Accurate prediction of springback after coining operation

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Abstract. A common approach used to reduce springback in flanging operations is to apply additional coining around the bent regions. In this strategy, the sheet metal part is compressed between two rigid dies having a clearance less than the sheet thickness. The aim is to bring additional compressive stresses especially around bending dominated regions. These stresses are slightly larger than the current yield stress of the material. By this way, the dominant bending stress state is reduced leading to less springback. The shell elements which are the state of the art in productive utilization of finite element simulations lack the ability to consider normal deformation which occurs during coining. Hence, it is not possible for process planners to decide on the degree of coining and to predict the springback results beforehand. In order to address this problem a set of experiments were performed, whereby deep drawn cups were coined around the punch radius region and cup bottom. To investigate the changed state of residual stresses, drawn cups were cut into halves and springback was measured. The same procedure was also simulated with the new thick shell elements which are improved to incorporate the normal stresses in thickness direction. It was seen that, by the help of this enhancement, the springback prediction is improved as compared to the conventional shell elements.

1. Introduction

One of the causes of springback in stamping operations is the bending moment which occurs around the bending radius after unloading. Bending may occur in drawing operations or in another flanging operation. In order to reduce the bending effects, an additional coining can be used in the bent regions. Such an operation can be performed in the forming operation itself or in an additional operation which is specifically designed for coining. Calibraton or re-strike are other common terms used for such an additional operation.

In coining, the material in and around the bending radius is compressed between two rigid tools having a clearance less than the current sheet thickness [1]. This superimposes an additional compression in the bending zones reducing the bending effect [2,3]. Applied forces are high enough to go beyond the elastic limit. Applied forces in the normal direction of the sheet create also the main challenge regarding the numerical analysis of such processes. Conventional shell element formulation cannot handle the through-thickness stresses. For that reason, 3D (solid) or 2D (plane strain) continuum elements were used to analyze the effect of coining on springback [4,5]. However, this solution is mostly not feasible for industrial applications due to high computational times. Analytical
works are also generally limited with simple V-bending problems [6,7]. Hence, there is a need for improvements in the shell element formulation to offer an effective solution for numerical modelling of industrially relevant stamping products.

In order to investigate the effect of coining, deep drawing experiments were performed, in which an axisymmetric cup was formed. The cups were then coined in two distinct regions: on the cup bottom or in punch radius. Coined and not coined cups were cut along the rolling direction to measure the springback. Same procedure was also simulated using new thick shell elements and the results were compared.

2. Experimental work

2.1. Material characterization

The sheet material used in this study was a C67S+LC with 1.0 mm thickness. This alloy is a cold rolled spring steel which can be easily formed. In addition, the microstructure of the material suits itself for heat treatments. After forming, the strength can be increased to 1600 MPa by heat treatment. Main application fields are clutches and bearings.

In order to obtain parameters for the finite element simulations, the sheet material was characterized by using uniaxial tension tests (0°, 45°, 90°), hydraulic bulge tests and disc compression tests. The results can be seen in Figure 1. Flow curve was obtained by combining uniaxial tension test data and bulge test data. Additionally the flow curve was extrapolated. Anisotropic material behavior was characterized by obtaining yield stresses and corresponding r-values from the performed experiments. The planar anisotropy Δr of the material was found to be 0.07, which would mean that nearly no earing is expected during deep drawing.

![Flow curve and yield locus of C67S+LC](image)

**Figure 1.** Flow curve and yield locus of C67S+LC

2.2. Coining experiments

All of the forming tests were performed on the sheet metal testing machine Erichsen-145-60. The punch diameter used both in drawing and coining experiments was 33 mm. Blank diameter was 64 mm. For the deep drawing experiments, two different tool clearances were used, namely 1.18 mm and 1.48 mm.
After deep drawing the cups are coined using two different strategies as presented in Figure 2. In the first method, only the radius of the cups was coined locally by using a conical tool. In this method a line contact is governed between the angled tool surface and cup radius. The cups were pressed against this tool by using a maximum punch force of 200 kN. In the second strategy, deep drawn cups were pressed against a flat tool. In this case, the coined region is a ring with a width of 1.5 mm as shown in the figure. The same coining force was set in those experiments.

![Figure 2. Conical and flat coining tools](image)

Formed cups can be seen in Figure 3. Different coining strategies lead to different geometries of the cups. After deep drawing the bottom of the cups are found to be flat. In the case of flat coining tools, the bottom of the cups has a concave form. The bottom of the cup was pressed into the centric punch cavity. The concave form is due to the fact that the material flows from the outer coined regions to the center of the cup. As a result of the conical tool, the bottom of the cup has a convex form. In this case the bottom of the cups bulges outwards due to the material flow from the radius to the center.

![Figure 3. Deep drawn and coined cups. Arrows showing the coined regions.](image)

After forming and coining operations, the cups were cut along the rolling direction. Geometries of the cups were measured by optical measurement systems before and after cutting. By this way the springback after cutting and the effect of coining on springback was captured.
3. Finite element simulations

Deep drawing and coining operations were modelled by using new thick shell elements having an enhanced formulation. The formulation accounts for the through-thickness stresses. A homogeneous mesh consisting of elements having a 1 mm side length was used in all simulations. The sheet material was modelled by using the BBC model (BBC2005).

Experimentally measured maximum punch forces are used in the simulations as coining forces. Figure 4 shows the experimentally and numerically obtained thicknesses before and after coining steps. In the case of flat tools, the thickness in the coined area was reduced by 0.07 mm both in the simulations and experiments which corresponds to a coining level of 7.2 %. The results are the same for both drawing clearances. In the case of the conical tool, plotted thicknesses were measured in the radius where coining takes place. Hereby, the thickness change is more severe as compared to flat tools. This is mainly due to the line contact which increases the local contact pressures causing more deformation. In this case, the thickness change is found to be 0.22 mm which results in a coining level of 23 %. As in the case of flat tools, the drawing clearance does not have a significant effect on the change of thickness during coining. The maximum difference between numerical and experimental results is less than 3.5 %.

![Figure 4. Thicknesses in coining zones before and after coining at a given force value](image-url)
Results of the springback analysis can be seen in Figure 5. Springback in those diagrams is defined as the change of radius of curvature after cutting. Radii of curvatures were measured at four horizontal sections shown in Figure 6, each having 5 mm vertical distance between them. The first section was selected at a height level which is 1.5 mm higher than the radius region. Experimental results show that the springback increases from the bottom of the cup to the ends. This is mainly due the geometrical stiffness of the bottom region. It is also seen that the case with the conical tools have less springback as compared to flat tools. The cases with the larger tool clearance have slightly larger springback values with a maximum difference of 0.1 mm.

The same problem was simulated by using conventional shell elements and new thick shell elements which consider the thickness stresses. Just like the experiments, deep drawn and coined cups were cut along the rolling direction and a springback step was calculated. It is seen that the enhanced formulation can predict the effect of coining on springback behaviour. Springback values obtained by conventional shell elements are in each case lower than the experimental measurements. This effect is more visible with larger drawing clearances. The maximum difference between the both element formulations is seen in the case of flat tools and larger clearances. In this case, the inward bulging of the bottom and material flow to the cup wall have a larger effect on the springback of the cup.

![Figure 5: Measured and simulated springback values. Springback defined as change in radius of curvature after cutting the cups](image)

4. **Conclusion**

Finite element simulation of coining process is currently neglected in process design of stamping applications. The main reason for that is the difficulty of modelling the thickness stresses. Shell elements which are widely used by process engineers are conventionally not capable of modelling the effect of applied stresses in thickness direction. On the other hand, coining is applied widely in stamping operations in order to reduce the springback. During or after flanging operations, bent
regions are plastified by using tools having clearances smaller than the material thickness. For that purpose, new thick shell element formulation was used in this study to predict the effect of coining. The study reveals the importance of the design of the coining operation which should be considered by the stamping engineers. The location and amount of coining have a direct effect on the geometry and springback of the final parts, which may lead to more springback if poorly designed. The thickness measurements and the springback values predicted by the enhanced elements are in good agreement with the experimental values.

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