Investigating springback in bending of advanced high-strength steel, Part II

Springback prediction

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Editors Note: This article is Part II of a two-part series that discusses springback in bending of advanced high-strength steels (AHSS). Part I, which appeared in the November/December 2010 issue, discussed V-bending and finite element analysis.

Springback is one of the major challenges to consider when stamping AHSS. Springback can be predicted using finite element simulation, but that method requires a license for special software. If a computer code can be incorporated with a press brake controller to predict springback quickly and accurately, manufacturing costs and lead-times will be reduced significantly. Thus, the development of such a computer code for predicting and correcting the springback is quite valuable.

Computer Code for Springback Prediction

BEND 4.0 is the latest version of the computer code used at the Center for Precision Forming (CPF) to predict the springback in air bending. In this analytical model,[1] the bent sheet along the arc length is divided into four zones (see **Figure 1**), depending on the amount of strain: plastic zone, elastoplastic zone, elastic zone, and rigid zone. In the plastic zone and rigid zone, it is assumed that there is no elastic deformation; therefore, only the elastoplastic zone and elastic zone contribute to springback.

Springback is calculated using the moment/curvature relation, $\frac{1}{r} - \frac{1}{r'} = \frac{M}{E'I}$ where $\frac{1}{r}$ is the curvature before springback, $\frac{1}{r'}$ is the curvature after springback, M is the loading moment, E′ is the plane strain modulus (= $E/(1-v^2)$), and I is moment of inertia. The springback angle can be obtained by integrating the equation $\Delta\theta_S = \theta - \theta' = \frac{M}{E'I} dS$ over the total arc length in the elastoplastic zone and elastic zone, where dS is the length of a small element of sheet.[2] Springback predictions for Al 2024 from the BEND computer program are plotted in **Figure 2**.

The analytical model is based on two assumptions:

1. The unloading elastic modulus is constant.

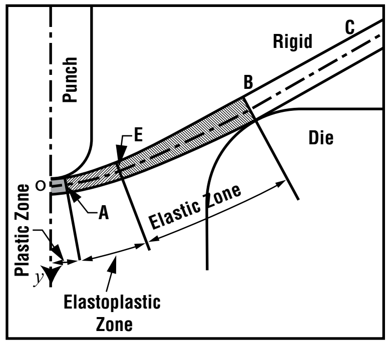

Figure 1

The bent sheet along the arc length is divided into four zones.

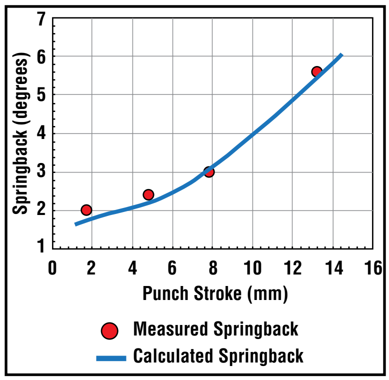

Figure 2

Springback predictions for Al 2024 were plotted against measured springback.

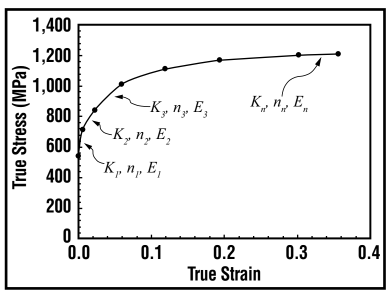

Figure 3

Strain is divided into small regions; E-modulus is interpolated; and different K and n values are estimated for each small region.

2. The material's properties can be described using Swift's model $[\bar{\sigma} = K(\epsilon_0 + \bar{\epsilon})^n]$.

However, as discussed in Part I, the material properties of AHSS do not satisfy either of these requirements. So an improved mathematical model was proposed by CPF.

Modification of the Analytical Model

One effective way to improve the methodology for predicting springback in bending of AHSS is to use E-modulus, K, and n values that vary with strain. Tabular data of E-modulus from tensile tests and flow stress from bulge tests is required as the input to the program to represent E-modulus, K, and n values.

The stress-strain curve is divided into many small regions according to the recorded strain data points. E-modulus is interpolated and assumed constant within each small region; different K and n values are estimated for each small region (see **Figure 3**).

When applying this model to actual bending analysis, the thickness of the sheet metal in the plastic region is divided into many small regions. In each region, the elastic modulus, K, and n can be assumed constant, and the values are estimated using the input tabular E-modulus and flow stress data, based on the strain value in that region (see **Figure 4**). Instead of integrating over the entire thickness using constant E-modulus, K, and n, the moment and stiffness are calculated by summing up the integrals over each small region with variable E-modulus, K, and n values.

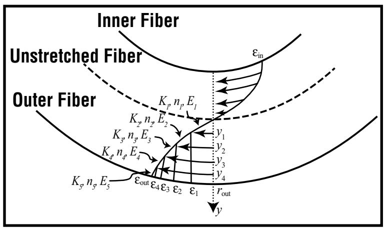

Figure 4

Thickness is divided into small regions with respect to tabular strain data; constant K, n, and E-modulus values correspond to strain values at different regions.

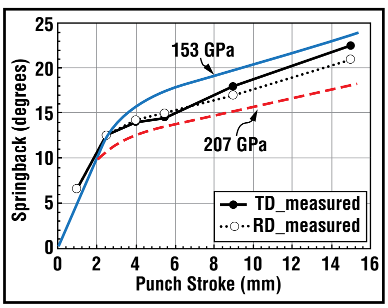

Figure 5

This springback prediction uses the highest and lowest E-modulus (TD = transverse direction, RD = rolling direction).

Springback Prediction From the Modified Computer Code

The computer code BEND was modified according to the improved mathematical model. To test the effectiveness of the new method, CPF compared experimental springback measurements of AHSS DP780 with the predictions from the program. The evaluation was conducted as follows:

1. Keep K and n constant; input highest (207 GPa) and lowest (153 GPa) values of E-modulus (see **Figure 5**).

2. Keep K and n constant; input variable E-modulus in function of largest strain. The largest strain value is calculated by taking the average of the strains at inner fiber and outer fiber in the plastic zone (see **Figure 6**).

3. Input variable K, n, and E-modulus values. Include all the effects of the nonconstant parameters.

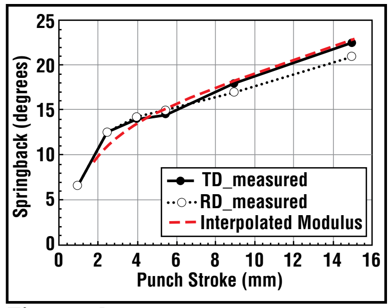

Figure 6

Predicted springback is shown using interpolated E-modulus for the largest average strain.

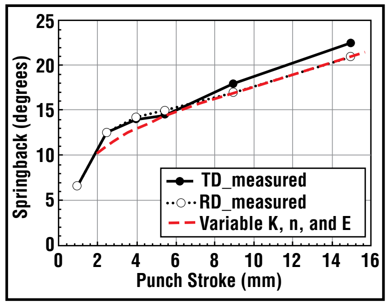

Figure 7

Springback is predicted using variable K, n, and E-modulus.

The good match between predictions and experiments indicated that the new analytical model can predict the springback in bending of AHSS accurately (see **Figure 7**).

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Notes

1. *H. Kim, N. Nargundkar, and T. Altan, "Prediction of Bend Allowance and Springback in Air Bending,"* Transactions of the ASME, *Vol. 129 (2007), pp. 342-351.*

2. *N. Nargundkar et al, "Prediction of Bend Allowance & Springback in Air-Bending,"* CPF Report No. ERC/NSM-04-R-45, *ERC/NSM, The Ohio State University, 2004.*