# Predicting springback when bending AHSS and aluminum alloys, Part II

## *Inverse analysis results and case studies*

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*Editor's Note: This article is Part II of a two-part series. Part I, which appeared in the November/December 2016 issue, discussed the challenges of determining Young's modulus, one of the most important parameters for springback prediction.*

### Nonlinear Unloading Behavior of Materials

When finite element (FE) simulation is used for predicting metal flow and springback, the material elasticity typically is defined by the handbook value of the Young's (E) modulus. The common way to determine the E-modulus is through a tensile test. However, the unloading behavior of the material usually is nonlinear because of unloading strains resulting from the repelling dislocations moving away from each other in addition to atomic bond relaxation when the applied stress is reduced.

Since the unloading behavior of metals following the plastic deformation is nonlinear, defining the material response using a constant E-modulus is not correct, and the resulting prediction of springback is inaccurate.

### Material Models for Accurate Springback Prediction

Several methods and constitutive models have been developed to improve springback prediction that consider the isotropic/anisotropic and kinematic hardening behavior of materials; the effect of friction; and the complex behavior of material, such as Bauschinger effect, transient hardening, and permanent softening.

Some of these models, such as the Yoshida-Uemori model, the quasi-plastic-elastic model, and the homogeneous anisotropic hardening model, have shown some improvement in springback prediction.

However, in most cases, several specific parameters have to be determined through different testing processes, such as the loading/unloading tensile test or the tension compression test, before the model can be used. The need for these extensive testing processes limits the industrial application of these models, especially considering batch-to-batch variations of material properties for the most currently available advanced high-strength steels (AHSS).

Furthermore, in most of these models, the required coefficients are developed using a uniaxial tension/compression test at relatively low strain. In actual stamping, however, the defor-

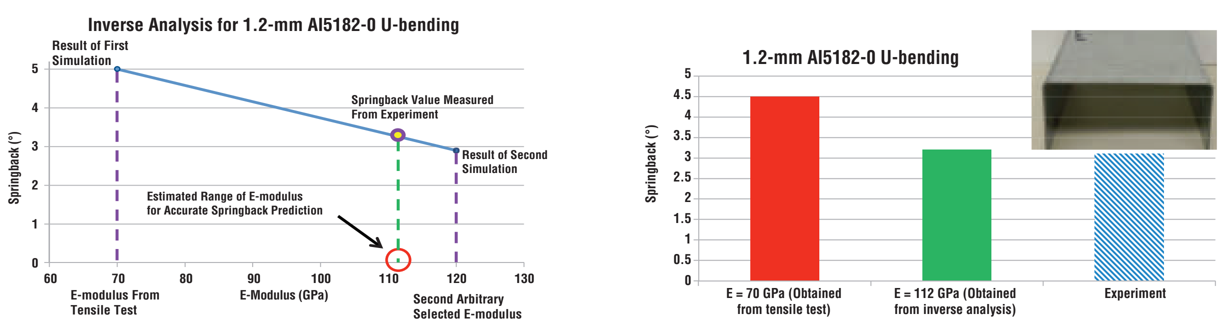


**Figure 1**

The appropriate average E-modulus for accurate springback prediction is determined by comparing the results of two simulations and experimental data.

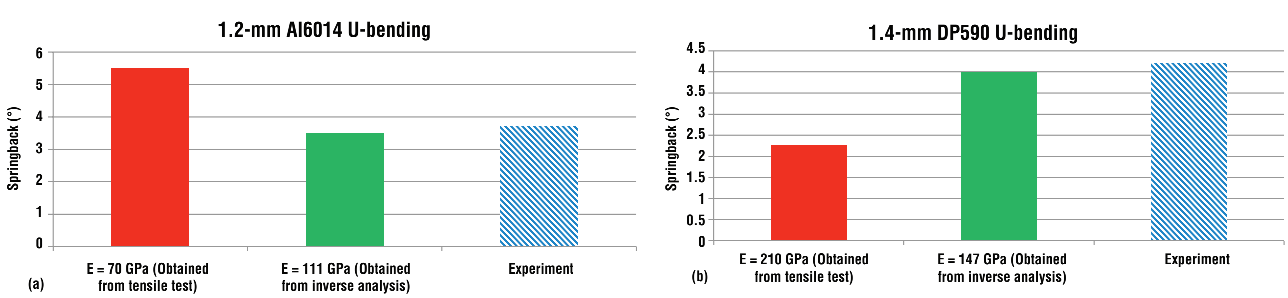


**Figure 2**

Springback prediction in U-bending of Al6014 and DP590 was improved using the inverse analysis method.

mation can be in a different strain state (plane strain or biaxial), and strains can be larger.

## Inverse Analysis

Research is ongoing at the Center for Precision Forming (CPF) at The Ohio State University to develop a practical method, called the *inverse analysis* method, to increase the accuracy of springback prediction. The objective is to reduce the prediction error and consequently save the cost and time for die modification and recut for springback compensation.

Flow stress and the E-modulus are the two most important material parameters for predicting springback. Therefore, accurate determination of E-modulus can improve springback prediction.

In the inverse analysis method, a constant apparent E-modulus can be used to predict springback determined via a bending test and FE simulation of the bending process. In this study, FE simulations were run in PAM-STAMP® using shell elements. The FE simulation was performed initially using the constant handbook value of the E-modulus, which usually is determined by the tensile test. A second simulation then was performed using another E-modulus value. The springback predicted by the second simulation was again compared with the experimental result. Finally, the appropriate apparent E-modulus for accurate prediction of springback was estimated (see **Figure 1**).

Inverse analysis has been tested in the following situations:

1. U-bending of several different AHSS and aluminum alloys. Results show a significant improvement of springback prediction (see **Figure 2**).

2. An industrial part made from DP980 material (see **Figure 3**). The part geometry and the experimental data were provided by Die Cad Group. **Figure 4** shows the predicted results compared to the 3-D scanned data of the panel formed in the tryout. The contour colors indicate the normal distance, in millimeters, of the predicted part geometry after springback to the actual experimental results. As shown, when the E = 120 GPa was used in the simulation, the springback prediction was closer to the real part than the simulation result with the handbook value of the E-modulus for DP980 (E = 205 GPa).

## Limitations of the Inverse Analysis Method

The inverse analysis method has two main limitations:

1. The elastic recovery of the material is a function of plastic strain. Therefore, the E-modulus as a parameter that determines the elastic recovery should be different for different strain values and distribution. The E-modulus determined through inverse analysis for a specific bending process is valid only for that bending operation and material thickness.

2. The real bending test with the actual tooling should be conducted to determine the apparent E-modulus. Therefore, this method can only reduce the number of die modifications and recuts during die tryout.

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*References*

J.Y. Lee, J.W. Lee, M.G. Lee, F. Barlat, *"An application of homogeneous anisotropic hardening to springback prediction in pre-strained U-draw/bending,"* International Journal of Solids and Structures, *Vol. 49 (2012), pp. 3562–3572.*

*Li Sun and R.H. Wagoner, "Complex unloading behavior: Nature of the deformation and its consistent constitutive representation,"* International Journal of Plasticity, *Vol. 27 (2011), pp. 1126–1144.*

*F. Yoshida et al., "Elastic-plastic behavior of steel sheets under in-plane cyclic tension-compression at large strain,"* International Journal of Plasticity, *Vol. 18 (2002), pp. 633-659.*

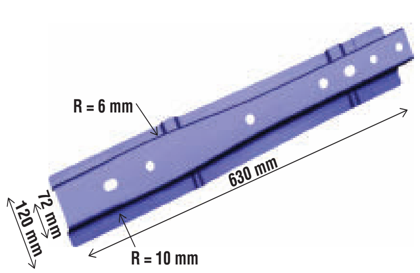


**Figure 3**

This is the geometry of the industrial scale part made from 1-mm DP980. Source: Die Cad Group.

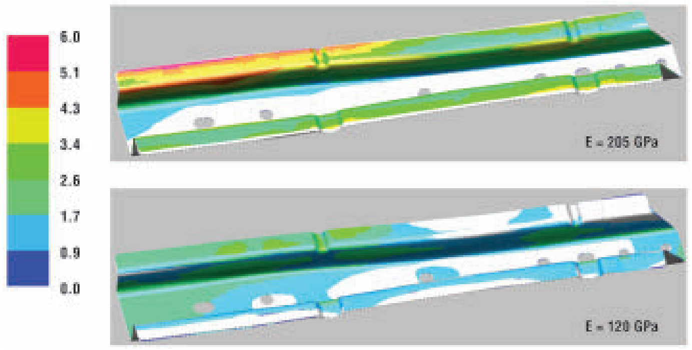


**Figure 4**

PAM-STAMP was used to obtain simulation results for two different E-modulus values. E = 205 GPa is the handbook value for DP980 material. The colors show the normal distance, in millimeters, between the simulated parts and the 3-D scan of the actual panel.