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Spring back prediction of deep drawing steel used in 60 and 90 degree V-bending

Peter Mulidrán[1], Emil Spišák[1]
[1]*Institute of Technology and Material Engineering,*
Faculty of Mechanical Engineering, Technical University of Košice, Košice, Slovakia

ABSTRACT

The springback of sheet metal parts is negative effect which occurs after the bending operation. Bend parts undergo deformation, which consists of elastic and plastic deformation. The springback effect is related to elastic deformation, which is governed by strain recovery of material after the load removal. The springback effect can be reduced by changing process conditions or by changing the geometry of forming tool. In bending operations it is possible to use the calibration force to minimize the springback effect.

In this contribution, the deep-drawing steel DC06 was used to study the effect of calibration force on the springback reduction of V – shaped part with 60 and 90 degree bending angle. To verify the test results, numerical simulations were conducted. In the numerical simulation, the yield criterion Hill48 was used in combination with Ludwik hardening law. Achieved data from numerical simulation were compared with experimental test results and the impact of calibration force on the springback reduction was evaluated.

Keywords *– V-bending, springback prediction, calibration force, springback reduction*

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I. INTRODUCTION

Deep drawing steels have been used in the automotive industry for the production of complex shaped parts where high values of strain are present for over three decades. The use of these steels can reduce material waste (stamping failures) and allow to design more complex shapes of car body parts such as hoods, fenders, tailgates etc.. The main advantage of these steels is high value of elongation, up to 60 %. The main disadvantages of the deep drawing steels compared to the mild steels are higher price and lower strength values (yield strength and tensile strength).

The bending process is one of the most used sheet forming operations and it represents plastic deformation of the material when the bending moment is applied. To achieve accurate parts produced by bending operation it is necessary to take into account specific properties of the sheet material, i.e., Young's modulus, yield stress, ratio of yield stress to ultimate tensile stress, and microstructure of the material [1-3].Springback involves small strains, similar in magnitude to other elastic deformation of metals. As such, it was formerly considered a simple phenomenon relative to the large-strain deformation required for forming. Nonetheless, appreciation for the subtleties of springback in two areas has grown dramatically. In particular, high precision is needed for the large strain plastic response that directly affects the stresses in the body before removal of external forces. The unloading, while nominally linear elastic for most cases, it can show remarkable departures from an ideal linear law [4-10]. The most common measure against the springback of the stamped parts is to design the forming tool in such a way that its geometry compensates for the springback. The other way for dealing with springback is to change process conditions to achieve springback reduction. The most common measure against the springback of the stamped parts is to design the forming tool in such a way that its geometry compensates for the springback. The other way for dealing with springback is to change process conditions to achieve springback reduction.

Lawanwong et al. [11] proposed a novel technology called "double-action bending" to eliminate springback of the stamped part made of advanced high-strength steel. They used FE analysis to determine process and tool parameters before the experiment try-out. Slota et al. [12] performed a numerical and experimental study in which the impact of the process parameters on the springback was studied. They found that higher values of blankholder force in combination with greater friction coefficient decrease the amount of springback of the hat-shaped part. Mulidrán et al. [13] studied the effect of counter pressure on the springback reduction of U-shaped part made of dual-phase steel. The use of counter pressure helped with the springback reduction. Cui et al. [14] proposed a new stamping method for forming the L-shaped part. They call this method an electromagnetic-assisted stamping (EMAS). They used a magnetic force to control the springback phenomenon. The results showed that as discharge voltage increases, the bent angle after springback decreases. Therefore, research related to the springback phenomenon which is oriented on process parameters can significantly help with the reduction or elimination of the springback which appears after the bending process.

In this contribution, the influence of calibration force which is applied at the ending of the bending process on the springback of V-shaped part was investigated. The yield criterion Hill48 in combination with Ludwik hardening law was used in the numerical simulation of V-bending of DC06 steel. The springback data achieved from these simulations were compared and analyzed with the experimental test results.

II. PROCESS CONDITIONS, MATERIAL PROPERTIES AND TOOL DESIGN

In this study, the influence of calibration force on the springback reduction was studied. The springback prediction results of V – Shaped part made of deep drawing steel DC06 achieved with use of the numerical simulation were evaluated and compared with experimental test results. In the FE analysis it is important to input correct process, geometrical, numerical and material variables to achieve precise predictions regarding the forming process [10]. The Hill48 model in combination with Ludwik hardening model was used for springback evaluation using the CAE software. The sheet thickness of the DC06 steel was 0.85 mm. The material properties measured in rolling direction of the used steel are shown in Table 1. The bending experiments were conducted on hydraulic press ZD-40. This device consists of a tensometer which was used to measure applied force. The Control unit of ZD-40 collected force data, which were then transferred to PC and later processed in Excel. Fig. 1 shows a bending tool with 90 degree working angle (left) and its dimensions (right) for the experimental testing.

The bending angle, angle of working surfaces of a bending tool was 90 and 60 degrees. The blank used for bending had a rectangular shape with dimensions of 90 mm x 40 mm. These specimens were cut 0° to the rolling direction. The thickness of the blank was 0.85 mm. Blanks were prepared using hydraulic shears LVD CS6/31. Three values of the calibration force which affect springback were experimentally tested and evaluated:

- Calibration force F_1 [N]
- Calibration force F_2 [N]
- Calibration force F_3 [N]

Table 1 Mechanical properties of DC06 steel

Material	**Yield strength σ_y [MPa]**	**Tensile strength σ_u [MPa]**	**Young´s modulus E [GPa]**	**Total elongation A_{80} [%]**	**Strain hardening exponent n [-]**	**Planar anisotropy coefficient R [-]**	**Poisson´s ratio V [-]**
DC06	145	292	195	50.8	0.261	1.888	0,3

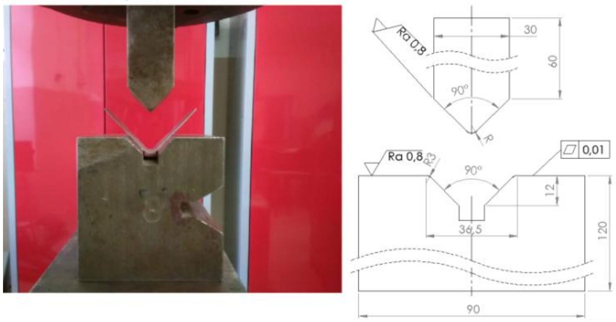

Fig. 1 Bending tool with 90 degree working angle used in the experiment: bending tool (left), general dimensions and schematic of the bending tool (right)

The calibration force values were determined during experimental testing. The lowest value F_1 represents bending without calibration. The second value F_2 was approximately 2 times the bending force value. The third value F_3 of the calibration force app. 4 times the bending force was chosen. The values of calibration forces are shown in Table 2. For each variable, five specimens were used in the testing. The impacts of these three variables on the springback are evaluated in the Results section.

The accuracy of the numerical simulation was set to fine. With this setting, program automatically generates mesh parameters for the tool. The triangular, shell elements were used in numerical simulations. The element size e_s: 0.8 was used in the numerical simulation. The value of time of step was t_s= 1.6 s. Other numerical parameters were constant, such as radius penetration was set to 0.16 and number of integration points was set by software to 11. The value coefficient of friction was set to 0.27. Figure 2 shows measurement of the arm opening angle *ß* [°] (left) and CAD model of the bending tool used in the simulation (right).

Table 2 Values of calibration forces used in V-bending

Working angle of tool α [°]	Calibration force F_1 [N]	Calibration force F_2 [N]	Calibration force F_3[N]
60	270	590	1090
90	280	560	1140

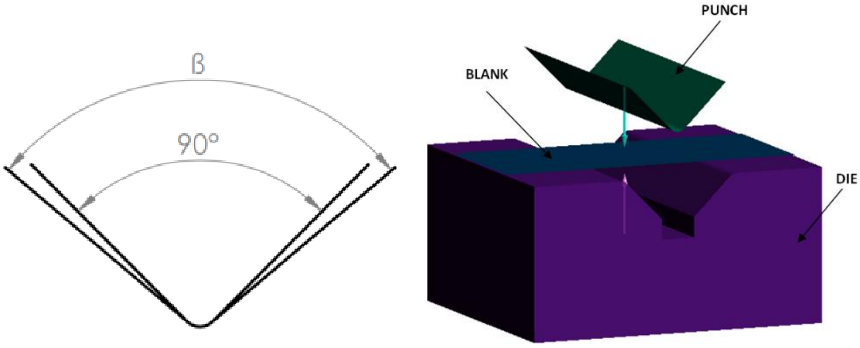

Fig. 2 Springback measurement of 90 degree V-shaped stamping(left), CAD model of bending tool with 90 degree working angle used in the simulation (right)

III. EXPERIMENTAL AND SIMULATION RESULTS

In this current study, the influence of calibration force on the springback of V – shaped part made of RAK 40/70 steel was studied. The experimental results were compared with simulation results and evaluated. For evaluation of the springback of the formed part, opening angle of arm *ß* was measured in cross section after springback calculation. The results of measured arm opening angles are shown in Tab. 3.

The experimental results showed correlation between calibration force F and arm opening angle *ß*. The same correlation was achieved in springback predictions with the use of FE analysis. The lowest springback, deviation between working angle of tool α and arm opening angle *ß* was measured when the highest value of calibration force F_3 was used in bending experiments; this applies for both tools with working angles 60 and 90 degrees respectively.

The simulation results regarding arm opening angle *ß* are shown in Table 4. These results showed good correlation with experimental results. The accuracy of the numerical prediction, the highest deviation between experimental and predicted angle *ß* was 6.4 °. This deviation was measured for 60° V-bending operation when the value of calibration force F_2 was applied.

Table 3 Experimental results of Arm opening angle ß [°]

Working angle of tool α [°]	Arm opening angle ß when force F_1 was applied [°]	Arm opening angle ß when force F_2 was applied [°]	Arm opening angle ß when force F_3 was applied [°]
60	66.1	55.8	54.8
90	91.2	89.5	87.4

Table 4 Simulation results of Arm opening angle ß [°]

Working angle of tool α [°]	Arm opening angle ß when force F_1 was applied [°]	Arm opening angle ß when force F_2 was applied [°]	Arm opening angle ß when force F_3 was applied [°]
60	68.2	62.4	57.5
90	93.4	92.1	86.3

IV. CONCLUSION

The springback prediction accuracy and springback reduction are the most challenging problems in forming processes. In the presented article, the influence of calibration force on the springback of V-shaped part made of DC06 steel was investigated. The higher values of calibration force F_3 showed lower values of arm opening angle, thus reducing springback effect. The reason for it is greater plastic deformation of the material in the bending radius region. With the increase of plastic deformation, the impact of elastic deformation is less prominent, thus reducing the springback of the formed part. Based on the experimental and numerical results, the following outputs can be stated:

- Significant reduction in value of arm opening angle β was achieved with the use of the calibration force F_3.
- Data achieved from experiments can be used in stamping V-shaped parts in industrial practice.
- The springback prediction of the V- shaped was less accurate, than anticipated. The reason for it can be explained by the use of isotropic hardening model.

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