S4R). A half model of the specimen only was considered in the simulations. All the numerical conditions, such as type and number of elements, integration scheme, boundary conditions, etc., remained identical as in the benchmark problem. The FE simulations were conducted with four material descriptions for each case.

## 5. Results

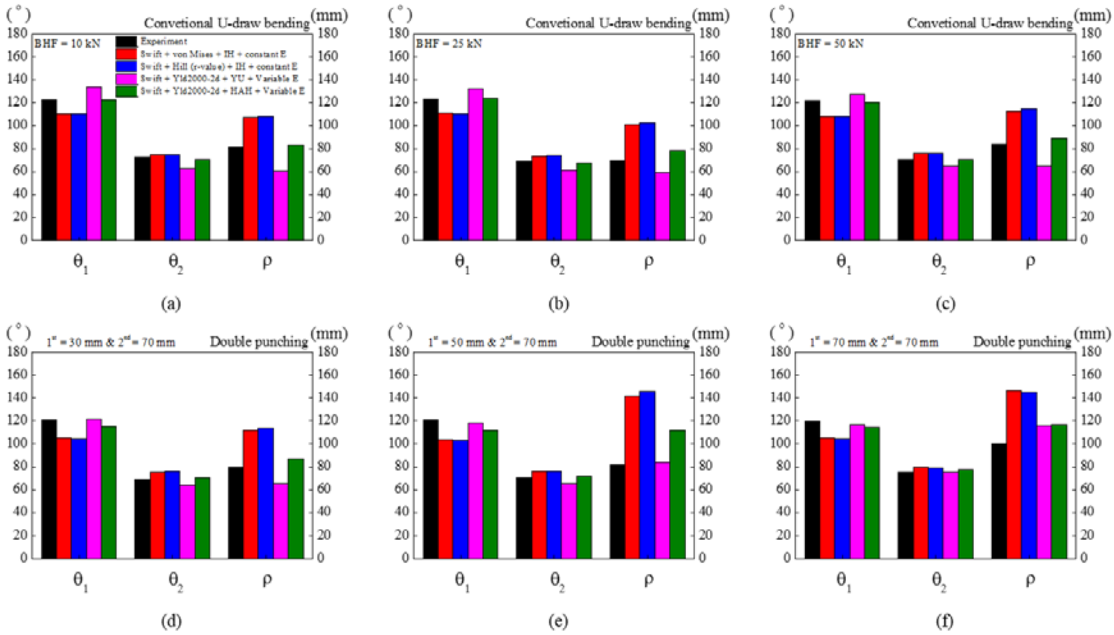



**Figure 2**. Springback results for $\theta_1, \theta_2$ and $\rho$ for DP980: (a) conventional U-draw when BHF = 10 kN, (b) conventional U-draw when BHF = 25, (c) conventional U-draw when BHF = 50 kN, (d) double stage 1st stroke 30 mm, (e) double stage 1st stroke 50 mm and (f) double stage 1st stroke 70 mm

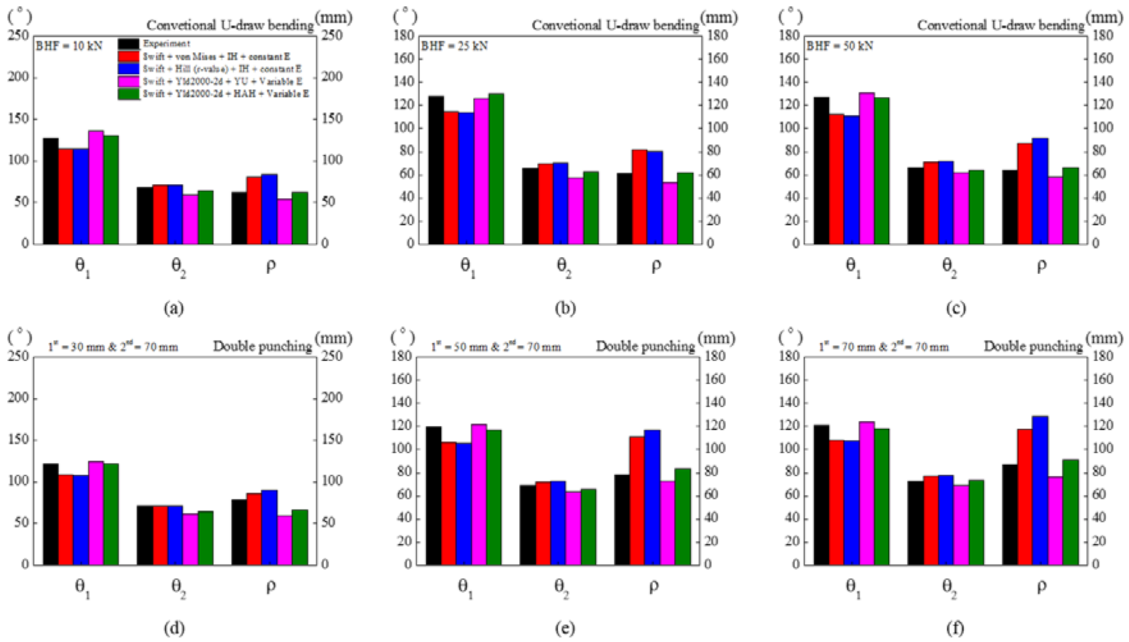



**Figure 3**. Springback results for $\theta_1, \theta_2$ and $\rho$ for TWIP980: (a) conventional U-draw when BHF = 10 kN, (b) conventional U-draw when BHF = 25, (c) conventional U-draw when BHF = 50 kN, (d) double stage 1st stroke 30 mm, (e) double stage 1st stroke 50 mm and (f) double stage 1st stroke 70 mm

Figs. 2-3 represent the springback predictions after conventional U-draw bending (a-c) and double stage stamping (e-f) for DP980 and TWIP980, respectively, as well as the experimental results. Two advanced hardening models lead to better predictions of the experiments compared to the results using isotropic hardening. After double stage stamping, the springback prediction accuracy deteriorates but the results obtained by the two advanced models are still in reasonable agreement with the experiments. It can be shown that this is because the two advanced models can describe complex hardening behaviors under strain path changes. Interestingly, the influence of the anisotropic yield function, using either Hill or von Mises, is very minor for springback.

## 6. Discussion

The internal stress predicted by the anisotropic hardening formulation (YU & HAH) is lower than that from isotropic hardening because the two advanced models can describe the complex flow behavior after load reversal. In turn, this results in a smaller amount of springback. On the other hand, the elastic modulus degradation contributes to larger amounts of springback. Eventually, these opposite elastic-plastic relations lead to an accurate prediction of springback. This work confirms that, in order to obtain accurate predictions, both elastic and plastic hardening descriptions must be considered simultaneously.

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