

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

## The inverse analysis method

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*Editor's Note: Part II of this article, which will appear in the January/February 2017 issue, will discuss the results and case studies of the newly introduced inverse analysis method for improving springback prediction.*

In the automotive industry, the use of advanced high-strength steels (AHSS) and high-strength aluminum alloys is increasing for weight reduction and for satisfying environmental regulations and safety standards. Springback is one of the most difficult and important challenges when forming high-strength alloys. To ensure part quality and to compensate for springback, some automotive dies are modified and recut three to five times during tryouts. Reduction of die development and die tryout time and cost would increase the accuracy and reliability of springback predictions.

Studies conducted by the Center for Precision Forming (CPF) at The Ohio State University indicate clearly that in addition to part geometry (usually specified by the designer or OEM), the main parameters that affect the magnitude of

springback are flow stress and E-modulus. Unloading behavior, strain hardening, plastic anisotropy, and Bauschinger effect of the material also affect springback. Therefore, reliable prediction of springback requires accurate determination of material properties.

### Effect of Flow Stress Curve

AHSS have a higher strength-to-ductility ratio than traditional steels. Springback is larger than in mild steels because of AHSS's higher yield strength and ultimate tensile strength (see **Figure 1**).

Accurate representation of the material hardening is important for reliable springback prediction. Usually the hardening behavior of the material is determined by isotropic hardening and the flow stress curve. Typically expressed as:

$$\sigma = K\varepsilon^n$$

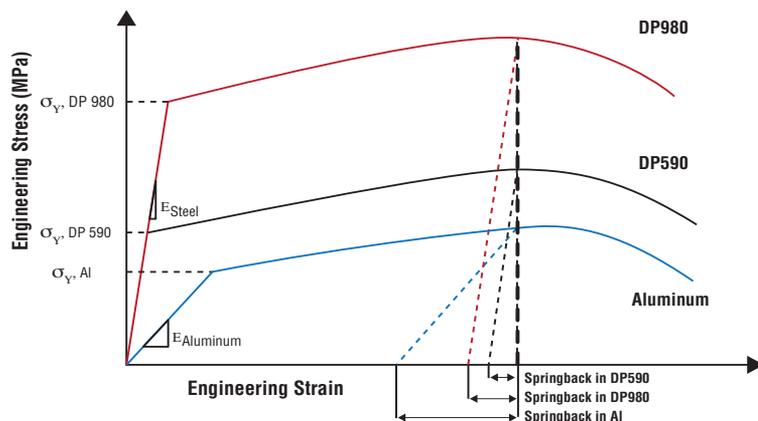
where:  $\sigma$  = True stress

$\varepsilon$  = True plastic strain

K = Strength coefficient

n = Strain hardening exponent

The flow stress curve can be determined from the uniaxial tensile test and



**Figure 1**

This is the engineering stress-strain graph for three materials. The effect of E-modulus and strength of the material on springback are shown.

the biaxial bulge test. The flow stress might change slightly from batch to batch for the same material, but measurement of the flow stress using the tensile test and bulge test can be considered to be reasonably accurate.

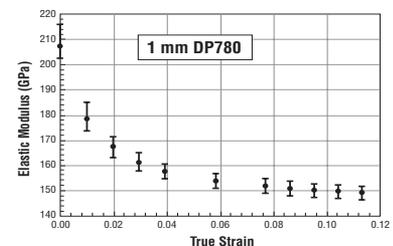
### Effect of E-Modulus

The E-modulus usually is determined from the uniaxial tensile test (see **Figure 1**). However, especially with AHSS, the stress-strain behavior of the material in the elastic region is not linear, and a large deviation from linear loading occurs. Therefore, determining of E-modulus through a tensile test often is not accurate.

While the E-modulus usually is assumed to be a constant value, research has shown that it is not a constant value but rather a function of plastic strain that changes with the magnitude of deformation or strain (see **Figure 2**).

One typical method to determine the E-modulus versus plastic strain is loading/unloading in a tensile test. However, a large deviation from linear unloading is observed following plastic deformation (see **Figure 3**). In most proposed practical methods for determination of the E-modulus, a linear slope of stress-strain data is used. This linear chord is determined by joining two points obtained from stress just before unloading and at zero applied stress. However, this method does not represent the realistic non-linear unloading behavior of the material.

In addition, the major deficiency in determining E-modulus through a tensile test is that the stress and strain in tensile are uniaxial. In other words, the tensile specimen is subject only to tensile



**Figure 2**

E-modulus versus plastic strain is obtained from a loading/unloading test. (Kardes, 2012)

(and, in some special test methods, only to compression) stresses. However, in bending operations in which springback is a major issue, the sheet is subject to tensile and compressive stress simultaneously throughout the sheet thickness (see Figure 4). Therefore, it is questionable whether the E-modulus as determined from the tensile test can be used for accurate prediction of springback in bending.

### Other Factors Affecting Springback Prediction

In addition to flow stress and E-modulus, strain hardening, plastic anisotropy, and Bauschinger effect also influence the accuracy of springback predictions.

To consider the effect of these parameters on springback, the Yoshida-Uemori model (Yoshida, 2002) is recommended. However, this model requires extensive testing to obtain the necessary parameters for the process simulation.

### The Inverse Analysis Method

A project currently is in progress at CPF to develop a cost-effective and practical method for improving the accuracy of springback prediction. The focus is on determining a constant E-modulus, called “apparent E-modulus,” for a given material, thickness, and bending operation that can provide more accurate springback prediction.

With this method, called inverse analysis, a bending test that represents the actual bending process of the real part is conducted and the springback measured for a selected material and thickness. A finite element simulation model of the same process is developed using an initial E-modulus obtained from a tensile test. By comparing the predicted springback with the experimental measurement, researchers conduct another simulation using a lower or higher E-modulus compared to the initially used value.

Results of the two simulations are plotted in a graph of springback versus E-modulus and interpolated by a linear function (see Figure 5). The value of the E-modulus, which provides the springback value that is measured from the

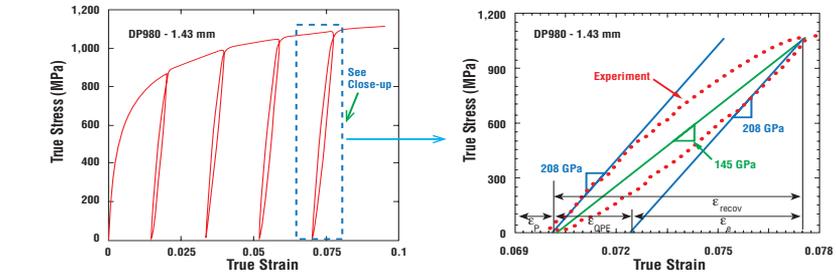


Figure 3

The graph on the left shows an example result of the loading/unloading test for determining E-modulus versus plastic strain. The graph on the right is a magnification of one of the loading/unloading cycles. (Sun and Wagoner, 2011 and 2013)

experiment, is considered as the apparent E-modulus for that material, thickness, and bending operation.

The initial results showed significant improvement in springback prediction.

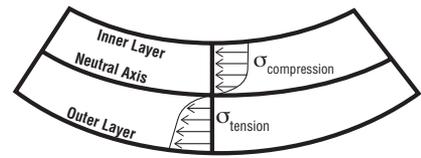


Figure 4

This schematic shows the stress distribution through the sheet thickness during the bending process. The inner layer is in compression, while the outer layer is in tensile state of stresses.

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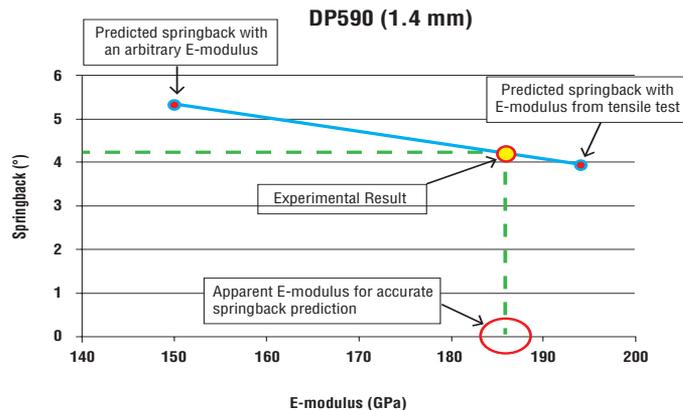


Figure 5

The inverse analysis method is used to determine an apparent E-modulus for more accurate prediction of springback.