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Residual stresses and springback reduction in U-channel drawing of Al5182-O by using a servo press and a servo hydraulic cushion

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Abstract. The increasing use of Al alloys in automotive industry brings new challenges regarding formability and springback. Servo presses and servo hydraulic cushions can accurately control ram motion and blank holder force during the forming process, reducing the difficulties encountered in forming Al alloys. This study presents an experimental and numerical analysis of springback and residual stresses induced during the U-channel drawing of Al 5182-0. During the U-channel drawing the draw-in of the sheet material into the die cavity is controlled by blank holder force. So, the material is under stretch bending condition when it slides around the die corner radius. When the material passes the die corner radius it unbends and becomes straight. The reverse loading resulted from the unbending process provides heterogeneous stress distribution through the sheet thickness in the wall section. The effect of post stretching, applied by the use of a servo hydraulic cushion, on residual stresses at the wall and springback is investigated. The benefit of using servo hydraulic cushion for reducing springback and residual stresses has been demonstrated experimentally. Results illustrate a significant reduction of residual stresses and springback when post stretching is applied.

1. Introduction

In sheet metal forming, elastic recovery after deformation and tool removal, known as springback, affects dimensional accuracy and geometric tolerances. To develop lighter vehicles, designers are turning toward new materials with higher strength than traditional steels. Springback is a stress driven phenomena and therefore, the issues caused by springback are more significant in parts made from high strength materials. Due to strict geometric tolerances and the need to reduce time to market, accurate prediction and control/reduction of springback is essential.

During the past decade, springback predictions have been conducted using numerical solutions and Finite Element (FE) methods. The accuracy of the prediction result is affected by several parameters such as material properties, material model, Coefficient of Friction (COF), numerical procedures, and element type and size. In terms of material properties, flow stress data of sheet material and E-modulus are two most important properties affecting the prediction of springback. Regarding to material model, plastic constitutive equations [1,2] and degradation of unloading elastic modulus [3,4] significantly affect the simulation results. The influence of COF on springback is also investigated by several researchers [5,6].

In addition to the parameters mentioned above, there are some other phenomena which can significantly affect the springback of the part in an industrial stamping operation. Owing to their complexity, it is practically impossible to consider these parameters in simulation. Examples of such phenomena are elastic deflection of tools and presses during the forming process [7] or the inertia and response time of the machine.

Regarding control and reduction of springback, in general, there are two practical ways [8]:

a) Obtain the final part within geometric tolerances after compensating for springback by altering the geometry of tooling
b) Applying additional stretch/tension forces to the part during the forming operation

Tooling geometry compensation is based on simulated prediction of springback as well as trial and error [9]. Effects of additional tension on reduction of springback has been shown both experimentally and numerically [10,11]. Sidewall curl springback produced from drawing process (process where the draw-in of the sheet material into die cavity is controlled by blank holder and material is under stretch force during the deformation) causes assembly difficulties and the post stretching method has been used to reduce the side wall curl. In this method, the sheet material undergoes extra stretching toward the end of deformation. This extra tension reduces the heterogeneous distribution of stresses through the sheet thickness at the wall area and consequently reduces springback and residual stresses.

To reduce the springback by post stretching there are two ways:
a) Design the tooling with drawbeads which start to contact the sheet toward the end of the deformation process
b) Use of Servo Hydraulic Cushion (SHC) to control of Blank Holder Force (BHF) during the deformation cycle and induce post stretching

In the present study, the use of SHC for reduction of springback and residual stress in a U-channel part is investigated experimentally and numerically. The effect of elastic deflection of the tools and COF on springback prediction is also considered.

2. Reduction of springback and residual stress by post-stretching – use of servo hydraulic cushion (SHC)

2.1. Servo hydraulic cushion

During the deep drawing process, the sheet material is restrained at the periphery of the BHF. Generally, the BHF is generated by pneumatic cushions, nitrogen cylinders, or hydraulic cushions. Hydraulic cushions allow for computer numerical control of the BHF by regulating the oil flow to the cushion cylinders. The main advantage of the SHC compared to other types of cushions is that the SHC allows controlling the BHF during the deformation.

2.2. Experiments

U-channel drawing of 1.2 mm Al5182-O was conducted to investigate the possibility of reduction of springback using the post stretching method by applying blank holder force (BHF) with an SHC. A 300-metric ton servo press with 100 metric-ton SHC was used. Information about the geometry and dimensions of the tooling is presented in Figure 1. The blank was rectangular with the dimensions of 720 mm × 120 mm and it was drawn to a stroke position of approximately 66 mm. Blanks were coated by a dry lubricant. Two constant blank holder forces (100 kN and 400 kN) and one variable BHF with time (100 kN to 700 kN) were used, Figure 2. The values of the BHFs are selected based on simulation predictions to avoid excessive thinning in the part. For the case of variable BHF, deformation starts with constant 100 kN BHF and then at stroke of 60 mm the BHF starts to raise up and reach to 700 kN at stroke of 65 mm. The variable BHF is selected to provide the post stretching condition for reduction of springback. Three replications were considered to ensure repeatability of the results.

During the test, the blank holder and the die displacements were recorded. This information was used to determine the exact final stroke and elastic deflection of the tools for each BHF.

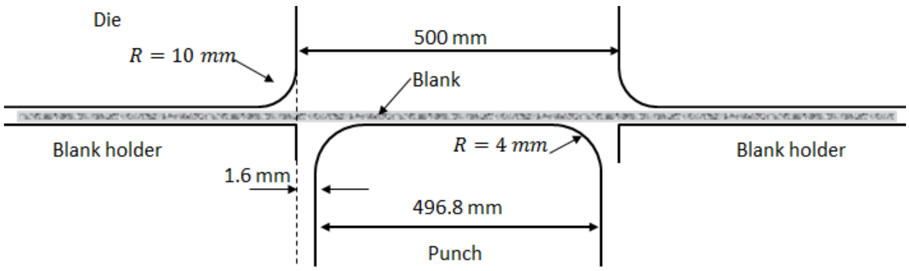

Figure 1. A schematic of tools and dimensions for the U-draw bending.

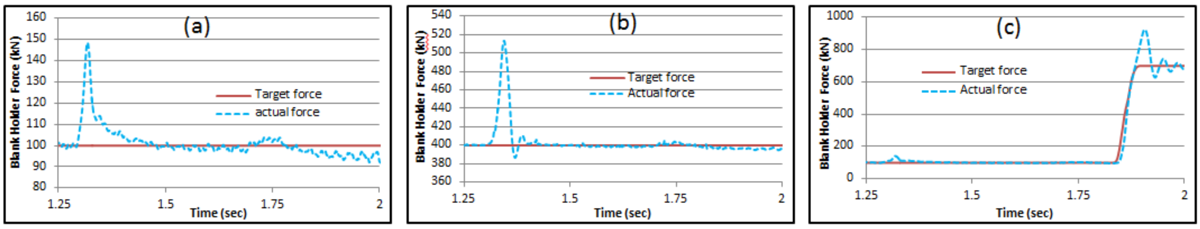

Figure 2. Three different BHFs used in the tests. (a) constant 100 kN, (b) constant 400 kN, (c) variable 100 to 700 kN. The solid lines show the target force and the dashed lines indicate the actual force applied by the cushion.

2.3. FE simulation

3-D FE simulation of the U-channel drawing process was developed using the AutoForm software package. The blank was created using shell elements and tools were modelled using rigid analytical surfaces. The flow stress of the material was determined from a tensile test and the true stress- true strain data was used directly in simulations. An E-modulus of 70 GPa was used as an initial estimate. By comparing the springback prediction and experimental measurement, the E-modulus was adjusted until the predicted springback matched measurements. An apparent E-modulus of 85 GPa, was used for the case of 100 kN BHF and 70 GPa for 400 kN and variable BHF. To determine the COF for each testing condition, flange length of the part was measured. Then simulations with different values of COF were conducted and the value of the COF that predicted a similar flange length to the measured value was assumed to be the COF for that test condition. For each testing condition (BHF value), the simulation was stopped at the exact forming stroke similar to the experiment and springback was predicted.

2.4. Results and discussion

Figure 3 shows the profiles of the parts obtained from the experiments and the simulations. As shown in this figure, there is a large side wall curl in the part for both constant 100 kN and 400 kN BHFs. The side wall curl is significantly reduced with the variable BHF (post stretching method). The predicted stress distribution along the sheet thickness at the wall area is shown in Figure 4, for the cases of constant 100 kN and variable BHFs. In the case of variable BHF all the compression stresses on the wall are converted to tension. The results clearly describe how the post stretching method reduces the heterogeneous stress distribution at the wall area, leading to a reduction of the residual stresses and springback.

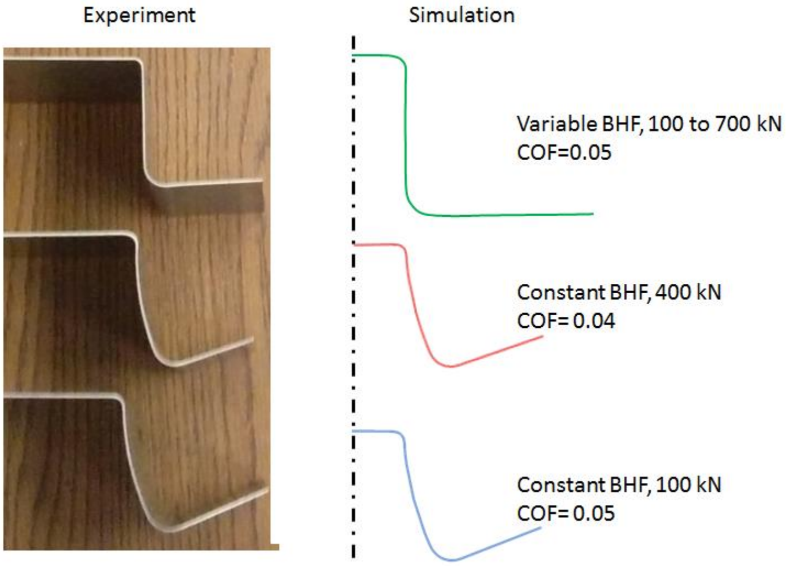

Figure 3. Experimental results and simulation predictions of springback for 3 different BHF values

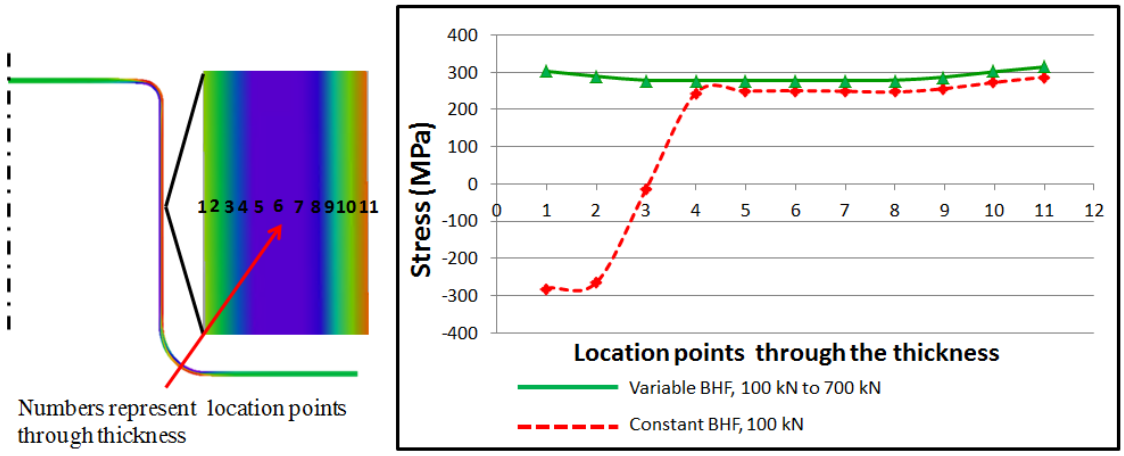

Figure 4. Stress distribution along the sheet thickness at wall area for two different BHF values

As illustrated in Figure 5 residual stresses, through the sheet thickness at the wall, are significantly reduced by applying post stretching. Lower residual stresses can provide higher load carrying capacity and increase the fatigue strength of the formed part.

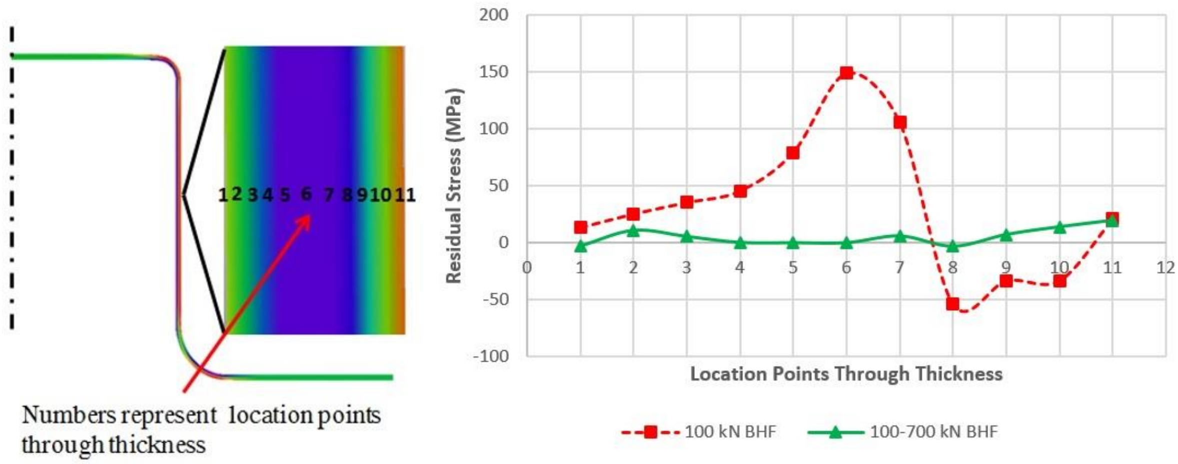

Figure 5. Residual stress distribution along the sheet thickness

3. Effect of coefficient of friction on springback prediction

The effect of the COF on simulation results is more significant for higher Blank holder forces. The COF calculated for the 400 kN BHF used in this study was about 0.04. This value is calculated by comparing the flange length in simulation and experiment. However, to investigate the effect of BHF on springback, additional simulation with higher COF were also conducted. Results show that with 400 kN BHF, failure results if the COF is higher than 0.07. Figure 6 shows the springback prediction for two different COFs, 0.04 and 0.07, compared to the experimental measurement.

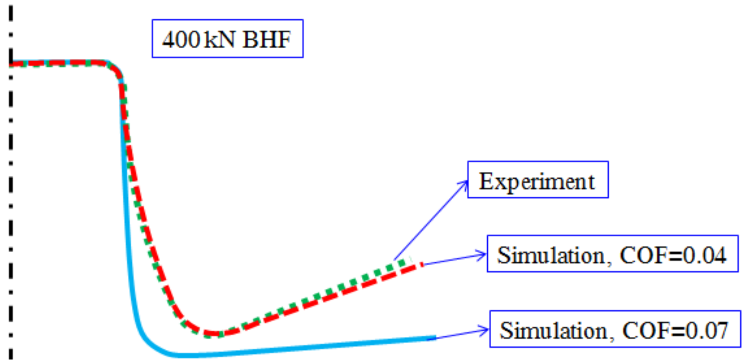

Figure 6. Effect of COF on springback prediction

4. Elastic deflection of the tools

The die displacement was continuously measured during the experiment to accurately determine the elastic deflection of the tools and the final stroke at each testing condition (BHFs). Figure 7 shows the profile of the die motion (ram motion) versus time and the magnified view close to bottom dead centre. Using the servo press provides the capability to significantly reduce the die speed when it starts to touch the sheet material to avoid the shock. After the soft touch the speed increases immediately to avoid increasing the forming cycle time. Results show that the total die displacement was not same in all testing conditions and the BHF affects the amount of die displacement. The die displacement is reduced by increasing the BHF. The die displacement, in the case of variable BHF where the maximum BHF close to the bottom dead center reached 700 kN, was about 0.5 mm less than the die displacement when 100 kN constant BHF was used.

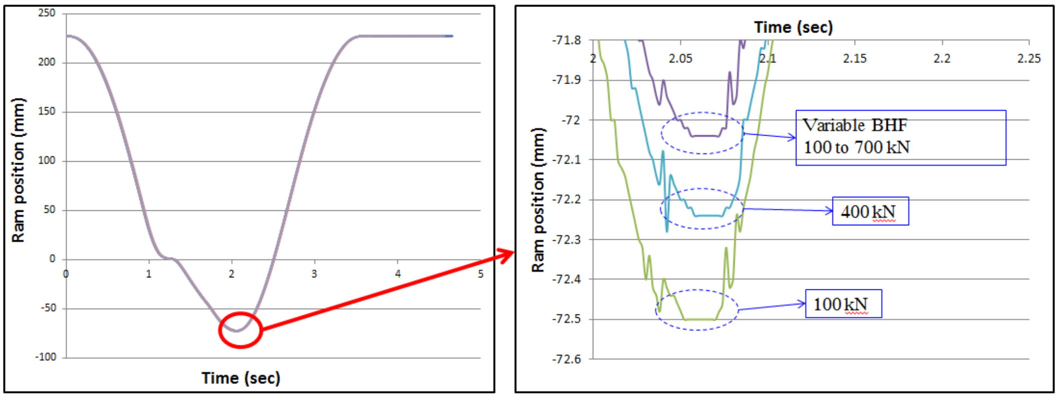

Figure 7. Measured die displacement versus time for three different BHFs.

5. Conclusions

Results of this study indicate that the side wall curl in drawn aluminium parts can be significant. Servo hydraulic cushion provides the capability to control the BHF through the die stroke and springback can be controlled significantly by applying the post stretching method. There are some limitations and the actual BHF is not always the same as the input values given to the controller of the SHC. Some parameters such as the forming speed, the range of BHF variation, the size of the cushion, and the speed of the closing and opening of the hydraulic valves can affect the accuracy of the actual force, compared to the input or target value.

Coefficient of friction is an important parameter that significantly affects the springback prediction. Also, elastic deflection of the tools can affect the test conditions. The elastic deflection of the tools is more critical when forming with a higher blank holder force.

6. Acknowledgement

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