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Effect of coining on springback behaviour

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Abstract. Especially due to utilization of high strength steels in automotive parts, accurate prediction and reduction of springback have gained more importance in the recent years. One of the widely used approaches to reduce the springback in deep drawn parts especially in and around the bent regions is coining (restrike operation). In this method, the sheet material in the springback-relevant regions is compressed between two rigid tools having clearences less than the sheet thickness. By this way, compressive stresses and strains are superimposed and therefore the bending effects are reduced. During coining, plastic deformation occurs in the thickness direction. In order to predict this behavior in process planning numerical simulations should be capable of considering the effects of through-thickness compression. In order to analyze this effect, axisymmetrical deep drawing tests were performed. In a further step, the bottom surface or the radius region of the geometry was compressed between the punch and additional tools. To analyze the springback behaviour, drawn geometries were cut along the rolling direction, so that the residual stresses are released. The same procedure was also simulated with shell elements having enhanced formulation to account for through-thickness deformation. Experimental springback results show that the coining process influences the springback and this can be captured by the enhancements in the shell formulation.

1. Introduction

Springback compensation or reduction is a major challenge especially in workpieces made of high strength materials. Coining is a common way of reducing springback especially in stamping processes. The terms “restrike” and “calibration” are also used in the literature for that operation. In coining, workpieces are compressed between two rigid tools having a clearance lower than the current sheet thickness. This can be performed directly in the forming operation or in an additional operation designed just for coining. Coining is performed especially in and around the bent regions [1], for example in flanging. By this way a compressive stress state is generated and unwanted effects of bending moments are minimized.

Experimental works show this effect mainly by using bent stripes of sheet metal [2–4]. The main effect behind the reduction of the springback was also analyzed analytically with the outcome that that the springback due to bending is directly related to applied coining loads and bending radius [5]. In industrial applications the decision regarding the coining level is still mostly based on former experiences and less on analytical or numerical analysis. For that reason, the coining tools are manufactured with additional offset and the right coining level is tuned during the tryout phase which costs extra time and money. The main reason behind this is the limitation of the conventional shell elements which are widely used in finite element simulations of stamping processes. Conventional shell element formulations do not consider the thickness stresses.

Therefore, accurate simulation of the through thickness deformation has been a main concern regarding numerical analysis of coining processes [6,7]. Utilization of solid elements is not a feasible solution for industrial applications due to high computational times. In order to be able to avoid intensive tryout works regarding the coining, the only possible solution is to improve the performance of the shell element formulation, so that the process engineers can perform finite element simulations without additional effort.

This study focuses on the prediction of the effect of coining on the springback results of deepdrawn cups. For that purpose cylindrical cups were drawn at first. Secondly, formed cups were coined in two distinct regions: bottom of the cup and punch radius region. All the cups (coined and not coined) were cut along the rolling direction to allow for springback and the effect of coining was measured in terms of change of radius of curvature. Finally, the drawing and coining operations were simulated by using enhanced shell elements and the results were compared.

2. Experiments

2.1. Material

As material for these experiments, a C67S+LC in 1 mm sheet thickness was used. This variant of a cold rolled spring steel can be easily formed, and its microstructure is well-suited for heat treatment. Applications can be found in clutches and bearings. In the conventional use, this material is heat-treated to strength of up to 1600 MPa after it has been formed.

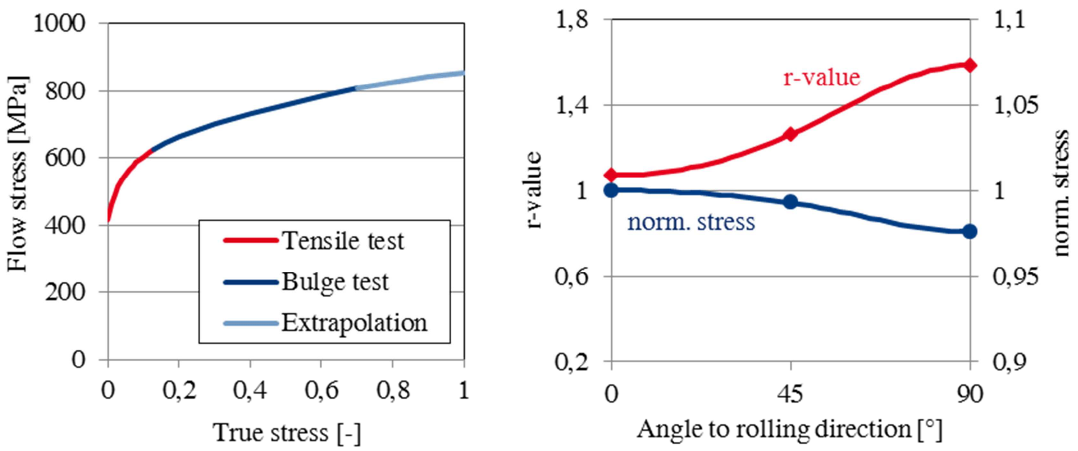

Figure 1. Material properties of C67S+LC.

In order to model the material, flow curve, yield stresses in different directions and r-values are needed. For that reason, the material was characterized with tensile tests, hydraulic bulge test and disc-compression tests. The determined flow curve is shown in Figure 1. The planar anisotropy of the material is Δr = 0.07. This means that during cup-drawing nearly no earing is to be expected.

2.2. Deep Drawing and Coining

The deep drawing and coining tests were carried out on the sheet metal testing machine Erichsen-145-60. The punch diameter is 33mm and the diameter of the blank is 64mm. For deep drawing, two different drawing clearances were used: 1.18 and 1.48mm. Drawing clearance is defined as the radial distance (gap) between punch and die (see figure 2).

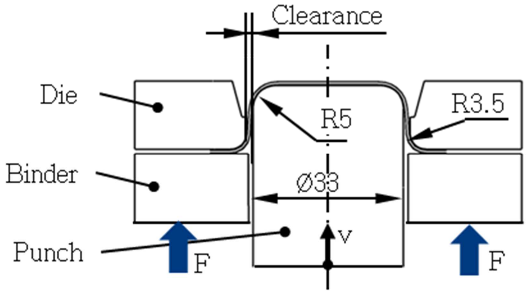

Figure 2. Tool Setup for Deep Drawing.

Two cases of coining were performed (see Figure 3) in order to analyse the effect of coining in different parts of the cup. In the first case, the cup bottom surface was pressed against a flat tool. It should be noted that the punch contains a cavity in the middle. So it is just pressed on the outer edge of the cup bottom having a ring width of 1.5 mm. In the second case, the cup was pressed against a conical die which coins the radius locally as shown in Figure 3. In this case there is only a line contact on the radius. In both variants, the punch was moved velocity controlled and stopped at a force of 200 kN.

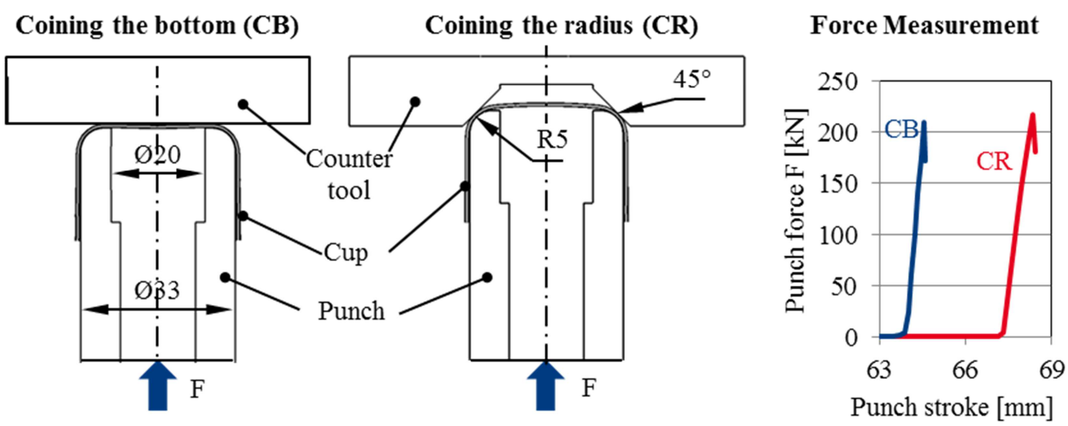

Figure 3. Coining tools and force measurements.

The deep-drawn and coined cups are shown in Figure 4. When coining is applied, the bottom of the cup changes its form. When coining the bottom surface, the inner bottom surface bulges inward, when coining the radius, the bottom surface bulges outwards. The thickness measurements on the cross-section show that the applied force was enough to plastify the coined regions locally.

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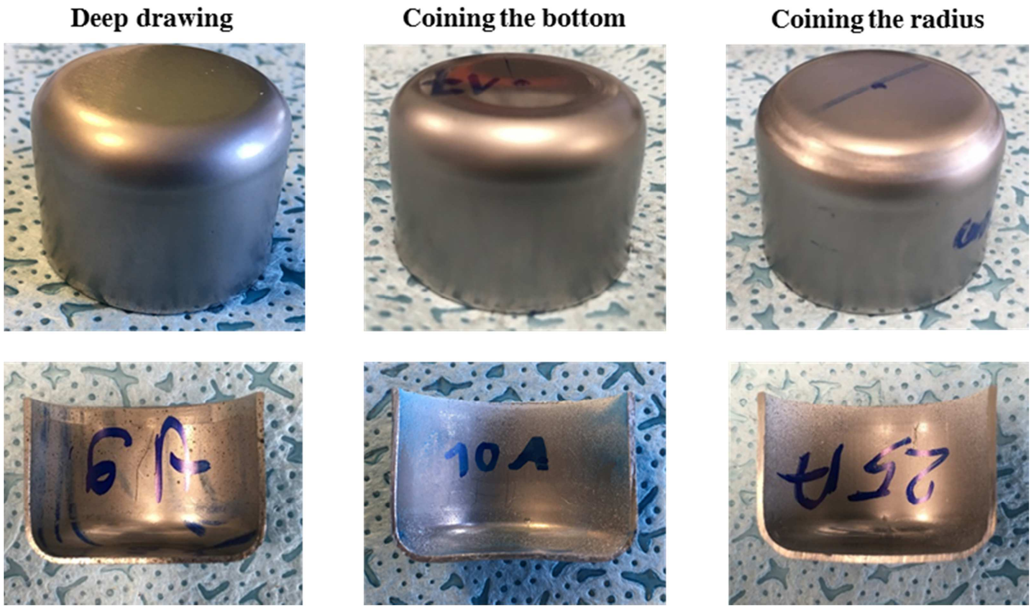

Figure 4. Cups before and after coining (deep drawing clearance 1.18mm).

After forming, the cup is cut in the middle. The cut takes place in the rolling direction. In order to measure the springback caused by the cutting, the outer sheet surface was optically measured. For this purpose, sections were generated perpendicular to the cup axis and at a distance of 5mm as shown in Figure 5.

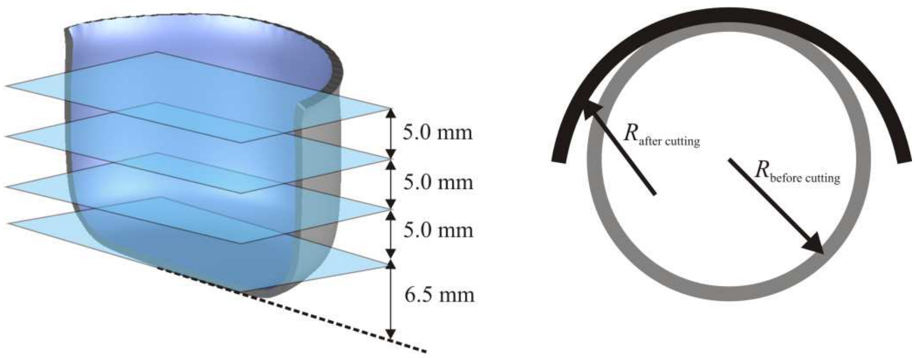

Figure 5. Measurement of springback at 4 sections.

Then the radii of curvature were determined in those sections. It was seen that the radius of the cup wall depends on the drawing clearance. With a small clearance, the radius is comparatively constant over the cup height. With a large clearance, the radius in the middle is greater than near the bottom and the edge. After cutting, the radius of curvature increases as expected. The increase is larger near the top than near the bottom (see figure 6). At those sections, springback was defined as difference between the radius of curvature before and after cutting.

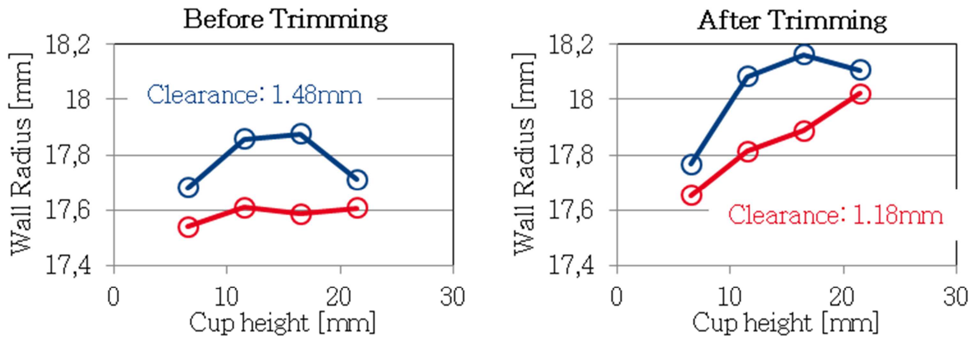

Figure 6. Example measurements (Coining the radius).

3. Numerical analysis

In order to analyze the problem numerically, a finite element model was constructed and simulated using AutoForm-Solver^{plus}. An efficient thick shell element formulation that allows taking into account through-thickness deformation of the material was implemented. Homogeneous mesh with a side length of 1 mm was used in all simulations without any adaptive refinement. The material was modeled with the BBC model (BBC 2005) [8]. The corresponding material input was defined by using the yield stresses and *r*-values under biaxial tension and uniaxial tension in 0°, 45° and 90°. A coulomb friction coefficient of 0.18 was used in all simulations.

In a first step, it was checked if the amount of coining coincides with the experiments at the same experimental force values. The results can be seen in Figure 7 for the cases coining the bottom (CB), coining the radius (CR) and after deep drawing (DD). For the case “coining the bottom” the thickness in the coined region is reduced by 0.07 mm both in simulation and experiments. For both drawing clearances the results are very similar. Numerically predicted thicknesses differ in that case with a difference less than 1 %. In the case of “coining the radius”, the thicknesses were measured in the middle of the coined radius as shown in the figure. In this case, the thickness change is more visible. Again the drawing clearance does not create a significant difference. The maximum difference between the simulations and experiments is 3.5 %. These results show that under the given force the correct amount of coining was simulated by the enhanced shell elements.

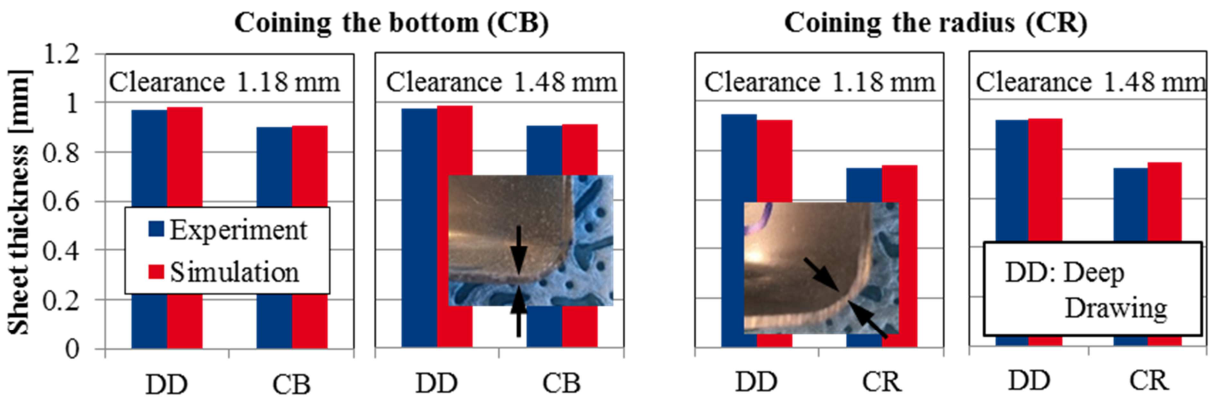

Figure 7. Sheet thickness before and after coining in the coined regions.

The results of the springback analysis can be seen in Figure 8. Upper three diagrams are showing the results for the cases with a drawing clearance of 1.18 mm. In the case of deep drawing without any coining, springback increases from the bottom of the cup to the edges almost linearly. This effect was also captured by the numerical simulations. It can be seen that the maximum change in radius of curvature is about 0.3 mm with a drawing clearance of 1.18 mm. Coining the bottom or radius region had a measurable effect on the springback results. It was seen that in both cases the maximum radius of curvature increases to an amount of 0.42 mm. Simulations also predict this increase with a high accuracy.

The increase in springback values can be explained by the fact that the coined cups have a closed geometry. Due to plastic deformation initiated at the coining regions, material flows towards the bottom (therefore bulging at the bottom) and towards the cup wall. The latter effect causes the cup edges to open more after the cutting operation. However, irregardsless of the increasing springback results, the change in springback is predicted correctly by the developed shell formulation.

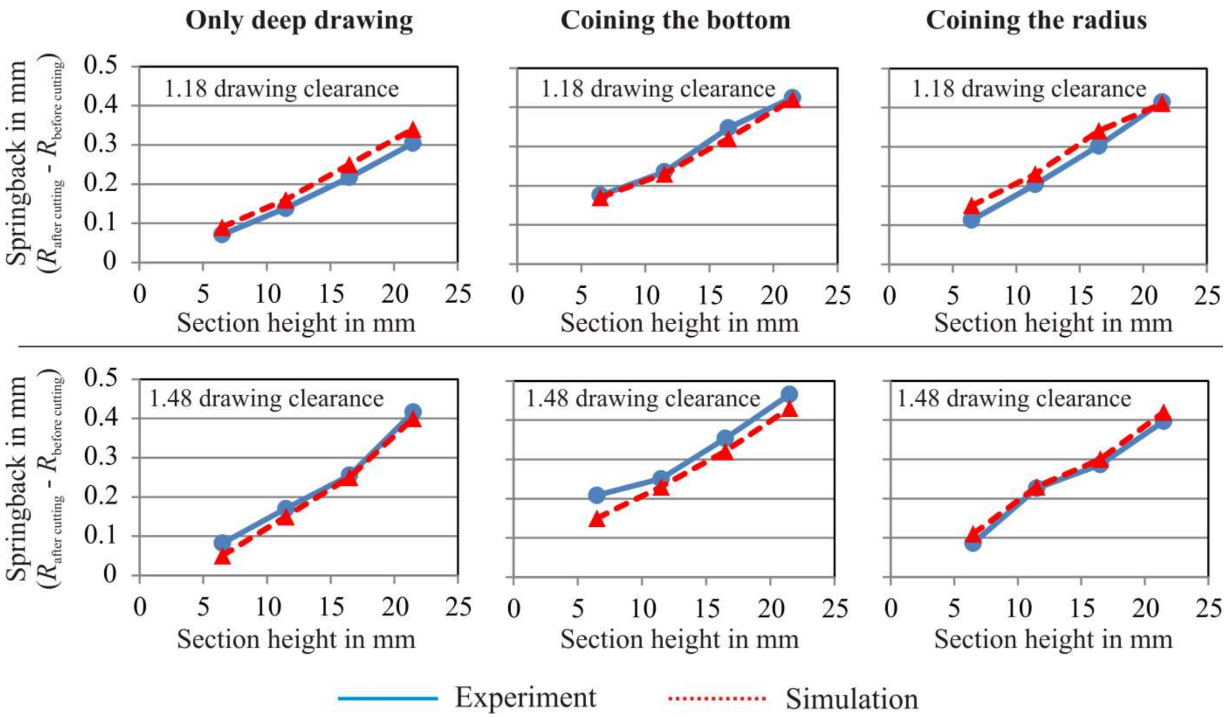

Figure 8. Springback results of all cases.

The results are also very similar in the case of drawing clearance of 1.48 mm. Again, springback is increasing almost linearly after deep drawing towards the edge of the cups. Due to coining, measured springback values increases. Overall, it can be seen that the experimentally measured effect on the cup springback behavior can be analyzed by the help of the improvements in the shell formulation.

4. Conclusion

Although coining is widely used in order to control the springback behavior, it is still a challenge regarding the finite element simulations, mainly due to through-thickness stresses. In order to address this problem, coining experiments were performed and the effect of coining was analyzed. It was shown experimentally that coining which is applied locally on selected parts of the workpiece has a global effect on the final geometry. Both the magnitude and the character of this effect could be captured by the improvements in the shell element formulation. The results also show that coining should be applied correctly in order to reduce springback. If coining is performed arbitrarily, springback may increase due to geometrical effects. With those improvements, process engineers can now design coining operations directly in simulation environment and analyze the effects of coining on the final geometry of the workpieces.

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