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Prediction of Springback in Straight Flanging using Finite Element Method

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Abstract: One of the important features of flanging process is elastic recovery during unloading leading to springback. The elastic recovery is associated with various tool and material parameters. It is difficult to analytically predict the elastic recovery accurately owing to the complex material deformation behavior. In this investigation, a commercially available Finite Element software is used for elasto-plastic analysis of flanging process. The springback is studied varying geometrical, material and friction parameters. The results of the simulation are validated with a few published experimental results.

1 Introduction

Flanging is one of the sheet metal forming processes frequently employed in various manufacturing industries. In this process, one edge of the sheet is bent to the desired angle while the other end is restrained either by the material itself or by force of a blank holder or pad. Flanges are generally used for rigidity, hidden joints, appearance, avoidance of sharp edges, and strengthening of a edge of sheet parts such as automobile front fenders and complex panels formed by drawing or stretch forming [Theis (1999)]. One of the important design problems in flanging pertains to springback. During the unloading phase in process, the elastic strain releases and the residual stresses redistribute resulting in springback. The springback may introduce surface distortion and unexpected out- of- tolerance in shape and dimensions. Therefore, it is important to predict the springback in designing the punch and the die [Math, Grizelj (2002)]. The increased access to powerful computers at relatively low costs has made the use of Computer Aided Engineering (CAE) systems almost mandatory in manufacturing industries. The advances in computer technology have enabled realistic simulation of flanging process by Finite Element Method (FEM) to predict the springback.

The prediction of springback in flanging operation using FEM has been employed by many in the past. For instance [Buranathiti and Cao (2004)] presented an analytical model to predict the springback in the straight flanging and results were compared with experimental ones. [Kulkarni and Prabhakar (2003)] studied the effect of strain rate on springback in T-temper (airframe). [Livatyali, Kinzel and Altan (2003)] proposed a solution for straight flanging process using advanced bending theory incorporating the geometric and material details of the process to a mathematical model. [Livatyali and Altan (2001) & Livatyali, Wu and Altan (2002)] studied straight flanging using experiment as well as FEM. They used coining to reduce the amount of springback in the flanging process and to improve the hemming quality. [Marciniak, Dunca and Hu (2002)] proposed an empirical moment-curvature relationship developed using a material specific bending test. [Muderrisoglu, Murata, Ahmetoglu, Kinzel and Altan (1996)] studied experimentally the bending, flanging and hemming of aluminum sheets and concluded that the flange height has significant effects on deformation load as compared to flange ratio. [Ruffini (1998)] proposed a neural network model to minimize the springback in a channel forming process. [Song, Olan, Cao, Liu and Li (2001)] studied the reliability of different methods in prediction of the springback. [Taylor, Cao, Karafillis and Boyce (1995)] discuss a numerical solution for sheet metal forming using implicit and explicit finite element method. [Vish-

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wanathan, Kinsey and Cao (2003) & Cao, Kinsey and Solla, (2000)] presented an artificial neural network approach with stepped binder force trajectory to control the springback angle and principal strain in a steel channel forming.

In many industries, springback is very important in tooling and process design. Prediction of springback as well as compensating for springback in tooling design are two important issues. This study aims at the prediction of springback for straight flanging process. In this study, FEM of straight flanging process was carried out to study the springback using commercial FE software. Various geometric as well as material parameters and friction conditions were considered to predict the effect on the springback.

2 Numerical analysis

The numerical analysis of flanging process was performed using MSC-Marc 2003 software.

2.1 Mesh and boundary conditions

Figure 1 shows the initial geometry of the flanging process used for the FEM. As the geometry is not symmetric, the entire geometry is considered for the numerical analysis. The curves in the FE model that define the shape of the die, the punch and the blank holder are designated as rigid bodies. Deformable body (sheet) is represented in FE mesh as shown in Figure 1. The number of nodes and elements in the deformable body are varied with the geometrical conditions. In performing the flanging analysis, plane strain four noded quadrilateral elements have been employed. Significant stresses develop only in the region near the curvature of the die and the region away from the bent portion remains nearly stress free. Therefore, the mesh density is varied to suitably capture the variation of the desired parameters. The displacements of the nodes of surface of the sheet are constrained by contact boundary conditions imposed by rigid die and punch surfaces. The curve representing the punch is constrained in the x-direction and the curves representing the die and the blankholder are constrained in both x and y direction. The entire simulation of the flanging process is carried out in a number of small incremental steps. In each step, it is ensured that the average incremental strain does not exceed about 20 % the yield strain.

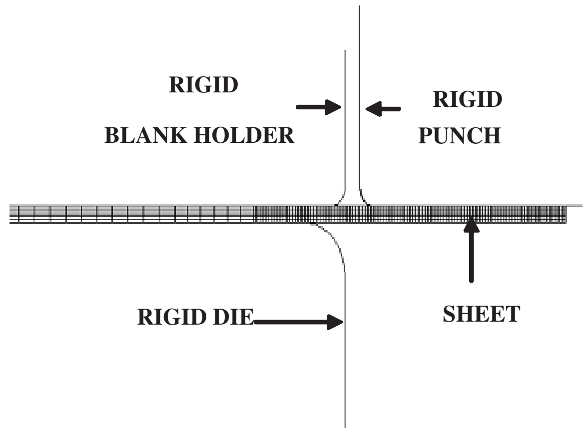

Figure 1: Initial geometry used for FE analysis

2.2 Geometric parameters

Springback refers to the shape difference between the fully loaded and unloaded configurations. Many geometrical parameters such as sheet thickness, tooling geometry, including the die radius and the gap between the die and the punch, flange length etc. are considered for simulation. In this study the 'gap' refers to the difference between the thickness of the sheet and the distance between the die & the punch. The geometrical parameters are shown in Table 1 to study the effect on springback parametrically.

Table 1: Geometrical Parameters

Thickness of the sheet (mm)	Radius of the die (mm)	Radius of the punch (mm)	The gap (mm)	The flange length (mm)
1,2,3	3,4,6	1,2,3,4	0.1,0.3, 0.5,0.7, 0.9,1.1	20,23, 25,30

2.3 Modeling of material

In the present study, a wide range of illustrative and representative values of mechanical properties such as yield strength, Young's modulus and strain hardening exponent are taken. These are so chosen to cover a wide range of structural materials used in manufacturing industries. Simple power law equation is used, to represent the flow of the material during the process.

$$\frac{\sigma}{\sigma_y} = \left(\frac{\varepsilon}{\varepsilon_y}\right)^n \tag{1}$$

Where σ_y and ε_y are stress and strain corresponding to yield conditions and 'n' is the strain hardening exponent. The material properties are shown in Table 2 for the parametric study by FE simulation.

Table 2: Material Properties

Yield stress (MPa)	Young's modulus (GPa)	Strain hardening exponent
75, 100, 125, 150	70, 100, 150, 200, 225	0.1, 0.15, 0.2, 0.25, 0.30, 0.35

2.4 Interface conditions

The friction at the interfaces of the die & the sheet, the punch & the sheet and the sheet & the blank holder are considered. Friction coefficient of 0.0, 0.125, 0.2, 0.3, 0.4 and 0.5 are considered in this study.

2.5 Assumptions

The following assumptions have been made:

a) The material is isotropic, homogeneous and there is no residual stress in the sheet, prior to the bending.

b) Thermal effects during the deformation process are neglected.

c) The width of the sheet is much larger than its thickness corresponding to plane strain condition.

d) Plane sections normal to the sheet surface and parallel to the bend axis remain plane.

e) The die and the punch are considered as rigid bodies throughout the analysis.

f) The blank holder is considered stationary and rigid. The gap between the blank holder and the die is taken exactly equal to the thickness of the sheet.

2.6 Calculation of the final radius

As shown in Figure 1, with the sheet resting on the die, punch is allowed to depress gradually. This is numerically carried out by assigning suitable downward y-displacements for the punch in set of increments. The sheet is initially bent to 90 degrees. Then the punch is gradually elevated by assigning an upward y displacement to free the sheet and the sheet is allowed to elastically relax itself incrementally and iteratively in each increment. Figures 2a to 2c represent a set of bending of the sheet corresponding to 14, 24 and 100 % of the total punch displacement. Figure 2d represents the final shape of the flange after releasing.

The springback is measured in terms of change of angle i.e. the difference between the initial (90 degrees) and final angle. The springback angle of the released sheet is calculated by considering the coordinate of two different points A and B as shown in Figure 2d.

3 Results and discussion

3.1 Validation

The published experimental results [Song, Olan, Cao, Liu and Li (2001)] for a length of sheet 150 mm, thickness of the sheet 1 mm, flange length 20 mm, radius of the die 3 mm and punch radius 1 mm for different gaps ranging from 0.1 to 1.1 mm are shown in Figure 3. It is plotted as springback angle as a function of the gap. The sheet of aluminum is used for the experiment has the following material properties; yield strength 146 MPa, Young's modulus 72 GPa, strain hardening exponent 0.30 and Poisson's ratio 0.3. Friction coefficient of 0.125 is assumed in this case.

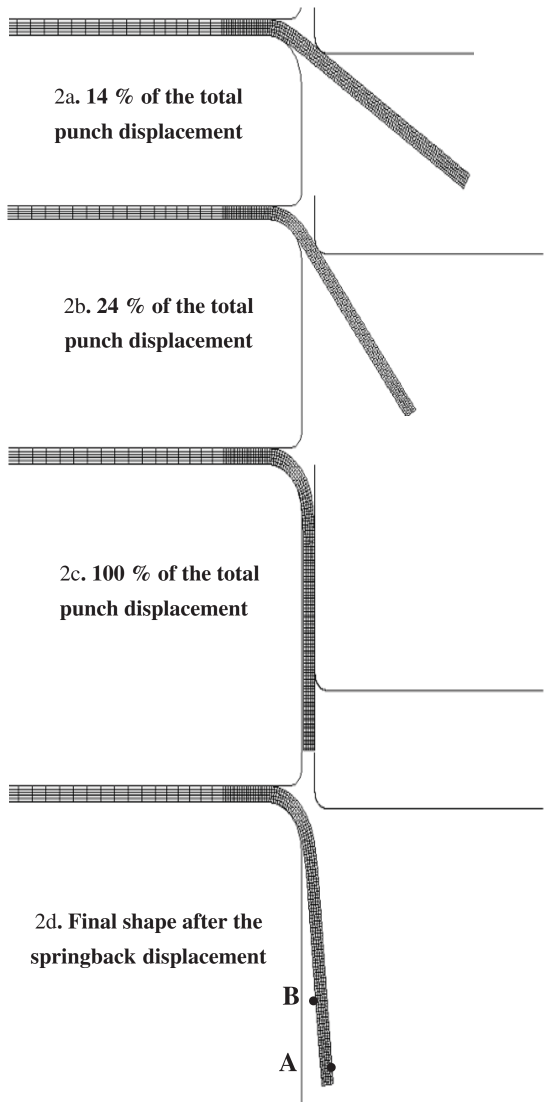

Figure 2: The deformation shapes for the flanging process at various stages of punch displacement

Experiment 1 and experiment 2 data in Figure 3 are two different experimental results carried out. The FE simulation is carried out considering an identical geometry and material parameters under the same friction condition. It can be seen from Figure 3 that the present results show a good agreement with the published experimental ones [Song, Olan, Cao, Liu and Li (2001)].

3.2 *Effect of geometrical parameters*

A plot between the springback angle and the gap for the die radii (3, 4 and 6 mm) keeping the thick-

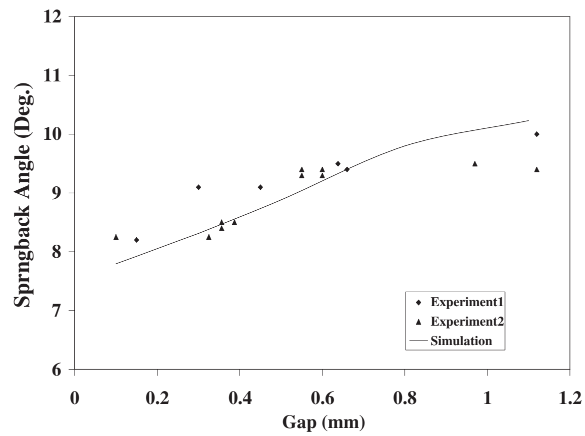

Figure 3: Validation of the simulated results with the published experimental results

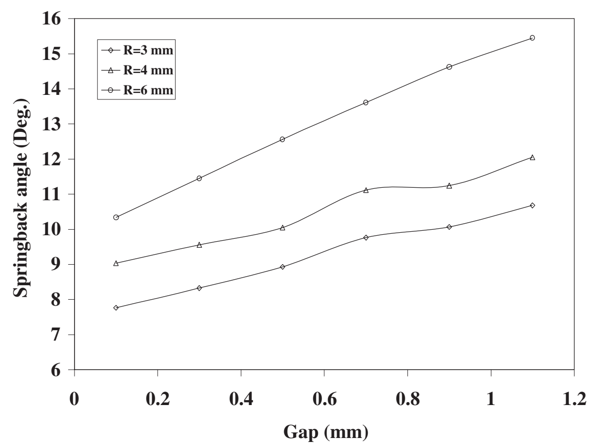

Figure 4: Effect of Die radius on springback

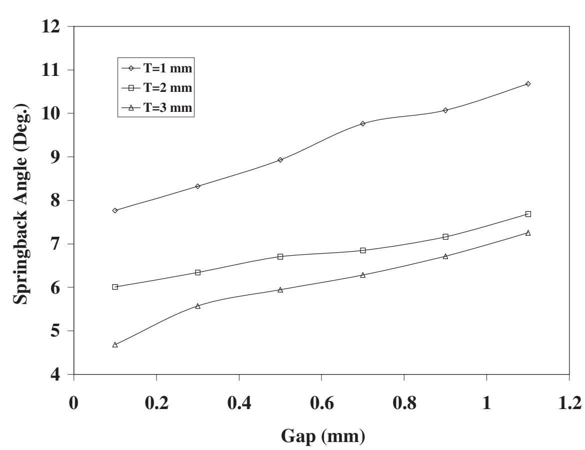

Figure 5: Effect of Thickness of sheet on springback

ness of the sheet to be 1 mm is shown in Figure 4. It can be easily seen from figure that the springback angle increases with increase in radius of the die. Figure 5 shows a plot between the springback angle and gap, for the thickness of sheet varies as 1, 2 and 3 mm. This figure illustrates that the springback angle decreases with increase in thickness of sheet. From these Figures (3,4 & 5) it can be summarized qualitatively, that larger the fraction of elastics energy to the total deformation energy deposited in the workpiece, there will be larger springback.

The effect of the punch radius is carried out considering radii of 1, 2, 3 and 4 mm. It has negligible effect on the springback and the springback angle varied only in the range of 8.10 to 8.20.

3.3 *Effect of flange length, gap*

Figure 6 illustrates the springback angle with respect to the gap for 20, 23, 25 and 30 mm length of the flange. It can be seen that there is not any major effect of flange length on springback angle, when the gap is between 0.1 mm to 0.4 mm. This figure, also depicts that springback is high for shorter flange length and low for higher flange length at the maximum gap of 1.1 mm.

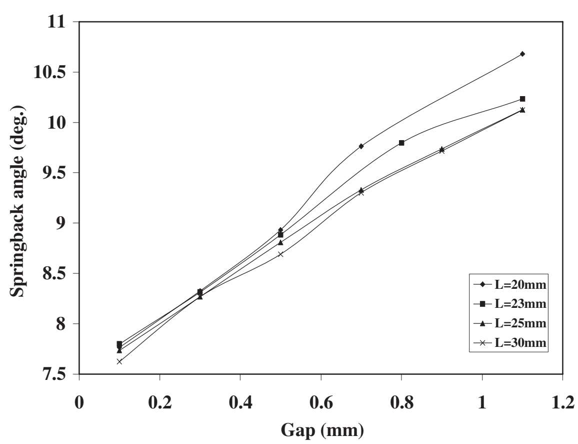

Figure 6: Effect of flange length on springback

Figure 7 shows springback angle as a function of flange length for different gaps. Springback is very high and reduces rapidly for flange length less than 13 mm. There is no severe effect of flange length on springback beyond a certain length. This once again goes to prove our earlier proposal that the ratio of elastic energy to the total deformation energy actually influences the springback.

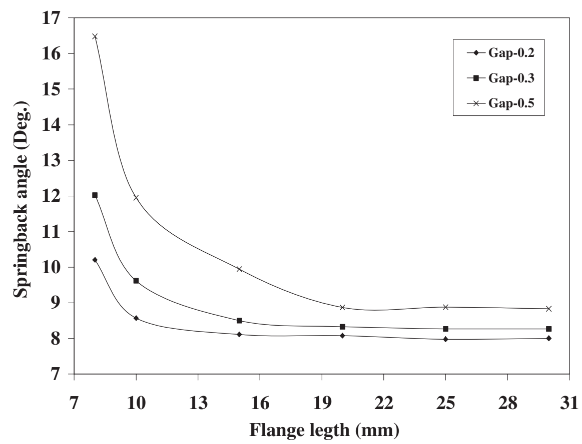

Figure 7: Effect of gap on saturation of springback with respect to flange length

3.4 *Effect of material parameter and friction*

Figure 8 & 9 show the springback angle for strain hardening exponent and different ratios of Yield strength & Young's modulus respectively. It can be seen from these figures that the springback angle increases with increase in strain hardening exponent and ratio of Yield strength to Young's modulus.

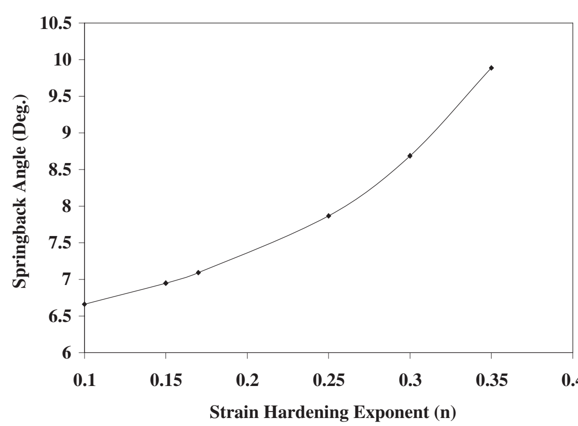

Figure 8: Effect of strain hardening exponent on springback

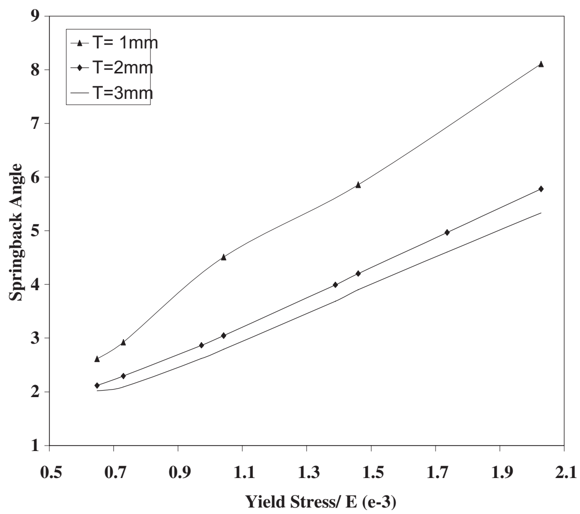

Figure 9: Effect of ratio of yield stress and Young's Modulus on springback

There is no severe effect of friction on the springback angle. The springback angle just varies from 8.6 to 8.9 degrees for friction coefficients ranging from 0.0 to 0.5.

4 Conclusion

A FEM based parametric analysis of flanging process of sheets is presented in this paper. The following conclusions emerge from this study:

- Springback angle increases with increase in the radius of the die, gap between the die and the punch, flange length, ratio of Yield stress to Young's modulus and strain hardening exponent.
- Springback angle decreases with increase in thickness of the sheet.
- The springback is high for the smaller flange lengths while it decreases with increase in length and finally gets saturated beyond a certain length.
- On the whole it can be qualitatively stated that springback angle increases with increase in the ratio of elastic energy to the total deformation energy deposited in the workpiece during the flanging deformation.

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