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Numerical and Experimental Evaluation of Springback in Advanced High Strength Steel

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The automotive industry is using more and more of Advanced High Strength Steel in order to reduce the weight of the car. Since this will generate more springback, it is of vital importance to be able to predict the amount of springback in the parts. Otherwise, many late changes have to be made in order to fit the parts in their position. In order to increase the ability to understand and test the behavior of the springback in sheet-metal parts, a new semi-industrial experimental tool, the flex-rail, has been developed. This is a very flexible tool, which can be used for various kinds of materials, from mild steel and aluminum to advanced high strength steel such as TRIP-steel and CP-steel by using different insert. The tool is designed for experimental analysis of 3D-springback, which is the case in the more complicated automotive parts, such as b-pillars and side members. The scope of this work is to analyze the springback behavior and prediction for Advanced High Strength Steel both numerically and experimentally. Sheet-metal-forming simulations were made in LS-DYNA. The results proved that the new geometry, flex-rail, gave a complex springback behavior for all tested materials. Furthermore, the prediction of springback showed good correlation in sections with small amounts of twist but that LS-DYNA under-predicts the springback for sections with large amounts of twist for all materials except DP600.

Keywords advanced high strength steel, sheet-metal forming, simulation, springback

1. Introduction

The ability to predict the forming behavior of sheet-metal parts is vital. The tool-making is a very time- and cost-consuming process and therefore we try to make the design process as efficient as possible. Today, sheet-metal-forming simulations are used all over the industry in order to get more effective tool-making processes. Thickness reductions, failures, strains, and forces can be predicted with an high accuracy by available software today, but springback prediction remains a problem. If the springback could be predicted with high accuracy, many recuts in the dies could be avoided to save time and money. Therefore, a lot of effort is aimed at springback prediction (Ref 1-11).

Introduction of Advanced High Strength Steels (AHSS), e.g., TRIP-steel, also has contributed to the difficulties of springback prediction, since these materials behave differently than mild steel. The behavior of such materials has been studied by, among others, Asgari et al. (Ref 12) and Pereira et al. (Ref 13).

In order to increase the ability to understand and test the behavior of springback in sheet-metal parts, a new tool has been developed. This is a very flexible tool, which can be used for various kinds of materials, from mild steel and aluminum to advanced high strength steel such as TRIP-steel and CP-steel. The same basic set-up is used for different materials, by using different inserts which change the draw radii, depending on material formability. Furthermore, the tool is designed for analyzing a 3D-springback, which is the case in the more complicated automotive parts, such as b-pillars and side members. If only 2D-springback is to be analyzed, the blank size can be adjusted for achieving this analysis. We now have a laboratory forming tool that produces sheet-metal part with springback complex enough to challenge the best available forming-simulation packages. Improvement in such software can now be evaluated in an objective and consistent way.

Sheet-metal-forming simulations, using LS-DYNA were done in order to analyze the accuracy of springback prediction. The results were compared to the results achieved in the experimental tool, the flex-rail.

In this study, the objective was to verify that the flex-rail generated a complex geometry containing flange angle change, sidewall curl, and twist which is necessary to be representative as a semi-industrial tool. Furthermore, the accuracy of springback prediction in LS-DYNA was evaluated. Three different materials were investigated (DP600, TRIP700, and HyTens1000) both experimentally and numerically.

2. Methodology

2.1 Geometry

After an iterative process, a geometry was found which should be easy to control (process) as well as versatile enough to catch the problems in a complex automotive part. The final geometry can be seen in Fig. 1.

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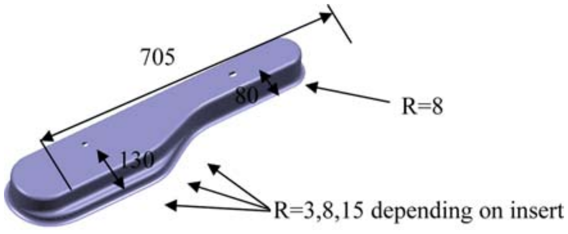


Fig. 1 Tool geometry

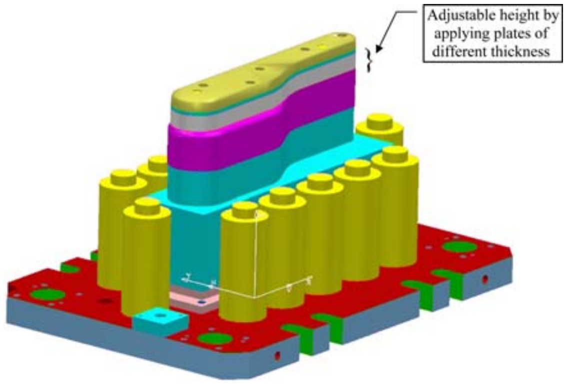


Fig. 2 Adjustable draw depth is achieved by applying insert plates of different thickness. The height can be varied between 50 and 100 mm

Fig. 3 ATOS evaluation

The geometry was based on FE-simulation results, which were judged reliable enough to predict the behavior and the forming limitations of the required geometry. The requirements of a complex springback behavior include:

- Flange/wall angle change
- Twist
- Sidewall Curl

These different types of springback behavior were all expected to show up in the chosen geometry. Shi and Zhang (Ref 14) report that these behaviors are often seen in formed parts, and therefore are interesting to study.

Another advantage with the chosen tool geometry is that several analyses can be made in the tool. The different analyses only require a variation of blank size and blank position. Examples of analyses are:

- Influence of closed or open edge of the springback in rail-forming applications
- Influence of step
- Influence of section variation

2.2 Tool

The purpose of the tool was to create a semi industrial, highly flexible tool which could be used for a wide range of materials. It should be possible to use materials ranging from mild steel to AHSS and with different thicknesses. The tool should generate a complex springback in order to represent the behavior of b-pillars and side members. After the geometry was defined, the tool material and hardening process were chosen to withstand the trials which forming AHSS implies concerning wear, forces, etc. Furthermore, it was desirable to manufacture the tool to be as flexible as possible. This means that both different materials, e.g., mild steel and AHSS, and material thicknesses should be processable on the same tool. The solution was to use different inserts which can be varied depending on material and thickness. Another feature which was built into the tool is a variable draw depth, which can be achieved by mounting spacers under the punch which make the distance between the top surface of the punch and the top surface of the step adjustable (see Fig. 2). By means of these spacer, the draw depth is adjustable between 50 and 100 mm.

2.3 Evaluation of the Springback

In order to evaluate the results, it was necessary to find stable reference points and to manufacture a fixture for evaluation. It was also necessary to find the same position for the reference points on the blank. The solution was to include a marking device in the tool that marked dots on the blank in the bottom position in the forming sequence. This was achieved by an ejection device, activated by a stand-alone circuit of pressurized air when the tool is fully closed and the blank thereby is locked in the correct position. After the part was removed, a hole and a slot were made in the marked positions. The blank could now be positioned in the reference fixture and a 3-2-1 alignment was established by 3 z-supports and two pins fitting in the hole and the slot. Then, the geometry was scanned by ATOS (Ref 15) in order to get a full picture of the deformed shape. The evaluation equipment can be seen in Fig. 3 and 4.

The springback was evaluated over the whole surface, but in order to present the results, three sections were chosen for evaluation; see Fig. 5.

2.4 Comparison between Experimental and Numerical Results

In order to achieve a similar process between numerical calculations and experiments, punch- and blank-holder forces were measured during the experiments. Furthermore, strains

Fig. 4 Reference fixture

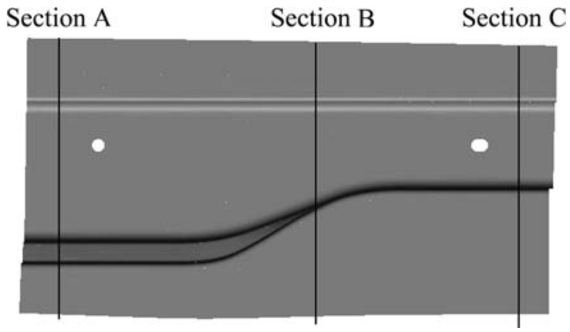


Fig. 5 Sections for evaluation. Sections A and C are placed on the same position as the z-supports in order to have the same position on the top surface for evaluation between experiments and simulations

were evaluated with an optical system called Argus (Ref 16). The strains were evaluated on the whole surface, in section B in Fig. 5, and in the section through the reference holes. As a final step, draw-in was also measured and compared. With this information the numerical parameters were set based on the achieved experimental values.

3. Mechanical Properties

3.1 Material

The mechanical properties for the analyzed materials are given in Table 1.

3.2 Friction Coefficient

The friction coefficient in the numerical analysis was chosen based on the comparison of punch force, strain distribution and draw-in from the experimental results. The chosen values can be seen in Table 2.

4. Tool Description

4.1 Tool

In order to have a well distributed blank holder pressure, the blank holder surface was chosen to be flat and 10 gas springs apply the pressure. The gas springs are internally connected and create a well distributed pressure on the blank holder. Thereby, hard points can be avoided which is favorable for evaluation of the results and as a comparison to FE-simulations.

Table 1 Mechanical properties

Material	*t*, mm	YS*, MPa	UTS**, MPa	R0	R45	R90	*n*(10, 15)
DP600	1.4	400	632	0.76	0.95	0.95	0.18
TRIP700	1.2	454	730	0.83	0.99	1.09	0.2
HyTens1000	1.5	845	1126	0.78	0.78	1.18	0.23

* Yield Strength
** Ultimate Tensile Strength

Table 2 Friction coefficients

Material	Friction coefficient
DP600	0.15
TRIP700	0.17
HyTens100	0.20

Three different sets of inserts were manufactured in order to have the ability to test different materials. The difference between the inserts is the chosen draw radii and radii of the step (3, 8 and 15). Of course, the largest radii can be used for all materials, but the smaller radii generate the possibility to study the influence of sharp radii. Furthermore, the inserts can be moved sideways, whereby the sheet thickness is continuously adjustable up to 2 mm.

The tool can be seen in Fig. 6.

The chosen tool material was Sleipner which was heat treated and applied with TIXON®-treatment (PVD treatment) (Ref 17).

4.2 Instrumentation

Pressure gauges were positioned under the punch. From these, the punch force can be measured. The pressure in the gas springs applies blank-holder pressure and, finally, a position transducer measures the tool movement.

5. Experiments

The experiments were performed in a hydraulic single-action press. The applied blank-holder force was progressive with a start value of 375 kN and an end value of 500 kN. The draw depth was set to 60 mm and the inserts with $r = 8$ mm were used.

Aral Ropa 4093 LN was used as lubricant and was distributed over the blank surface. The lubricant was well distributed and the amount was controlled by applied weight. The amount was 2-3 g/m^2. Between the experiments, the tool surfaces were cleaned in order to have the same condition for each new experiment.

The initial position of the blank was measured for each experiment and was chosen with respect to achieving a balanced draw-in between the sides. The blank size was 500×375 mm with its rolling direction along the short side.

A grid of dots was applied on the outer surface in order to measure strains with Argus on each blank.

Each part was positioned in the reference fixture and measured with ATOS. The overall deviation was evaluated as well as that of chosen sections.

6. Simulation

Simulations were made in the dynamic explicit FE code LS-DYNA (Ref 18).

The blank was modeled by Belytschko-Lin-Tsay (Ref 19) quadrilateral, fully integrated shell elements with seven integration points in the thickness direction. The material model, introduced by Barlat-Lian (Ref 20) with isotropic hardening, was used. Adaptive mesh was used with a final element size of 0.2*draw radius. Different m-values were tested. For both TRIP700 and HyTens 1000, $m = 8$ was chosen and for DP600 $m = 6$.

7. Results

The friction coefficient was chosen based on correlation to experimental results for punch force, strain distribution, and draw-in. The results indicate some remarkably high friction coefficients but the chosen values gave good correlation to experimental results.

The comparisons between springback results of numerical and experimental tests can be found in Fig. 7-10.

As can be seen in Fig. 8–10, the simulation shows an under prediction of the springback for all cases, except for DP600, section C. However, the overall behavior is correctly predicted. An example can be seen in Fig. 7.

All materials show the same behavior, but different magnitudes. The twist in the wall and the flange is due to both the decrease in section and the lack of step in the wall in the narrow part. This twist can also be seen in the surface with reference points. Furthermore, the flange in the marked area showed a wave-like pattern, with the "deepest" part a distance from the flange and not at the edge. The simulations showed more of a tendency to level out towards the edge at the narrow end.

For DP600, the results show good correlation in sections A and B but a bad correlation in section C. Furthermore, a large variation between the experiments can be seen in section C. This indicates an unstable area. The simulation cannot capture the "wave-like" flange shape correctly. The simulation

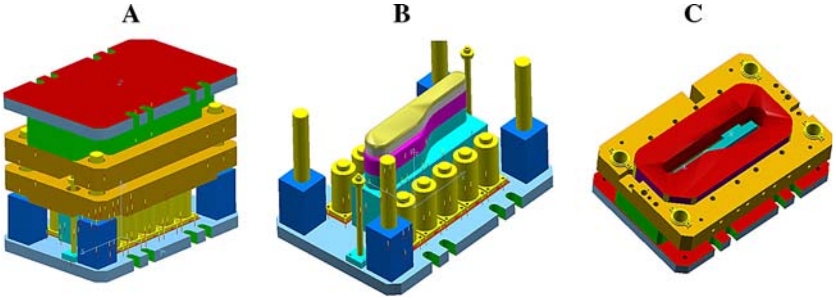


Fig. 6 Tool set-up. (a) Complete tool; (b) Punch and gas springs; (c) Inserts and blank holder

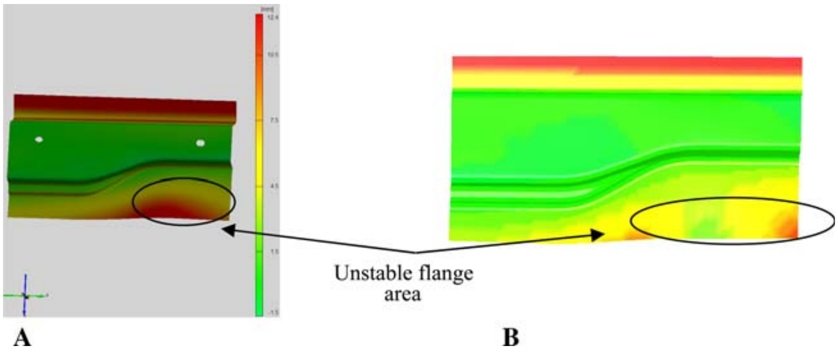


Fig. 7 Overall springback behavior for material TRIP700. The scale shows deviation from nominal value. (a) Experimental springback; (b) Numerical springback

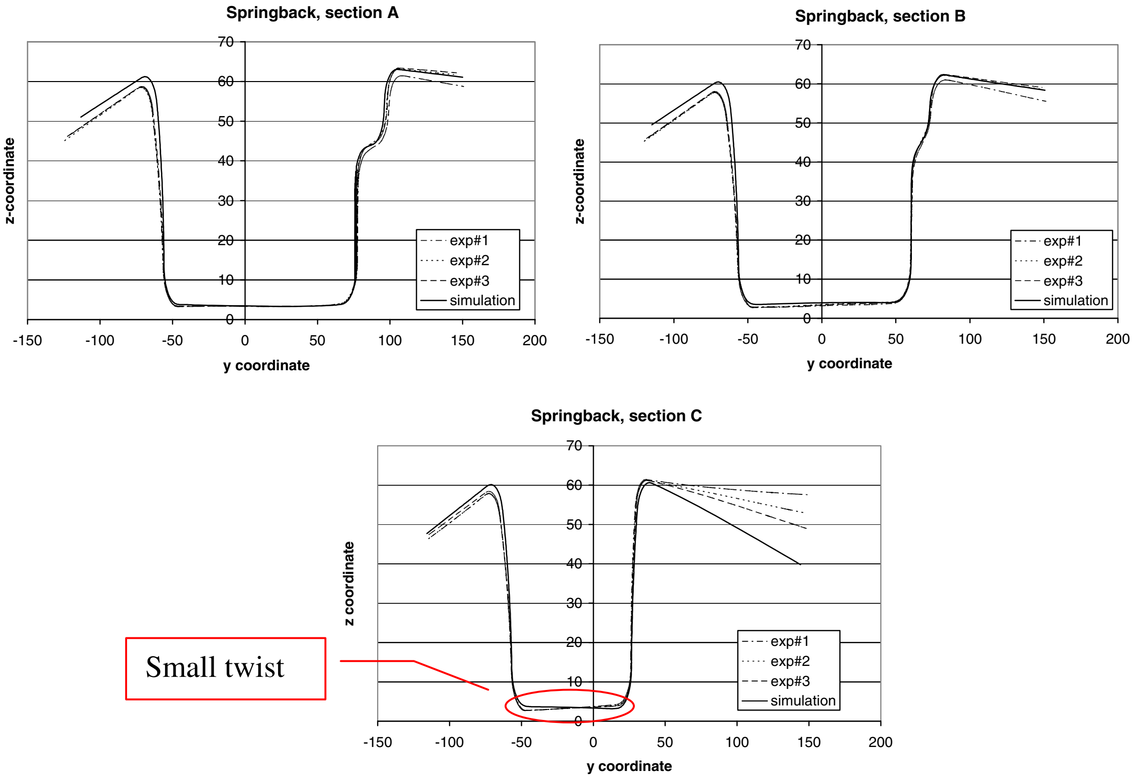


Fig. 8 Springback comparison for DP600

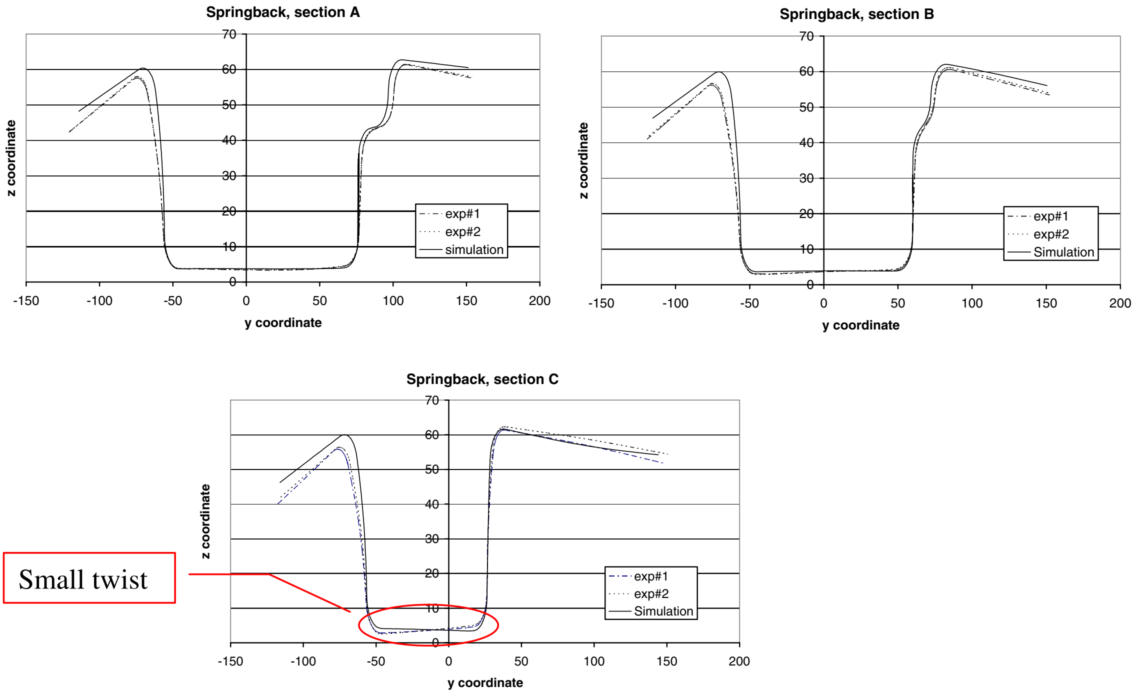
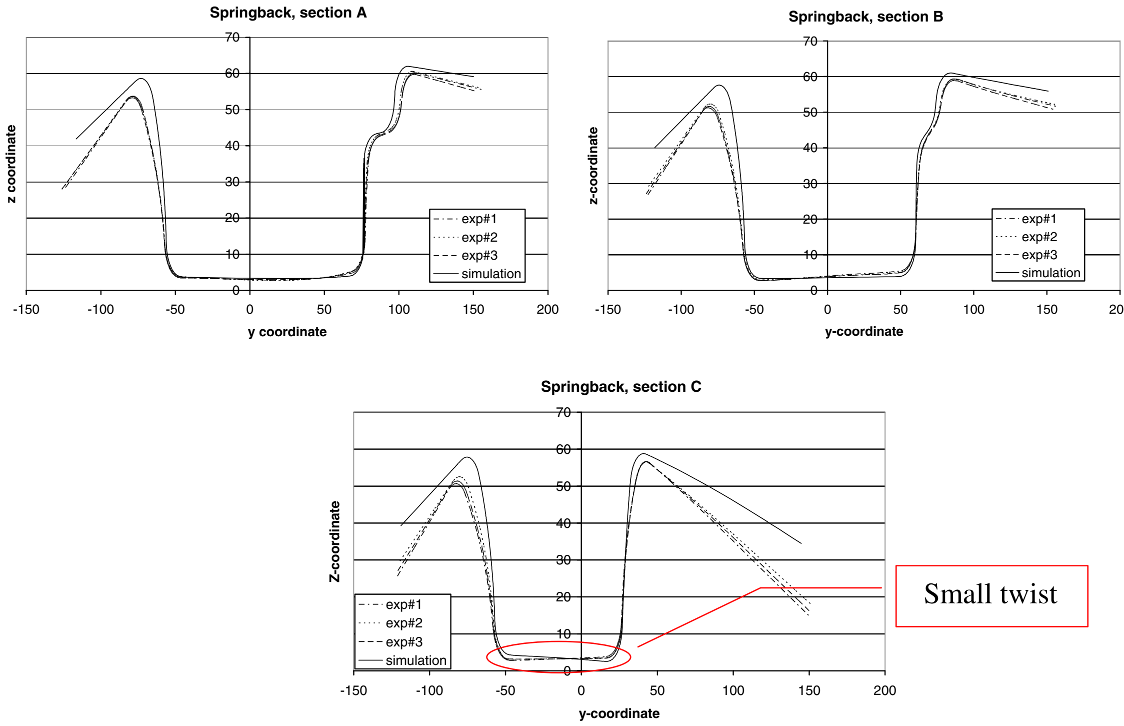


Fig. 9 Springback comparison for TRIP700

underestimates the springback in sections A and B while it overestimates it in section C. One reason for this difference is the difficulty in predicting the bending behavior in the flange. Another difference to notice is that the simulations do not indicate the small twist on the surface with the reference points as it is shown in the experiments (see Fig. 8).

For material TRIP700, the simulation underestimates the springback for all sections. However, the underestimation is relatively small. For this material, the simulation captures the behavior of the flange for all sections. Furthermore, the small twist of the surface with reference holes is indicated only in the experiments and not in the simulations.



Small twist

Fig. 10 Springback comparison for HyTens1000

Finally, for the stainless steel—HyTens1000, the springback is very large, with small variation between the experimental results. The simulation, however, shows a large underestimation of the springback. Furthermore, the small twist of the surface with reference holes is indicated only in the experiments and not in the simulations.

8. Conclusions

The tool, the flex-rail, proved to be very flexible and gave a complex springback behavior for all tested materials. The complex springback behavior contained flange/wall angle change, twist, and sidewall curl which is representative for a complex part, e.g., B-pillar or a side member. Therefore, it can be used for verification of the prediction possibilities for FE-codes to predict springback in complex geometries. The advantage with the flex-rail is that it is possible to have good control of the ingoing parameters and to provide the FE-simulation with good input data. It is also suitable for test in 2D-analysis of different sections by adjusting the blank size to more fundamental studies. Furthermore, it can be used as a laboratory tool and be a representative for the complex shape in production parts. We now have a laboratory forming tool that produces sheet-metal part with springback complex enough to challenge the best available forming-simulation packages. Improvement in such software can now be evaluated in an objective and consistent way.

The difference between the three experimental samples is relatively small which gives good repeatability in the experiments. The exception is the flange area in section C for DP600.

The simulation under predicts the springback for all materials, except for section C in DP600. It can also be seen that the deviance is largest in the area contained in section C for both DP600 and HyTens1000. In this area, the increased stiffness from the step is not present and a twist is achieved. Obviously, this twist is difficult to predict since the deviations between numerical and experimental results are much smaller in sections A and B.

The friction coefficients used are remarkably high since the surface was smooth and a lubricant was used. However, they were used since they were calibrated to punch force, strain distribution and draw-in of the experiments.

In this study, there has been no analysis of the influence of more advanced material models, developed for TRIP- and stainless steels. Furthermore, it would be interesting to study the influence of other material characteristics, e.g., the Bauschinger effect.

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