Numerical and experimental evaluation of springback in a front side member

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Abstract

Changes in geometry after springback are a major problem for the automotive industry. In order to make adjustments of the part to be formed, extra processes are needed. Since their implementation is both time-consuming and expensive, the industry would stand to gain if geometrical changes could be predicted at the time that the tool is being designed. Today, sheet-metal-forming simulations are, to a large extent, used to evaluate the forming process. Reliable results of the forming process can be obtained regarding, for instance, thinning, forces and fractures, but prediction of springback is not accurate enough to be fully reliable. Furthermore, the introduction of new, high strength steels, such as TRIP steels, emphasize the springback problem even more. This demands an increased ability to accurately predict the outcome of the forming process.

In this study a part of an automotive side front section (front side member inner) was studied and a comparison both regarding material behaviour and of accuracy of the FE simulations was made. Mild steel, Rephos steel and TRIP700 were compared both experimentally and numerically. The results showed that TRIP steel has a significantly larger springback than the other materials. Furthermore, the FE simulations overestimate the twisting in this part for all materials, with the TRIP material showing the largest deviation between the experiments and the simulations. The prediction of punch forces was, however, accurate for all materials.

Key words: Sheet-metal forming, Simulation, Finite element method, Springback

1 Introduction

Changes in the geometry after springback are a big and costly problem in the automotive industry. The assembly process cannot handle parts with too much deviation in geometry and therefore adjusting operations are required. These extra operations cost both time and money in the production process and should be reduced to a minimum.

Today, sheet-metal-forming simulations are commonly used to assess the forming process. Reliable results of the forming process can be obtained regarding thinning, forces and fractures. The simulations have contributed to a significant decrease in the use of try-out tools [1], thus decreasing both lead time and costs. The sheet-metal-forming simulations are today widely used in the automotive industry [2], [3]. However, prediction of springback is not accurate enough to be fully reliable, and therefore experimental tests are still required, to a large extent in order to evaluate the deviation in geometry due to the springback. The use of Finite Element (FE) simulations, decrease both the lead time and costs in the development of new parts compared to experimental tests.

Previous publications [4]-[9] have shown that the accuracy in springback predictions for automotive panels has increased, and that the accuracy is sufficiently good to apply die compensation based on simulation results. However, improvements are still called for. In order to test the possibility to predict springback, a test tool was analysed, namely, a front side member inner to Volvo S40. The geometry consists both of a simple U-shaped part (front) and a complex part (rear). The springback will therefore consist of both section opening (front) and twisting (caused by the complex rear part). These are problems which occur in the production process and their study is of significant interest.

In this study three different materials were analysed in order to investigate the correspondence between experiment and FE simulation for different qualities of material. The materials in question were mild steel, Rephos steel and TRIP steel.

TRIP steel is a relatively new material with a potential to decrease the weight or increase the strength of a part. It has a significant deformation hardening and is therefore suitable for deep-drawn parts which have demands on both high formability and high strength. The formability has been studied by Konieczny [10] and Kamura et al. [11], who found that TRIP steel has good formability and is suitable for automotive applications. However, as this material is used to a small extent in the automotive industry and it therefore was of interest to include it in this study.

The experiments were performed under controlled conditions. In order to verify the simulation results, these were compared to experimental results after both the blank holder closing (binder wrap) and the forming/springback. A trimming operation after forming was also included in the study.

2 Methodology

2.1 Methodology for experimental tests

The chosen geometry is well defined, since it is the geometry of a try-out tool, for which CAD data correspond to the physical tool. The experimental test was performed in a hydraulic double-action press, which provided the possibility to perform a well-controlled process.

In order to have a well-defined process to simulate, distances of 0.1mm between the blank holder and the die were used during the forming process. Hence, the flow of material will be controlled by the drawbeads which provide the restraining forces, and the binder will only control the tendency of the blank to wrinkle during the forming process.

In order to calibrate the draw-in in the simulation, one part was analysed after the blank holder was closed. This part was used as a reference when the draw-in was measured after the final drawing. The draw-in was then measured as the change in flange width between binder wrap and final shape at several positions. In order to have the correct position after the blank holder was closed, also the flange width was measured and compared to the simulation results. Furthermore, the punch force was registered in order to compare it with the simulation results.

The trimming was done by laser cutting.

The measurement of the springback was based on a 3-2-1 system. This means that all six rigid body modes are suppressed by support in 5 points. These points are located at three points in Z, two points in y and one in x (see figure 1). The parts were measured in a CMM machine and the deviation from the CAD model was evaluated in two different sections, which correspond to the two different cases mentioned in section 1 (see figure 1): A U-profile which generates 2D-opening (section A) and a more complex section (section B) which also generates twisting.

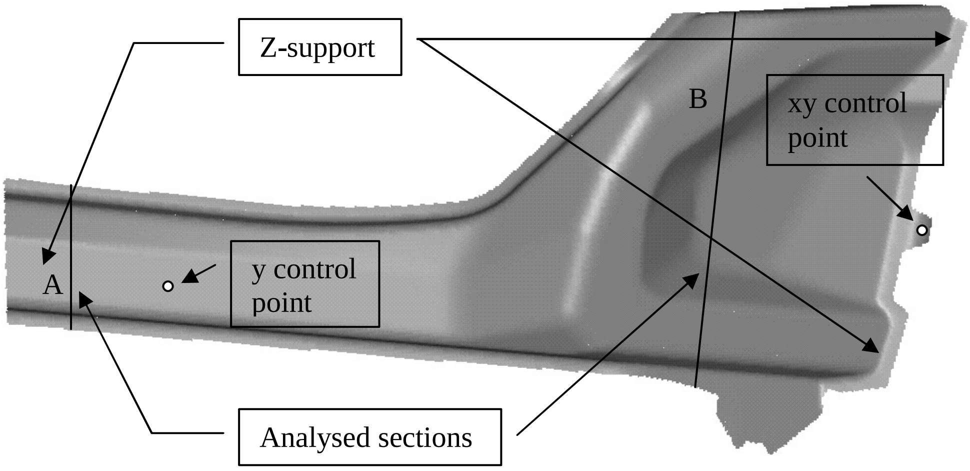

Figure 1: *Support points and evaluated sections.*

Three parts were evaluated for each material in order to find the scatter in the experimental results.

The methodology for the experimental analysis is described in figure 2 together with the methodology for the simulation.

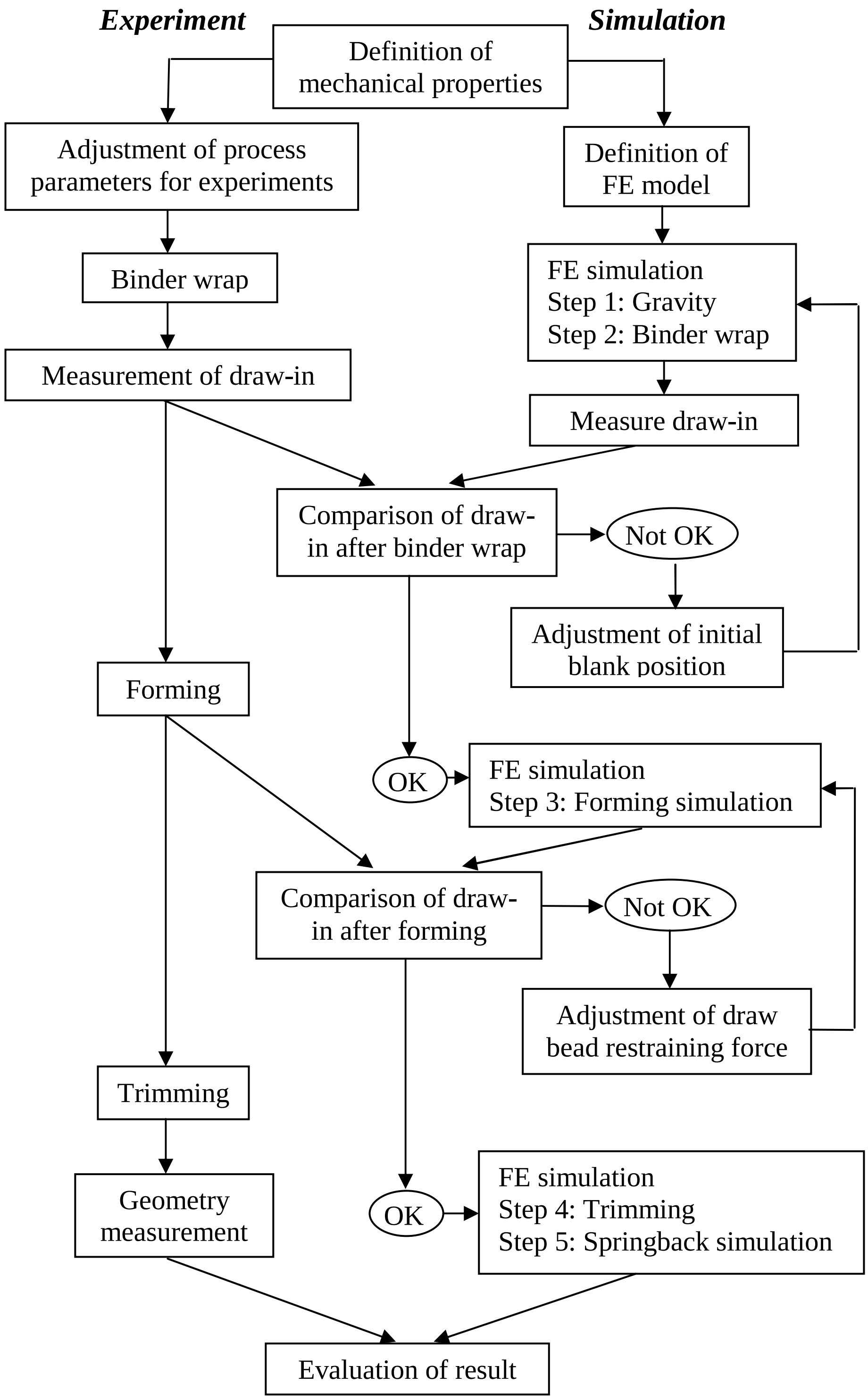

Figure 2: *Methodology for simulations and experiments.*

2.2 Simulation methodology

The simulation methodology is described in figure 2. First the mechanical properties of the material were obtained from a tensile test.

Based on the CAD geometry, a FE model was created. The simulation was divided into five steps:

1. Gravity simulation.
2. Binder wrap simulation.
3. Forming simulation.
4. Trimming.
5. Springback simulation.

Since the surface of the binder is curved it was necessary to find the correct initial positioning of the blank. This was done by using a coarse model in step 1 and 2 in order to save computing time. The first two steps were looped manually until convergence with the experimental results was achieved. After convergence the sheet-metal-forming process was simulated (step 3). This was also done in a process with a coarse model until convergence with the experimental results was found. In step 3 the draw-bead restraining force was optimised. If the results differed, a new set of drawbead restraining forces was applied and step 3 was looped until convergence was found. This iterative procedure was done manually, but an optimisation process, described by Jansson et al. [12], would be preferable in further studies. After convergence was found a coarse model was used in step 1. Then the model was uniformly refined to the fine model and was used in the following steps. Between the individual steps, a result file with all data about the blank (a dynain file) was used.

In the springback simulation the same reference points were used as in the experiments (see figure 1).

3 Mechanical properties

3.1 Material

Three different materials were analysed in this study: Mild steel, Rephos steel and TRIP steel. The mechanical properties are given in table 1.

Table 1: *Mechanical properties.*

Material	t [mm]	Rp0.2 [MPa]	Rm [MPa]	R0	R45	R90
V1158-32	1.5	150	303	2.07	1.58	2.57
V-1437	1.5	278	389	1.11	0.81	1.33
TRIP700	1.6	476	690	0.76	0.86	1.0

3.2 Friction coefficient

The friction coefficient was chosen to be 0.15. Studies of different friction coefficients did not give any significant difference in the results. The drawbead restraining force dominates material flow and thus the build-up of the stress field for this geometry. Therefore the friction coefficient has minor effect on the results.

4 Experiments

A try-out tool for the part, denoted front side member inner, was used for this investigation. It is defined by CAD data, which agree well with the actual tool surfaces. The geometry of a formed part can be seen in figure 1.

The tests were performed in a 1000-metric-tons hydraulic press, normally used for try-outs of production tools. The press was equipped with sensors for measuring the punch force and the blank holder force. All sensors were connected to a PC system. Figure 3 shows a photograph of the tool in the press.

Figure 3: *The tool in the press.*

Old lubricant and rust were cleaned off the tool before the trials were carried out, and also between the trials. Distance plates of 0.1 mm between the blank holder and the die were used in all cases. All steel materials were stamped without any extra lubrication. The punch forces and draw-in for each part were noted.

In order to calibrate the simulations, the draw-in was measured both after binder wrap and after forming as described in section 2. The springback of the parts was then measured by the 3-2-1 principle (see section 2.1) in two different sections.

5 Simulation

The simulations were performed with the dynamic explicit FE code LS-DYNA [13], [14]. Each simulation was divided into five steps and between each step a file with the blank properties was saved. A flow chart of the simulation procedure can be seen in figure 2. The gravity and springback simulations were done using implicit time integration, while binder wrap, forming and trimming were done using explicit time integration. After the gravity simulation the blank mesh was uniformly refined twice, and reached a final size of draw radius/4. This has been seen in previous studies [1], [15] to be suitable.

The blank was modelled by quadrilateral, fully integrated, shell elements with five integration points in thickness direction [14], which have been found suitable in previous studies [15]. The material model introduced by Barlat-Lian [16], with isotropic hardening and m=8 for Rephos/TRIP steel and the quadratic yield function introduced by Hill [17] with isotropic hardening for mild steel, was used. The m-value was chosen based on studies at Volvo Cars Body Components (VCBC).

6 Results

In the experiments three parts were produced for each case. The mean values are presented in the results. The correspondence in punch force was good, but the springback comparison showed deviations between the experimental results and the simulations.

A comparison of punch forces at maximum draw depth can be seen in table 2. The experimental results are presented as the mean value with the variation achieved in the trials.

Table 2: *Punch forces at maximum draw depth.*

Material	**Punch force experiments [kN]**	**Punch force simulation [kN]**
V-1158	2000±36	2025
V-1437	2446.5±78.5	2425
TRIP700	3374.5±30.5	3600

The springback was evaluated for two sections (see figure 1). The results were compared with the values from the CAD model and the deviation was calculated. For a part of this type, it is mainly the flanges which are involved when the rail is to be assembled to other parts, and therefore the areas around the flanges are the most interesting in the comparison. For this reason the deviance in the flanges was taken into consideration in the evaluation. Figure 4 explains how the deviation was measured. The results are presented in table 3.

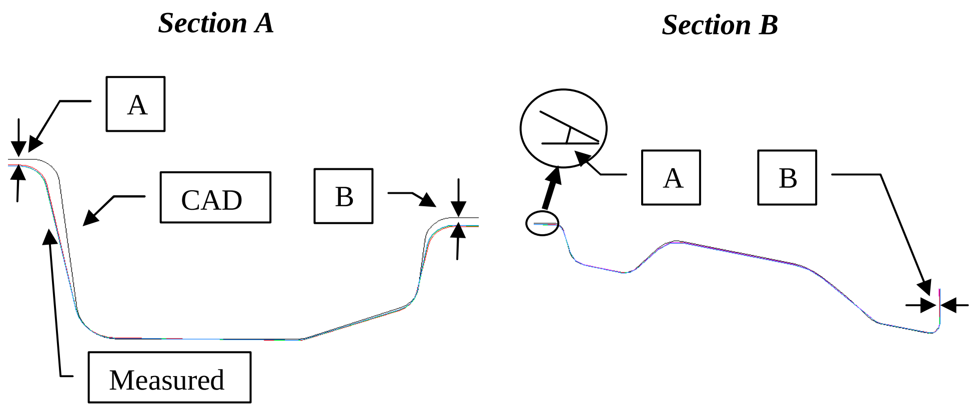

Figure 4: *Measurement of deviance.*

Table 3: *Results of springback comparison.*

Point	Material					
				1158		
		Section A			**Section B**	
	Exp	*Sim*	*Dev*	*Exp*	*Sim*	*Dev*
A	2mm	-1.3mm	-3.3mm	1°	0.5°	-0.5°
B	3mm	1.5mm	-1.5mm	0.5mm	0.5mm	-
				1437		
		Section A			**Section B**	
	Exp	*Sim*	*Dev*	*Exp*	*Sim*	*Dev*
A	2.5mm	-1.0mm	-3.5mm	1.0°	0°	-1.0°
B	3.5mm	1.5mm	-2.0mm	1mm	1mm	-
				TRIP700		
		Section A			**Section B**	
	Exp	*Sim*	*Dev*	*Exp*	*Sim*	*Dev*
A	6.5mm	-3.8mm	-9.3mm	2°	0.5°	-1.5°
B	7.5mm	10mm	2.5mm	1.5mm	2mm	0.5mm

In table 3 results which indicate that the section opens during springback, are positive. This is illustrated in figure 4. The deviation is calculated as the simulation results minus the experimental results.

7 Discussion and conclusions

It was possible to form all materials with the current tool geometry. In an automotive application materials 1437 and DP600 are commonly used. The possibility to use TRIP steel will contribute to a decrease in thickness with retained crash characteristics. However, the results of this study show a significantly greater springback for TRIP steel than for the other materials. This is an important observation, since it would cause problems in production with such material qualities. This effect has also been shown by Pehrsson and Liljengren [18]. The TRIP effect (conversion from austenite to martensite) with increasing strain levels implies that the material hardens causing an increasing springback in the material. Another problem is the weldability of the TRIP material, which is very poor according to trials made at VCBC. The conclusion is that TRIP material should be further developed in order to be feasible for use in automotive applications.

The FE simulation overestimate the twisting compared to the experimental results. This can be seen by the negative values found in section A for the FE-simulations. One reason for the bad correlation is that the drawbeads are modelled by restraining forces instead of being modelled as geometrical drawbeads. Since the material goes through bending and unbending in its passage through the drawbeads in the experiments, the material will harden. This effect is not seen in the FE simulations. Due to the large draw depth some of the material, which has passed the drawbeads, will be located in the side wall at the end of the drawing process and affect the springback results. In parts with a small draw depth (where a small amount of material passes the drawbeads and slides into the side wall) this effect is much smaller. Therefore it would be interesting to do an additional study where the drawbeads are modelled geometrically, and to investigate whether the FE simulation results improve. Furthermore, it would be of interest to study the effect of the hardening behaviour with a more accurate material description e.g. with mixed hardening.

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