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ANALYSIS OF THE RESIDUAL STRESS IN SHEET METAL U BENDING

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ABSTRACT
The distribution of the residual stress throughout the sheet metal after a U bending operation determines the intensity of springback in the resulted part. Nowadays there is an increasing tendency to use the finite element method in the design of sheet metal forming processes and the classical trial and error procedures are replaced with simulations. This paper presents a series of simulations of the U bending process and correlates the evolution of residual stress with the springback phenomenon.
Keywords: residual stress, springback, U bending

1. INTRODUCTION
The designing of a forming process requires taking into consideration the modifications introduced by springback to the formed part: shape changes, angular variations etc. Springback is mainly an elastic phenomenon determined by the distribution of residual stress through the sheet metal after plasic forming.
There are numerous studies concerning sheet metal forming processes and spirngback. Karafillis and Boyce [1] proposed an inverse springback calculation method to obtain the desired part geometry after springback and they also elaborated a tool correction method. Li et al [2] proposed an explicit finite element method in conjuction with the ortogonal regresion analysis for the prediction of springback. Papeleux and Ponthot [3] used an implicit dynamic time integration scheme that is able to simulate the whole process including loading and unloading phases. Yamamura et al [4] have simulated springback by a static explicit FEM code, using an algorithm for canceling the non-equilibrated forces. Pourboghrat and Chu [5,6] have developed a robust method for predicting springback and sidewall curvature in U bending operations using moment-curvature relationships derived for sheets undergoing plane-strain stretching, bending and unbending deformations using a membrane finite element solution. Ruffini and Cao [7] proposed a neural network control system for springback reduction in a channel section stamping process.
The present paper illustrates a study about the relations between springback and residual stress in U bending of sheet metal using finite element method.
The blank holder force is, referring to the literature, one of the most sensitive process parameters in sheet forming, and therefore can be used to precisely control the deformation process. During the forming process of a U shaped part, the sidewall goes through a complicated bending, stretching and unbending process. The stress distribution through the thickness of the side wall is the following: the side near the die has tensile stress and the side near the punch has compressing stress, which would promote a residual bending moment and result in sidewall curl. Using a large blankholder force in the forming process is useful to remove sidewall curl. When the blankholder force is increased the stress distribution through the thickness of the sidewall may be turned to tensile stress over the whole section. Accordingly, springback directions of both sides become consistent decreasing the shape distortions.

2. SIMULATION OF THE U BENDING PROCESS AND SPRINGBACK PHENOMENON

The simulation process consisted in two stages: the first stage for U bending simulation, where the forming of the sheet metal was modeled according to the constraints and conditions observed during some experimental tests and the second stage for springback simulation in which the sheet metal was released from all the constraints of the prior stage allowing it to undergo all the shape changes.

The simulation of U bending operation used an explicit finite element method while springback was simulated using an implicit integration method. The objective was to obtain a model with an accurate prediction of springback intensity, stress and strain state at the end of the forming process.

Springback parameters that were observed during the analysis are presented in figure 1: sidewall radius ρ, bottom angle θ_1, flange angle θ_2.

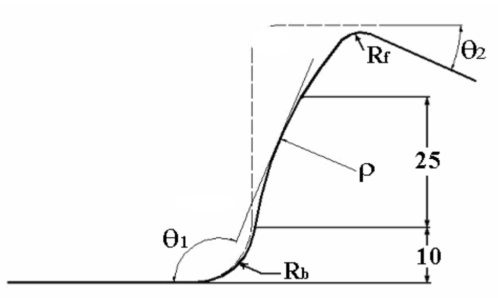


Figure 1. Springback parameters

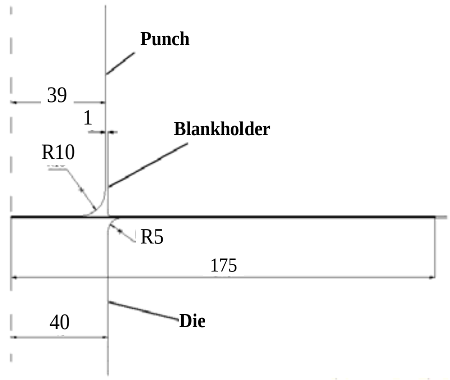


Figure 2. Geometry of the model

A plane strain state was considered for the simulation of the process. Because the part is symmetric only half of the assembly was modeled. The geometrical model and tools dimensions are presented in figure 2. The initial dimensions of the sheet metal are 350 mm length, 30 mm width and 0.8 mm thick. The sheet was considered deformable body and the model used shell elements (S4R) on one row with 5 integration points through the thickness. The tools (punch, die and blankholder) were modeled as rigid because of the advantage of reduced calculus efforts and a good contact behavior.

The material, a mild steel, was modeled as elasto-plastic, where elasticity is considered isotropic and plasticity was modeled as anisotropic using Hill quadratic anisotropic yield criterion. For contact conditions a modified Coulomb friction law combined with penalty method was used.

During this study the blankholder force had a variation between 35kN and 200kN.

3. SIMULATION RESULTS

The variation of the blankholder force value had an important impact over the intensity of springback. The profiles of the parts resulted from the simulations with finite element are presented in figure 3. The increasing values of the force lead to shapes closer to theoretical profile of the part.

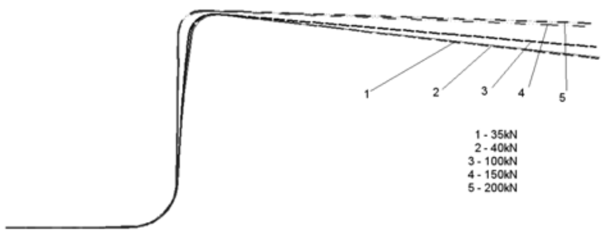
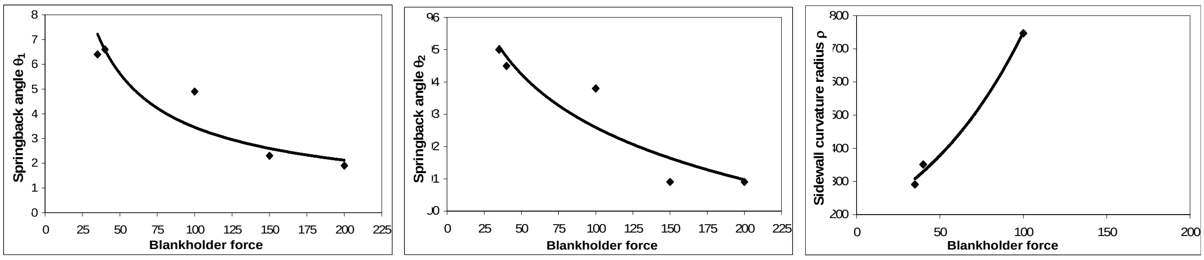


Figure 3. Variation of part shape due to springback for different blankholder force values



a. Variation of bottom angle θ_1 *b. Variation of flange angle* θ_2 *c. Variation of sidewall radius* ρ

Figure 4. Variation of springback parameters

Table 1. The values for springback parameters.

Blankholder force (kN)	Bottom angle θ_1 (deg)	Flange angle θ_2 (deg)	Sidewall radius ρ (mm)
200	1.9	91.12	–
150	2.3	92.3	–
100	4.9	93.8	747
40	6.6	94.5	351
35	6.4	95	291

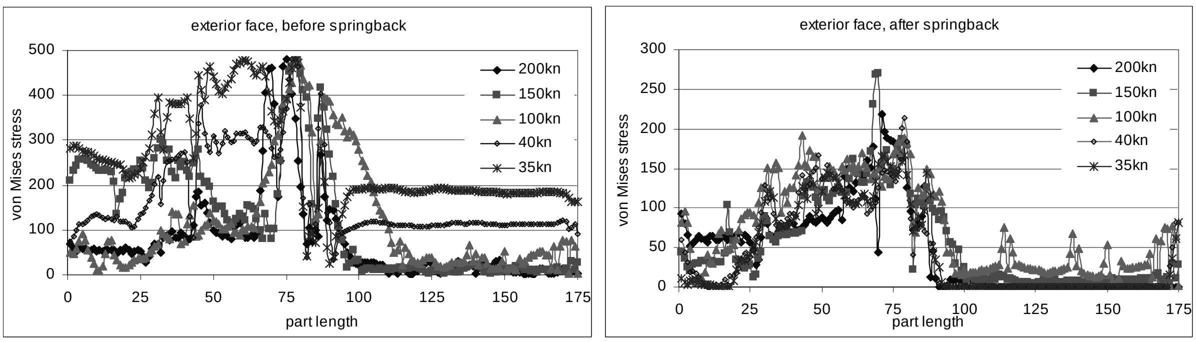
The variation of springback parameters determined by the increasing blankholder force is presented in figure 4 and in table 1.

The effects of the increasing blankholder force values on springback parameters are the following:

- the decrease of flange angle from 6.6^o for the force of 35kN to1.9^o for the force of 200kN;
- the decrease of bottom angle from 95^o when the blankholder force was 35kN to 90.9^o for the force equal to 200kN;
- the increase of the sidewall curvature from 291mm for the force 35kN to a straight wall when the blankholder force is 200kN.

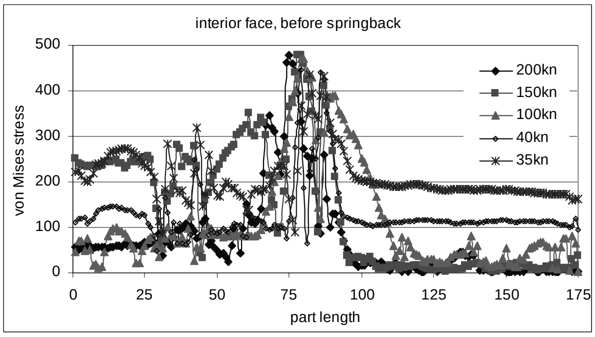
The variation of the springback parameters can be explained by the modification of stress and strain state of the material depending on blankholder force values. The evolution of these states is illustrated in the graphics from the following figures:

- the evolution of the equivalent stress states on the exterior surface of the part depending on blankholder force is presented in figure 5. The increase of blankholder force determines, prior to springback, a decreasing of the stress level along the part excepting the zone where the material is bended over of die profile radius. After springback, the stress level is higher on the bottom of the part for the bigger forces;

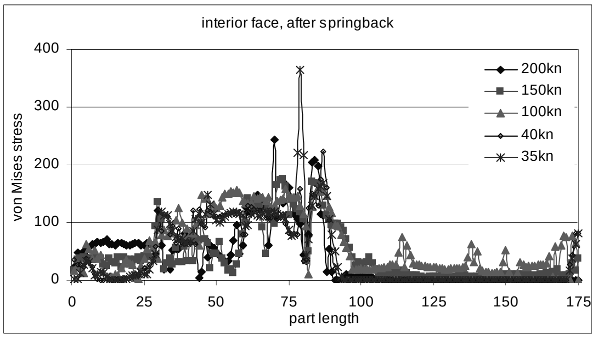


a. Stress state on the exterior surface of the part before springback *b. Stress state on the exterior surface of the part after springback*

Figure 5. Residual stress on the exterior surface



a. Stress state on the interior surface of the part before springback



b. Stress state on the interior surface of the part after springback

Figure 6. Residual stress on the interior surface

- in figure 6 the stresses on the interior surface of the part are represented, before and after springback, as function of blankholder force. Before springback, an increase of the blankholder force generates a decrease of the stresses, excepting the die profile radius region. After springback, the stresses on the bottom region are higher for the bigger forces;

4. CONCLUSIONS

The paper presents a study concerning the relationship between the residual stress and springback in the case of U bended sheet metal parts. Finite element method was used in this research for the simulation of the forming process and springback phenomenon.

The main factor of influence studied was blankholder force. The finite element analysis concluded that the increase of blankholder force values from 35 kN to 200 kN leads to the reduction of the stress levels on both faces of the part and this was reflected in a lower value of springback parameters. Utilization of high blankholder forces in U bending blocks the flow of the material into the die cavity, leading to the elimination of the differences between the stress states on the two faces of the part, especially in the sidewall region, with positive consequences on the reduction of springback parameters.

5. REFERENCES

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