Effect of Material and Geometrical Parameters on the Springback of Metallic Sheets

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Abstract: One of the greatest challenges of manufacturing sheet metal parts is the elastic recovery phenomenon during unloading which leads to springback. Precise prediction of springback after removing the bending tools is the key to designing the bending tools, to controling the bending process and assessing of the accuracy of the part's geometry. This paper aims at the numerical investigation of the effects of material and geometrical parameters on springback amount. The plane-strain finite element model of the air-bending process, which is based on the updated Lagrangian elastoplastic finite element approximation, is employed for this purpose. Results showed that the Springback decreases with the elastic modulus, increases with the yield stress, Strength coefficient, die width, and sheet thickness. The most significant parameters which influence the springback are the sheet thickness, the strength coefficient the young's modulus, and the die width respectively.
[Jaber Abu Qudeiri, Fayiz Abu Khadra, Abdulrahman Al-Ahmari, Usama Umar. **Effect of Material and Geometrical Parameters on the Springback of Metallic Sheets**. *Life Sci J* 2013;10(2):1531-1536]. (ISSN:1097-8135). http://www.lifesciencesite.com. 207

Keywords: Sheet metal bending; springback, finite element analysis; updated Lagrangian

1. Introduction

Press forming in the manufacturing of engineering metal sheet parts is a cost effective technique since it allows the elimination of machining and welding operations. The components produced by the sheet–metal forming range from simple to complex shapes that can be very small, such as certain parts for the electronic industry, or large, such as car bodies for the automotive industry. Such products in their production cycle experience several modes of deformation, namely bending, stretching or drawing, operating separately or simultaneously in the various regions of the sheet.

Bending process in sheet forming operations controls the accuracy of the formed products. This is due to several mechanisms among which the elastic springback is the most important. An accurate analysis of the elastic phenomena in bending is extremely important to determine the punch stroke required to achieve a particular bend angle after springback.

A number of analytical models based on materials properties and tool geometry is available to predict springback [1-6]. Most of the analytical models are based on a lot of simplified assumptions due to the complexity of the problem and thus do not provide accurate predictions.

The finite element method becomes reliable in simulating the process before experimental development and die tryout are conducted. Nilsson et al. [7] simulated springback in V-die bending for several materials neglecting friction. The true stress-strain curve from a tensile test was used as the material description. They noted a good correlation between simulation and experimental results. Huang and Leu [8] have used elasto-plastic incremental finite element computer code based on an updated Lagrangian formulation to simulate the V-die bending process of sheet metal under the plane-strain condition. Isotropic and normal anisotropic material behavior was considered including nonlinear work hardening. Huang et al. [9] studied springback and springforward phenomena in V-bending process using an elasto-plastic incremental finite element calculation. Lee and Yang [10] evaluated the numerical parameters that influence the springback prediction by using FE analysis of a stamping process. Li et al. [11] used a linear hardening model and an elasto-plastic power-exponent hardening model to study the springback in V-free bending. According to their results, the material-hardening mode directly affects the springback simulation accuracy. Li, Zhao et al. [12] predicted springback of wide sheet metal air bending process. Garcia-Romeu, et al. [13] determined the Springback of sheet metals in an air bending process based on an experimental work. Fu and Mo [14] predicted the springback of high-strength sheet metal under air bending forming and tool design based on GA–BPNN. Baseri, Rahmani et al. [15] proposed predictive models of the springback in the bending process. Han, et al. [16] studied the effect of different material models and different methods on the springback angle.

Sheet metal bending belonging to the out of plane forming process is characterized by large deformation, as well as frictional contact boundary changes during the process. This implies that the finite element analysis of the sheet metal bending process is quite difficult; hence remarkably research efforts are still focused on its advancement. In practice, the understanding of the effect of material parameters and the process parameters on springback amount is essential for systematic tool design. In this paper the influence of material properties and the process parameters on the amount of springback are investigated.

2. Air bending process

Figure 1 depicts a two-dimensional schematic view representation of the sheet metal Air-bending configuration. In general, the bending process can be divided into two stages: loading and unloading. In the loading stage, the sheet metal is bent into the die shape, during which, the sheet undergoes elastoplastic deformation under frictional resistance. The second stage represents removal of the deformed sheet metal from the tools set during the unloading step, while experiencing residual stress release. Owing to mechanical relaxation, the dimension of the final product, particularly the bending angle, becomes different from that of the product before unloading. This dimensional difference is called the springback. And is calculated using the following equation (see Figure 1)

$$\Delta\theta = \theta_1 - \theta_2 \qquad (1)$$

where θ_1 and θ_2 are the angle before and after unloading , respectively.

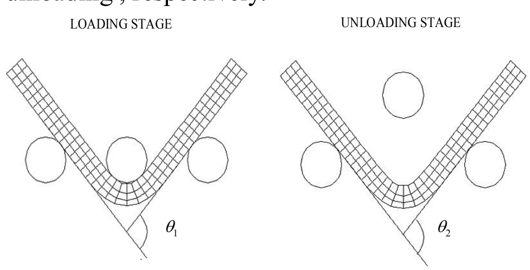

Figure 1. Schematic representation of the Air bending process

3. Finite element analysis

3.1 Basic Assumptions

1. The sheet metal is assumed to be a continuum, which means the body, does not contain any empty space or void.
2. The sheet is assumed to be isotropic and homogenous, this assumption means the material properties do not vary in direction or orientation since homogenized material has identical properties at all points.

In actual sheet bending process, a certain amount of lateral strain would be inevitable. The magnitude of this strain would, however, be fairly small in usual situations where the width of the sheet is at least 5-6 times the sheet thickness (t). The effect of the lateral strain would therefore be insignificant on the moment curvature relationship for the bent sheet. For this reason the finite element analysis is simplified to 2D plane strain problem.

3.2 Element type

A four-node, isoperimetric, and arbitrary quadrilateral plane strain is used. This element uses bilinear interpolation functions; the strains tend to be constant throughout the element. This results in a poor representation of shear behavior. The bending characteristics can be improved by using alternative interpolation functions by activation the assumed strain formulation to improve the bending characteristics of this element [17]. Although this increases the stiffness assembly costs per element, it improves the accuracy. The stiffness of this element is formed using four-point Gauss Ian integration. This element is suitable for linear analysis and for complex non-linear analysis that involves contact, plasticity and large deformation. The nature of the free bending process, the work piece geometry, bending moment, force direction, material response caused by the elastic–plastic strain, and strain-hardening are constantly affected, thus a continuum element is ideal for this simulation.

3.3 Finite element procedure

The implicit model is based on the updated Lagrange formulation which takes into account both material and geometrical non-linearity The full Newton-Rahpson method was chosen for the solution of the nonlinear finite element equations. The Netown-Raphson is based on an incremental step-by-step solution, assumes the equilibrium configuration of the body at a discrete time t and determines the solution for the discrete time t+Δt, where Δt is the time increment. The method has quadratic convergences properties and the stiffness matrix is reassembled each iteration. This means that in subsequent iterations the relative error decreases quadratically. The correct choice of Δt is fundamental to obtain a quick iterative convergence. Moreover, such a choice strongly influence the validity of the contact algorithmic particular, obtaining effective solutions often requires very small values of the time increment. Since at each step the stiffness matrix must be assembled and inverted with the above iterative procedure, the CPU times required to complete the simulation of the process are typically very high.

3.4 Material behavior

In sheet metal one of the most important factors is the relation between stress and strain The bending process causes the metal to undergo deformation as the punch moves, thus, the metal strain hardens due to the elastic–plastic strain. The metal elastic properties are composed of the young's modulus (E) and the yield point. Yielding occurs after the yield point stress is exceeded, the metal yields, plastic deformation occurs, in dealing with yielding and plasticity. The strain hardening is described by Swift's [18] equation as

$$\overline{\sigma} = k(\varepsilon_0 + \overline{\varepsilon})^n \quad (2)$$

where k, ε_0 , and n are material constants, and $\overline{\varepsilon}$ is the equivalent plastic strain.

The sheet material is considered as an isotropic hardening one. Isotropic hardening means that the yield surface remains the same shape and has the same origin during hardening, with only the size changing, i.e. the radius of the yield surface expands, due to work hardening.

3.5 Loading and unloading procedures

The analysis consists of two steps, corresponding to the phases of the bending process itself. First, the punch is moved through a particular distance, which models the actual loading stage. Second the analysis simulates the springback. The punch is moved back to its initial position. When the implicit finite element analysis is used in combination with an elastic plastic material model, it allows simulation of springback upon the removal of all contact loads in the fully loaded state. The release option is used to enable release of the deformable body's nodes, which have been in contact with the rigid bodies, i.e. removing the rigid surface, and evaluating mechanical springback.

4. Result and Discussion

The finite element model described in the previous section was used to study the influence of the material parameters as well as the influence of the process parameters on springback.

4.1 *Deformation analysis of the bending process*

The deformation of the sheet with the Von Misses stress distribution at the end of the loading stage and after unloading is shown in Figure 2a and 2b respectively.

From Figure 2a it can be seen that the bending stress increases toward the outer surface and toward the punch axis, as expected. It can be also seen that the neutral line shifts toward the punch near the punch axis and is at about half the thickness in other locations. Figure 2b shows the residual stress distribution on the sheet after the unloading process where a reduction of the stress occurs due to springback of the sheet.

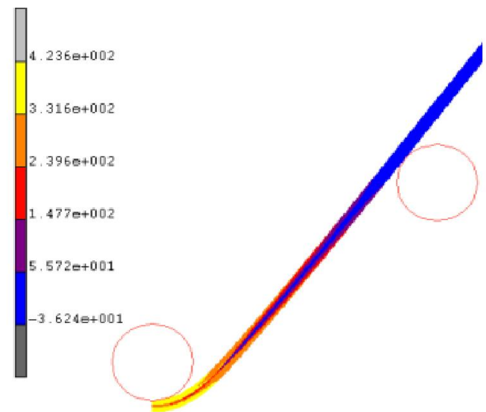

Figure 2 a. Von Misses stress distribution at the end of the loading stage

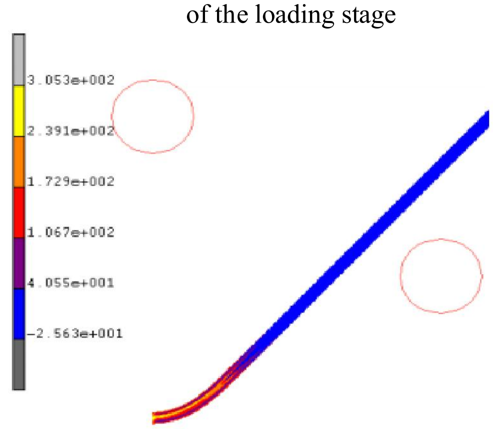

Figure 2 b. Von Misses stress distribution after unloading

4.2 *Effects of material parameters*

To study the effect of material parameters on the springback amount, one material parameter was varied whereas the other parameters were kept constant. The result is given in Figures 3-6 where the relation between the bending angle under load θ_1 and the springback amount are presented for three levels for parameters of each material. Figure 3 shows the effect of the E on the springback amount for a given bending angle before unloading. It is obvious that a lower elastic modulus values produce higher springback because they produce higher strain.

Figure 4 shows the effect of the yield strength (σ) on the springback amount. It can be seen from the figure that the springback amount increases as the σ increases because the extent of the region subjected to elastic strain increases with increasing σ. This means that an increase of the σ-to-E ratio increases springback.

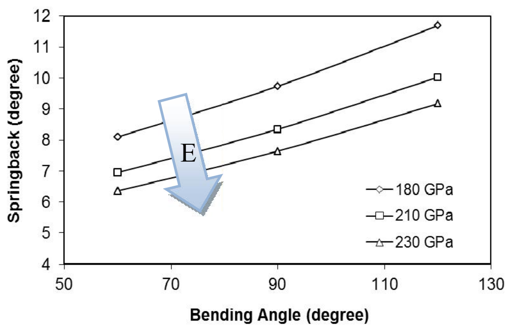

Figure 3. Effect of the young's modulus on the springback amount

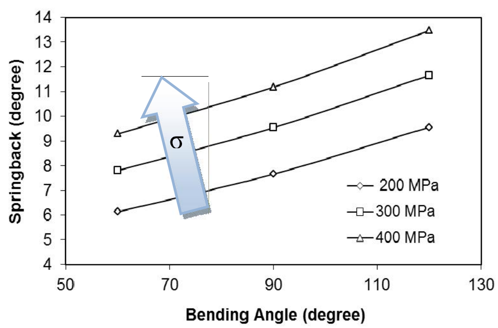

Figure 4. Effect of the yield strength on the springback amount

Similarly the increases in the strength coefficient (k) increase the springback amount as shown in Figure 5 where an increase in the strain hardening coefficient decrease the springback as shown in Figure 6.

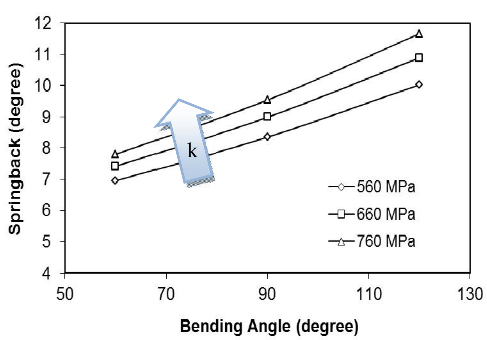

Figure 5. Effect of the strength coefficient on the springback amount

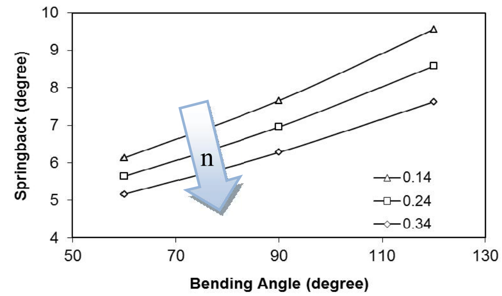

Figure 6. Effect of the strain hardening constant on the springback amount

4.3 *Effects of geometrical parameters*

In general, the geometry of the tooling in the air bending process is established by three parameters: the die width (w), the die radius (R_d) and the punch radius (R_p). To study the effect of these parameters on the springback amount a variation study was conducted. The results are shown in Figures 7 to 9. The relationship between the bending angle under load and the springback is presented for three levels for each parameter.

The width of the die is an important parameter, as it determines the length of the sheet that is used to transfer the punch force into a bending moment. Accordingly, w has extremely large influence on both the punch displacement to achieve a bending angle before unloading and the springback amount as shown in Figure 7. This increase in the springback amount can be attributed to the increase of the inner sheet radius before unloading as w is increased.

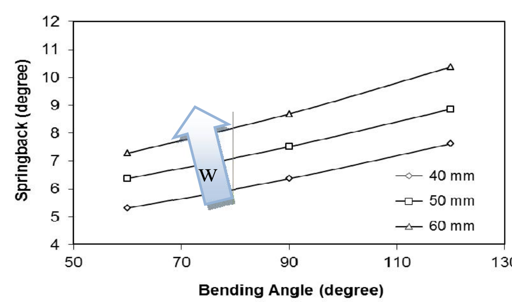

Figure 7. Effect of the die width on the springback amount

Figure 8 shows the effect of the R_d on the springback amount. It can be seen from the Figure that an increase in the R_d increases the springback amount for a given bending angle before springback This can be attributed to the increase of the inner sheet radius before unloading, because the increase of the R_d has similar effect as the increase of the w as both parameters increase the effective w which is the distance between the point of the sheet contact with the die and the point which the sheet leaves contact with the punch nose radius. However, when the R_d is large, the moment arm is initially large and continuously decreases as the deformation proceeds becoming nearly constant in the later stage of bending. Therefore the effect of the increase of the R_d reduces with increasing bending angle before springback.

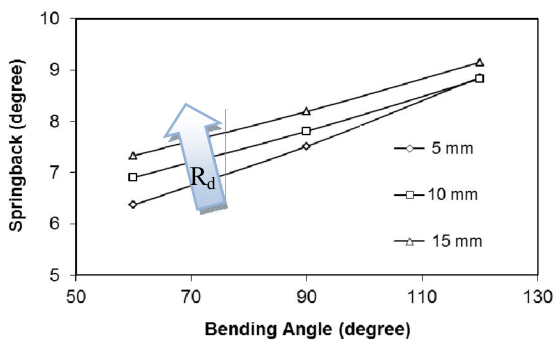

Figure 8. Effect of the die radius on the springback amount

From Figure 9, it can be seen that the change in the R_p slightly affects the springback amount. This variation can be attributed to the change in the inner curvature radius of the bend. When R_p is sufficiently larger than the sheet thickness, the inner radius of the bend can be smaller than that of the R_p. Contrarily, when R_p is almost equal to t, a large curvature radius of the bend can be expected. The springback increases slightly as the R_p increases for smaller bending angle before springback. However this effect reduces with increasing bending angle θ_1, so that after a certain bending angle the springback decreases with increasing R_p. Compared to the influence of w on springback, the effect of the R_p is very small.

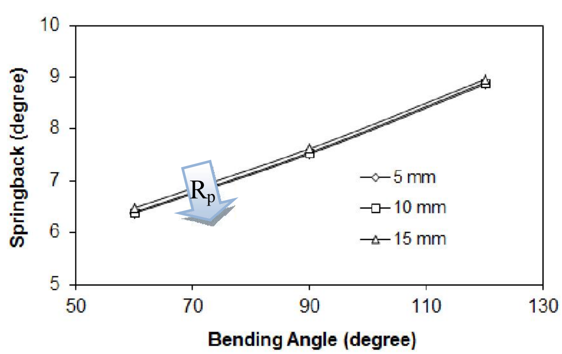

Figure 9. Effect of the punch radius on the springback amount

4.4 *General Sensitivity Analysis*

General sensitivity analysis is typically conducted by analysts as a fast way to tell which input parameters are important to a particular output feature. A first order derivative of the output feature of interest with respect to each input parameter is computed using finite differencing. The value of this derivative is computed with the level of the input parameter under consideration set at its extreme values, while the values of the remaining input parameters are held at their nominal values. Each input parameter is set at its low range value and then its high range value while the others are held at their middle, or nominal value. Output feature values were calculated using finite element model. Estimates of the derivatives were then calculated using these input output pairs according to the simple finite differencing formula

$$\frac{\partial Out}{\partial In} \approx \frac{Out_{Hi} - Out_{Low}}{In_{Hi} - In_{Low}} \quad (3)$$

where Out and In refer to output features and input parameters (all normalized before the calculation to eliminate scaling issues), respectively, and Hi and Low refer to the level at which the input parameter of interest is set.

Results of these finite difference calculations are shown below in Figure 10. As can be seen, the most important parameters to the springback amount are t, k, E, and w, respectively. This means that changing one of the input parameters while the others were held at their nominal values resulted in a significant change in the value of the springback. It can also be seen that the R_p has very little effect on the springback.

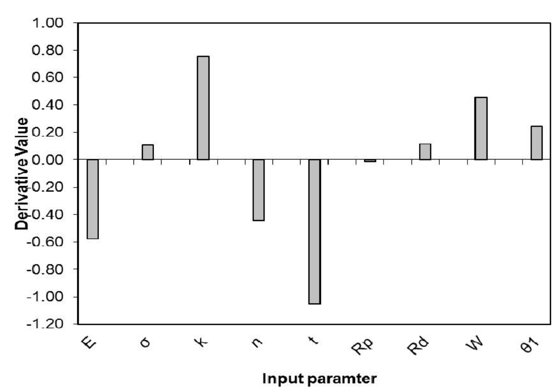

Figure 10. Results of the general sensitivity analysis for springback

4. Conclusions

A numerical model based on the updated Lagrangian formulation has been proposed in this paper to calculate springback in the plan-strain air bending process. To study the effect of material parameters and the process parameters on the springback amount a variation study and general sensitivity analysis were conducted. Based on this study the following remarks can be drawn:

1. Springback decreases with the elastic modulus E because the resistance to elastic bending increases with the young' modulus.
2. Springback increases with the yield stress, strength coefficient since the higher these values are the greater the resistance to plastic yielding.
3. A large die width causes more springback than a smaller one. A similar conclusion can be reached for the die radius.
4. The punch radius has a small effect on springback
5. The most significant parameters which influence the springback amount are the sheet thickness, the strength coefficient, the young's modulus, and the die width, respectively.

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