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Effect of normal anisotropy on springback

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Abstract

Share of high and advanced high strength steels in automobile is increasing, however, such steels generally have poor formability and high amount of springback. One of the focus areas of research in high strength automotive steel is to increase the normal anisotropy to get better formability. Effect of strength and process parameters on springback has been studied by many researchers but that of anisotropy has not been studied by many. In the present work the effect of anisotropy on springback is predicted using finite element analysis for the benchmark problem of Numisheet-2005 [2005 Numisheet Benchmark 2, Springback prediction of a cross member, Proceedings of the 6th International Conference and Workshop on Numerical Simulation of 3D Sheet Metal Forming Processes, Detroit, USA, August 15–19, 2005]. An analytical model is developed to cross check the trends predicted from the finite element analysis. The effective stress has not been treated as a constant and the radial stress is considered in the present model. Both the models (FE and analytical) predict that higher anisotropy, in general, gives higher springback. Finite element analysis of the problem shows that springback is minimum for an isotropic material.

Keywords: Springback; Normal anisotropy; FEA; High strength steels

1. Introduction

High and advanced high strength steels are finding wide acceptance in the automotive industry. However, one of the major problems in stamping automotive parts with high strength steel sheets is the increased levels of springback. In springback, there are two issues:

- Control of springback during forming and
- Prediction of springback so that it is compensated during dies design stage.

Various researchers developed a variety of manufacturing techniques to control the springback. Sunseri et al. [1] showed that a variable binder force history during forming operation can reduce the springback amount while maintaining a relatively low maximum strain. In their study an initial low binder force followed by a higher binder force was used. Ruffini and Cao [2] and Cao et al. [3] proposed neural network based models to minimize the springback in a channel forming process. It was shown that even for large variations in friction condition and material properties the springback is quite low. Cao et al. [3] showed that a stepped binder force can reduce the springback significantly. Two critical values, high binder force and percent punch of total punch displacement (the outputs from the neural network) are used for the process control. In their study, the material was assumed to be isotropic, elasto-plastic following the von-Mises yield criterion. Hardening was assumed to be isotropic.

Though control of springback is important, the prediction of it is desirable. Both analytical and numerical models have been developed for the prediction.

Zhang and Lin [4] proposed an analytical solution for springback in components stamped by a rigid punch and an elastic die whereas, Morestin et al. [5] proposed a model in which the Prandtl–Reuss plasticity equations associated with a non-linear kinematic hardening model was solved. The calculation takes into account the change in Young’s modulus with plastic strain. Liu [6] proposed a simple model for predicting the springback and bendability. He considered the normal anisotropy and strain-hardening exponent in his model, however, the effective stress is considered to be constant through out the bending. His prediction showed that with increase in normal anisotropy the springback increases but did not give any reason. Wang et al. [7] established a mathematical solution for plane-strain bending of sheet and plate. Using their model they predicted that bending moment and, therefore, the springback increases with increase

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in strength, strain-hardening and normal anisotropy. They used Hill's (1979) non-quadratic yield criteria but did not consider the radial stress and, therefore, their model may not be suitable for thick sheets or in severe bending condition. Pourboghrat and Chu [8] used a moment–curvature relationship derived for sheets undergoing plane-strain stretching, bending and unbending deformations. They used membrane finite element method with bending/unbending corrections to calculate springback. The use of membrane element in the solution reduced CPU time considerably.

Though the analytical models are simple and easy to use for parametric studies, these in general do not represent the real condition. Numerical methods like FEM are frequently used to solve the real life problems. Samual [9] provided an FE program for predicting springback and sidewall curl whereas Lee and Yang [10] evaluated quantitatively the numerical factors influencing the springback prediction. Effects of contact damping parameter, penalty parameter, blank element size, number of corner elements and punch velocity were evaluated using the Taguchi method and found that the number of corner elements and the blank element size are the main factors influencing the springback prediction. It was concluded by them that kinematic hardening should be included for more realistic simulations. Gomes et al. [11] investigated the springback in simple U-shape from Numisheet-93 using three different material models; Barlat's yield criteria, Hill's transverse anisotropic model and von-Mises' yield criteria. They found discrepancies between the results obtained from the different material models. Ragai et al. [12] studied the effect of sheet anisotropy on springback in draw bending of stainless steel 410 numerical methods and experiments.

Though many techniques were proposed, its prediction is still a challenging issue. Many researchers have reported that poor representation of Bauschinger effect is one of the main reasons for poor springback prediction accuracy. In a recent study [13] it was shown that the stress paths of a material point moving over a radius can be quite different when using an isotropic or a kinematic hardening model. The stress magnitudes are similar at the beginning and the end of the stamping but the stress state is actually quite different. Gau and Kinzel [14] proposed a bending experiment to study the effect of Bauschinger effect on springback in aluminium and concluded that the total strain method is not sufficient to model springback when sheet undergoes cyclic deformation. In another work Gau and Kinzel [15] proposed a new hardening model in which they assumed that actuated surface both translates and expands during deformation. All surfaces within the actuated surface have a rigid body translation as described in Mroz method. Kim et al. [16] did the measurement of anisotropy, Bauschinger effect and transient behaviour of automotive dual phase steels. For the anisotropy measurement, non-quadratic anisotropic yield function Yld2000-2d has been utilized and its material parameters have been obtained using the uni-axial tension tests as well as the hydraulic bulge test. To measure the hardening behaviour including the Bauschinger and transient behaviour, they proposed a new tension and compression test. It was concluded that the Chaboche model well represented the Bauschinger effect and the transient behaviour.

Most of the FE simulations used for sheet metal forming prediction assume that springback is purely elastic and linear. However, Cleveland and Ghosh [17] showed that the unloading is not linear. It was demonstrated that the inelastic strain released from the formed state can be a major source of additional strain recovery, the magnitude of which depends on the forming stress state. It has been shown by them that 10–20% error in the estimation of springback is possible if the anelastic effects during loading and unloading, is ignored. Such effects arise from mobile dislocations which can move in response to the internal repulsive forces.

Many works have so far been done on prediction and control of the springback. However, there are a few literatures dealing with the effects of material properties other than strength. Material scientists are working towards increasing the normal anisotropy by having a favourable texture for better formability, and therefore, it is required to know the effect of normal anisotropy on springback. In the present work the effect of normal anisotropy on the amount of springback is evaluated for the benchmark problem of Numisheet-2005 [18]. An analytical model for plane-strain bending is also developed and used for assessing the effect of various parameters, including normal anisotropy, on springback. In the present analytical model radial stress has been considered and the effective stress is not treated as a constant value (unlike [6,7]). Also this model provides a closed form solution.

2. Analysis

In the present model the material is assumed to be rigid plastic and strain-hardening with normal anisotropy. Bauschinger effect is neglected and Holloman's equation is used for modelling the hardening. The neutral axis is assumed to coincide with the geometrical mid plane of the sheet.

Fig. 1 shows the stresses acting on a small element in the deforming sheet.

The force equilibrium equation for the small element making an angle $d\theta$ at the centre is,

$$\frac{d\sigma_r}{dr} = \frac{\sigma_\theta - \sigma_r}{r} \tag{1}$$

Using the Hills's yield criteria and associated flow rule the expressions for equivalent stress and strain can be written as

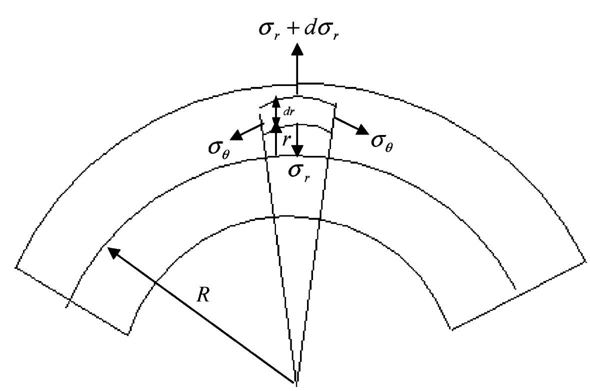

Fig. 1. State of stress on a small material element in pure bending.