Forming of ultra-high-strength sheet metals with alternating blank draw-in

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Abstract

Reduction of the vehicle weight and improvement of the passenger safety are permanently defined requirements for design and manufacturing of the dedicated car body components. One possibility to fulfil before mentioned requirements is use of thin walled ultra-high-strength steel sheets for manufacturing of the car body structural parts. However, when forming such kind of sheet metal materials, severe problems may result from the large amount of springback, which occurs after release of formed part. In order to reduce part shape deviations from nominal, forming of a hat channel shaped part geometry with the alternating blank draw-in was modelled and simulated in this study. In this investigation an ultra-high-strength steel of DP 980 grade was used. Performed simulations were calculated by using the FE-Code LS-Dyna. In order to detect advantages of this kind of forming process, conventional deep drawing of the same part geometry was simulated as well. Simulation results showed that the part shape deviations after forming with the alternating blank draw-in occur significantly reduced when comparing to part shape deviations occurring after conventional deep drawing with this symmetrical flange draw-in. Evaluation of simulation results before and after release of the part was carried out along three different cross sections to understand influence of complex stress state on springback occurrence of component. Finally, successful process management which delivers negligible part shape deviations is presented in this paper.

Keywords: Ultra-high-strength sheet metal, forming, springback, flange draw-in.

1 Introduction

One possibility to decrease fuel consumption and carbon dioxide emissions of vehicles is to reduce weight of the car body. The use of advanced high strength steels (AHSS) as well as ultra-high-strength steels (UHSS) for manufacturing the car body reinforcement parts offers exceptional opportunities to reduce weight of the vehicle as well as to increase crash performance [1]. However, a serious problem in the application of AHSS and UHSS is the extremely large springback which occurs after the part release. When the part is taken out of the die cavity after the forming process, a stress relief occurs in order to reach a state of appropriate stress balance in the part. This phenomenon causes springback which can be defined as a part shape dimensional change which occurs during the unloading process [2], [3]. Depending on part geometry and type of forming process, different kinds of springback can arise: angle change, sidewall curl, radii change and torsion or twisting. Fig. 1 shows the mentioned kinds of springback.

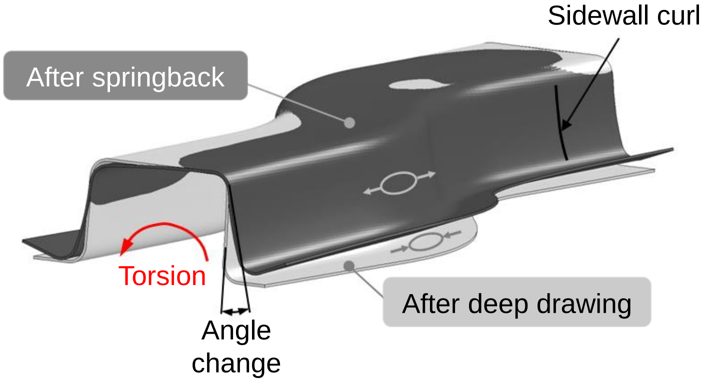

Fig. 1: Different kinds of springback when deep drawing U-shaped parts [1]

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Springback is affected by many parameters such as sheet metal thickness, blank shape, ultimate tensile strength, hardening rate, elasticity modulus, forming method, tool radii and tool clearance as well as forming conditions. Besides these parameters, inhomogeneous stress and strain distribution along the formed part together with the elastic-plastic behaviour of the workpiece material affects springback occurrence too [4], [5].

Decades ago, springback compensations for simple 2D part shapes usually were considered by using handbook tables. In case of complex part geometries, tools were manufactured and used for tryout with required shape. After comparing the obtained part shapes with the reference geometry and identified deviations which are outside the given tolerance, the springback compensation measures were defined based on experience. But, with constant increase of the sheet metal strength for manufacturing of dedicated car body parts, compensation techniques based on trial and error have not shown satisfactory results any more.

In the recent past various strategies to minimise springback have been investigated. Some of them taking into account applying of geometrical methods such as implementation of stiffening features into the part shape [5], [6]. Mentioned possibilities can be applied as long as the part functionality is not affected. The other possibility which may contribute to achieve final goal in terms of dimensional accuracy and limited springback considers a range of methods based on modifying the stress-strain conditions in the part by appropriate arrangements such as adjustable and controllable blank holder forces which are time dependent to press ram stroke. These strategies were already applied successfully in forming of high-strength steel alloys up to 600 MPa of tensile strength and have been proven successfully in practice. When using these techniques for forming of stronger steel materials (tensile strength higher than 600 MPa), results achieved and knowledge applied with respect to component accuracy are not satisfactory due to the increased tendency towards springback and twisting.

2 Simulation of deep drawing

Simulation of deep drawing of curved hat channel shaped part geometry was carried out by using LS-Dyna code. Firstly, software CATIA V5 was used for modelling the tool active surfaces and blank shape (*Fig. 2*). The analysed part can be divided into two straight areas having a length of 120 mm and two curved areas with a radius of 325 mm. The drawing depth of the part amounts constantly to 40 mm. The punch and die radii were chosen to 5.8 mm and 6 mm, respectively.

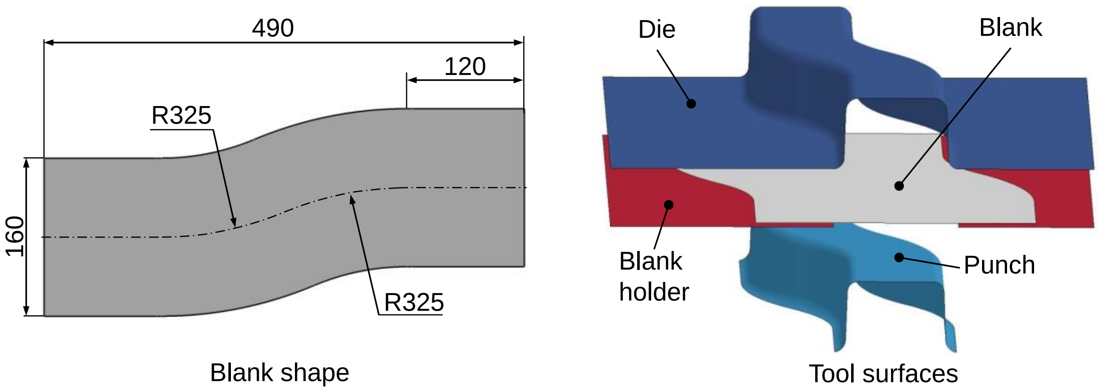

Fig. 2: Simulation setup

For modelling the deep drawing process the software *eta/DYNAFORM 5.9* was used. The blank was meshed with the fully integrated shell elements (*ELFORM 16*), taking into account nine integration points throughout the sheet thickness. The applied blank holder force in this case amounted to 1500 kN. The friction coefficient in the contact area between the blank and the tool active surfaces was defined as a constant value during forming and amounted to 0.125. Contact between the tool active surfaces and the blank was described with the contact type **CONTACT_FORMING_ONE_WAY_SURFACE_TO_SURFACE* considering to soft constraint option 0.

For all tool parts, material model **MAT_RIGID* was applied. Employed material model for blank material was **MAT_125* (**MAT_KINEMATIC_HARDENING_TRANSVERSELY_ANISOTROPIC*). This material model combines Yoshida's non-linear kinematic hardening rule with material type 37 [7], [8]. Material properties for the blank material (DP 980) with the thickness of 0.97 mm were obtained from a uniaxial tensile test. Flow curve was approximated by using the Hocket-Sherby rule. The main reason

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for simulative work was to analyse the stress distribution in characteristic part areas during forming process as well as to predict shape deflections after the part release.

After the simulation was finished, stress distributions throughout the sheet thickness were analysed at the three part sidewall sections. Two sections (section 1 and 3, *Fig. 3*) were defined near the part's end, 220 mm away from the middle of the part. Section 2 is positioned in the middle of the part and is oriented perpendicular onto the tangent of the part curvature. Evaluation of occurred stress values was provided for the finite elements which are located at the defined sections exactly in the middle of the part's sidewall. It is noticeable that a significant difference in stress amount between the inner and outer part sidewall fibre is occurred. Simulation results showed that for all three considered sections, compressive stresses at the inner side of the part sidewall and at the outer side tensile stresses occur (*Fig. 3*). When comparing all evaluated results, the highest stress difference is located in the middle of the part's sidewall at the defined section 1. The calculated values of stress in the z-direction from the inner and outer part side (for selected finite element I) were estimated as -879 MPa and 1005 MPa, respectively.

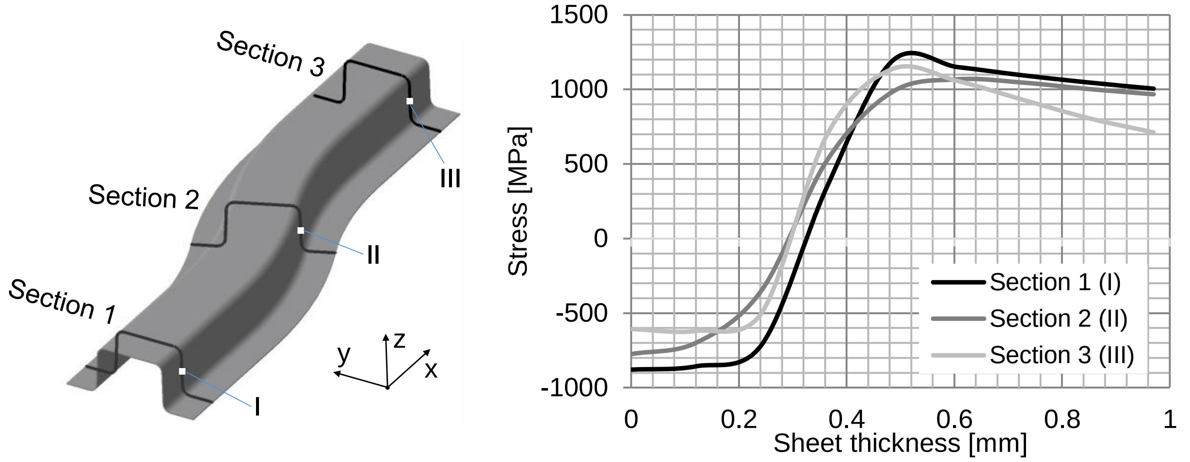

Fig. 3: Stress distribution throughout sheet thickness during deep drawing

After release of the part, when the contacts between the part and the corresponding tool surfaces were disabled, stress relief occurs with the aim to reach a state of appropriate stress balance in the part. The part fibres which showed tensile stresses at the end of deep drawing process will tend to be shorter after release, while the fibres with the compressive stresses will tend to become longer. Because of significant identified stress difference between inner and outer part sidewall fibre, tremendous springback amount can be expected. Fig. 4 shows calculated part shape deviations after deep drawing. Evaluation of the occurred part shape deviations was provided by using the software *GOM Inspect*. For that purpose, released part shape (shape after springback) was converted into *STL* file. Then the results contained in mentioned file were compared with the reference geometry of the part. The largest part shape deviations were measured in the area near to part's flange. Largest deviation between released and reference part geometry in this area was found by approx. 8 mm.

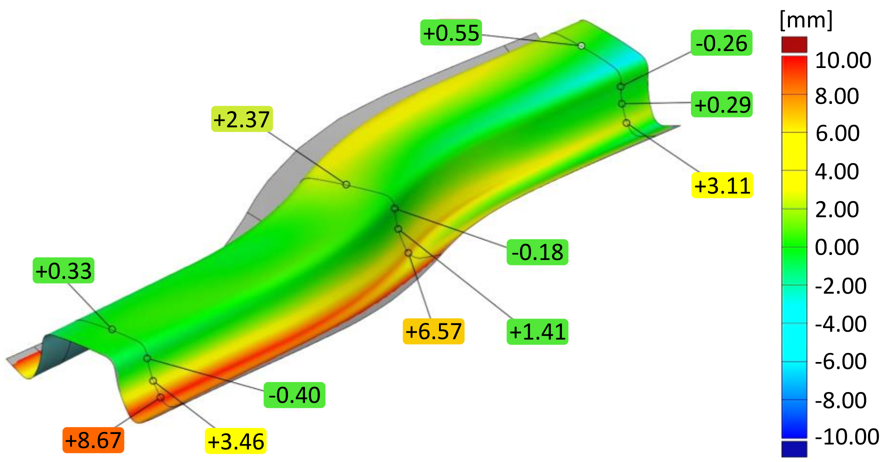

Fig. 4: Simulated part shape deviations after deep drawing

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3 Simulation of forming with alternating blank draw-in

Forming with an alternating blank draw-in or “pendular drawing” is a novel approach in sheet metal forming [1]. This kind of forming process was developed at the Institute for Metal Forming Technology (IFU) Stuttgart, and can be applied for forming of hat channel shaped parts with open ends, even if blank material is prepared out of ultra-high-strength steel sheets. The main advantage of this kind of forming process is the significantly reduced amount of springback after release when comparing to common springback amounts after conventional deep drawing.

In this case, the blank is first drawn to a defined drawing depth h_1 from only one side, while the blank draw-in from the opposite part side is disabled. After the first required drawing depth has been achieved (end of step I), the side of the blank draw-in will be changed. In the second forming step, the blank will be drawn from the opposite part side (left in this case). These actions will be repeated until the final drawing depth is achieved [1]. Concept of the forming with the alternating blank draw-in is schematically shown in Fig. 5.

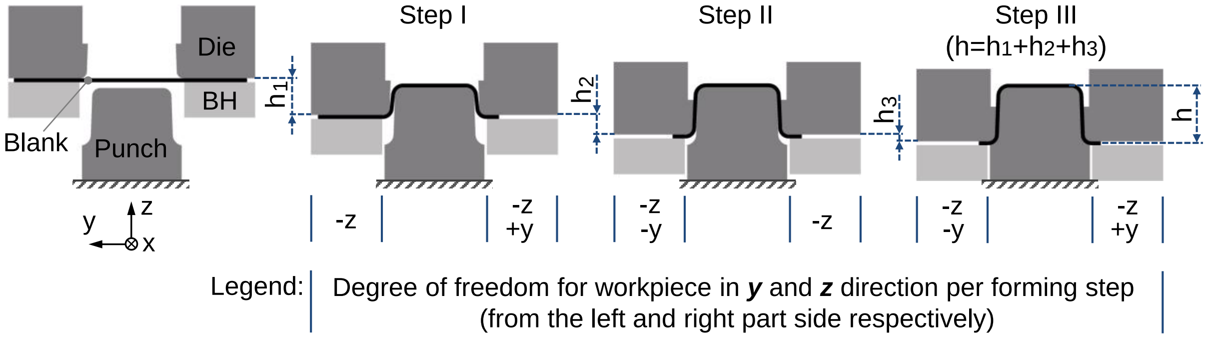

Fig. 5: Concept of the forming with alternating blank draw-in

The workpiece area that was formed over the punch radius in the first step, located on the part’s bottom, will be drawn back into the part’s sidewall in a second step. As a result of this action, a repeated “bending and unbending” over the punch radius is performed. Due to that, the tremendous stress difference between outer and inner part fibre which usually occurs in case of conventional deep drawing will be minimised or almost balanced when forming with the alternating blank draw-in. Finally, for the last few millimeters of the drawing depth, as high as possible restraining forces from both sides of the blank can be applied in order to stretch the part’s sidewalls and to further improve part precision. In order to better understand the effects of blank draw-in alternation during forming process, appropriate simulation is prepared and stress values for the sections already defined in Fig. 3 were analysed. For this purpose the stresses in z-direction were evaluated after first as well as after third (last) forming step for the finite elements located in the middle of the part’s sidewall (Fig. 6). Optimal part depths per forming step were determined by simulation.

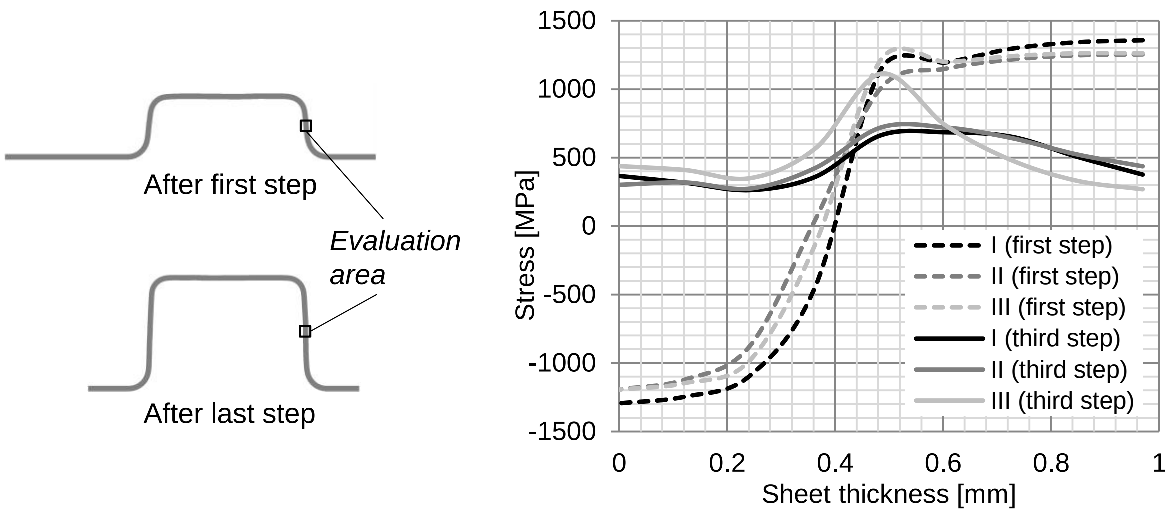

Fig. 6: Stress distribution throughout sheet thickness during forming with alternating blank draw-in

In this case, for the first 21.5 mm of the entire forming depth the blank is drawn-in just from the right side. For the next 13.5 mm the blank is drawn-in from the left (opposite) side. Alternation of the blank draw-in in simulation was influenced by applying different restraining forces in contact area between the tool active surfaces (die and blank holder) and the corresponding part flange side. In the last forming step (remaining 5 mm of the complete forming depth), the blank is drawn-in from both sides by applying equal restraining forces (applied blank holder force per part flange side is 750 kN). Simulation results showed that after first forming step a tremendous difference in stress amount from the inner and outer part sidewall fibre for the selected finite elements occurred. The highest stress difference after the first forming step was evaluated for finite element I which is located exactly in the middle of the part sidewall at section 1. The values of stress in z-direction from the inner and outer part side (for selected finite element I) were -1295 MPa and 1357 MPa, respectively. This tendency of stress distribution in the part sidewall is comparable with the stress distribution, which normally occurs by conventional deep drawing. After third (last) forming step, this difference in the middle of the part sidewall was reduced significantly (Fig. 6). The highest stress difference after the third forming step was identified for selected finite element III (located at the section 3). Measured values of the stress in z-direction from the inner and outer part side were 438 MPa and 268 MPa, respectively. Due to this significantly reduced or almost balanced stress difference between the inner and outer considered part sidewall fibre, a minimised amount of springback can be expected. Fig. 7 shows calculated part shape deviations after forming with alternating blank draw-in (pendular drawing). When comparing obtained results after forming with alternating blank draw-in with the results obtained after conventional deep drawing, significantly reduced amount of springback after forming with alternating blank draw-in can be noticed.

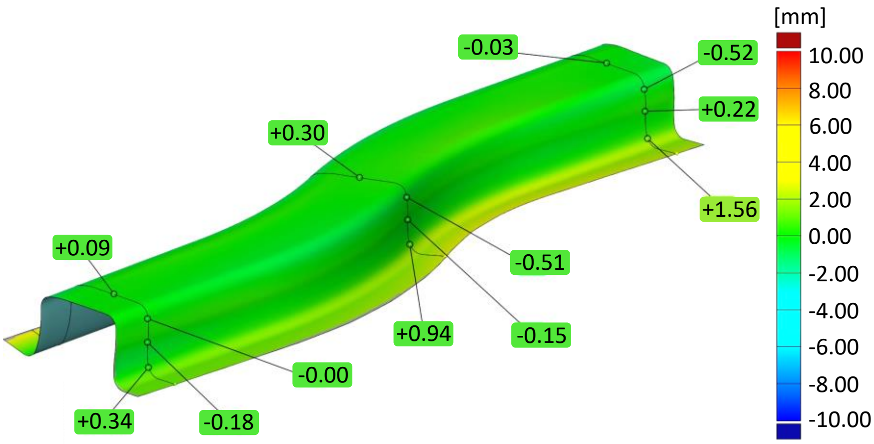

Fig. 7: Simulated part shape deviations after forming with alternating blank draw-in

4 Experimental work

Experimental validation of simulative identified possibility for springback reduction by forming with alternating blank draw-in has been performed with the AIDA-Press, a single action servo driven press with die cushion. The used tool was designed for conventional deep drawing through use of the mentioned press (*Fig. 8*).

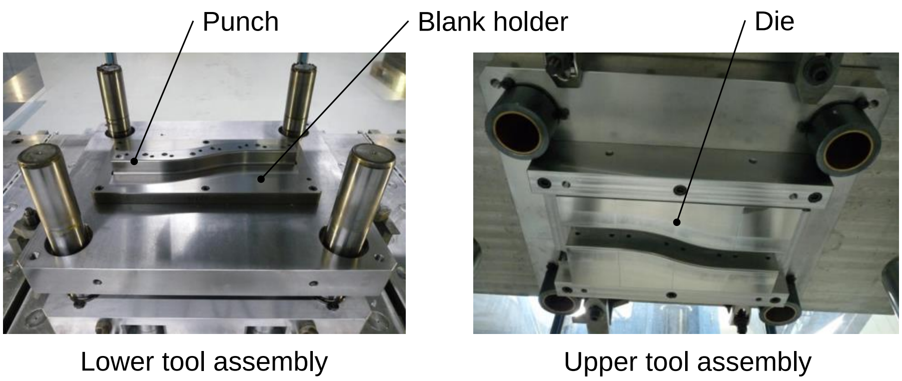

Fig. 8: Tool used for experimental validation

Due to that, alternation of the blank draw-in for considered forming steps was achieved through lubrication of the appropriate part flange side which is in contact with the tool, while the opposite part flange side at the same time was dry. The lubricant used in the experiment was mineral oil M100, produced by the company *Georg Oest Mineralölwerk GmbH & Co. KG*. After forming, the obtained part was digitised by using the optical measurement system GOM ATOS 5M, and the results were evaluated in the three characteristic sections by comparing the part shape deflections with the reference geometry (CAD model of the part). Evaluation of the occurred part shape deviations was provided by using the software GOM Inspect. Released part shape was aligned in the same manner regarding to reference geometry as in case of evaluation the simulative determined part shape deviations. *Fig. 9* shows part shapes after each forming step as well as measurement results after the final (third) forming step.

When comparing experimental obtained part shape deviations (*Fig. 9*) with the simulative predicted springback amount (*Fig. 7*), small difference in results can be identified. Some of the reasons which can cause this small deviation in results are: difference in tribological conditions between simulation and reality, machining quality of the tool active parts, etc. In the simulation, tribological behaviour between the workpiece and the tool is described with the friction coefficient which is here defined as a constant value. But in reality, friction is dependent from the contact pressure and the tool surface roughness. It means, the friction value is changeable in the contact area between tool and workpiece. Furthermore, the simulation is prepared regarding to CAD data of the tool. Nevertheless, the tool parts are manufactured within the required tolerance. Due to that, a significant deviation between the CAD data and the tool surfaces after manufacturing emerge which can cause certain errors in simulative prediction of springback amount.

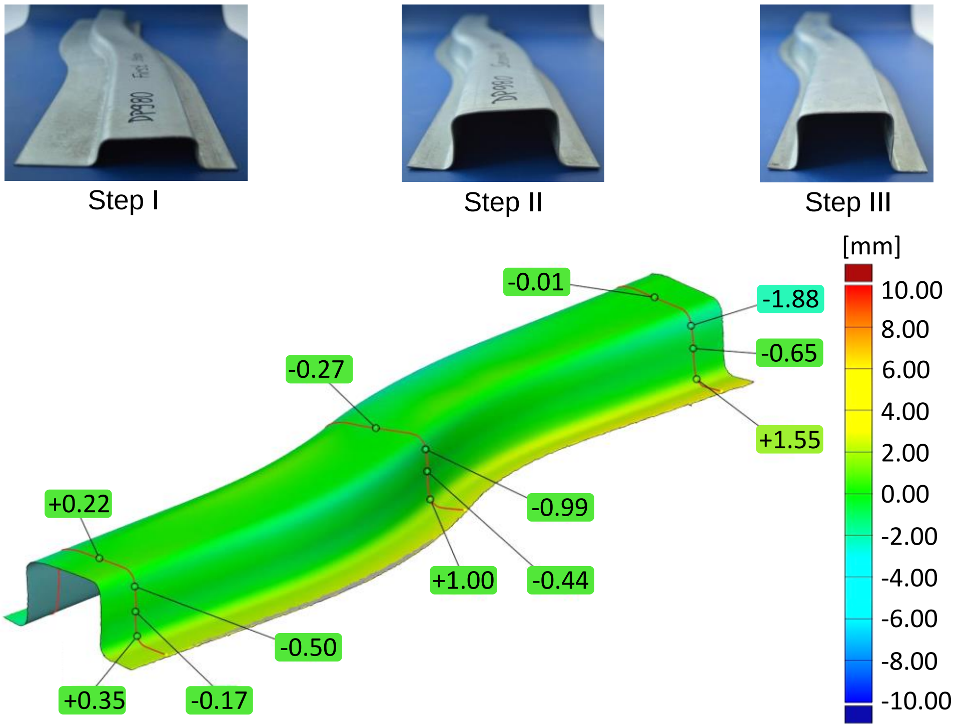

Fig. 9: Experimentally determined part shape deviations after forming with alternating blank draw-in

5 Summary

In this paper, a novel approach for successful reduction of springback amount when forming UHSS was presented. Simulation and experimental work were provided for a hat channel shaped part geometry. The simulation results showed that after conventional deep drawing a tremendous stress difference between the inner and outer part sidewall fibre occurs. This large stress difference was identified as a main reason for tremendous springback amount after the part release.

During forming with alternating blank draw-in, the workpiece undergoes repeated bending and unbending over the punch radius. This effect causes reduction of the stress difference in the part sidewall throughout the sheet thickness. The results of this investigation showed that by forming with the alternating blank draw-in during the press ram stroke, it is possible to reduce part shape deviations significantly (in the area that is near to part's flange for more than 6 mm).

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Also, there is satisfying matching between simulation and experimental results. The highest identified deviation between simulated and experimental obtained part shape deviation amounts to 1.36 mm (simulative and experimental obtained shape deviations at the section 3 considering to exactly same evaluation place were -0.52 mm and -1.88 mm, respectively).

6 Literature

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