ONE DAY TRY-OUT,
IDENTIFYING INFLUENCE AND SENSITIVITY IN STAMPING

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ABSTRACT: Sheet metal forming simulations are on a high accuracy level nowadays. However, the step from simulation to reality, at the first time faced at the tool try-out, is not always a one-to-one conversion. Because of various assumptions and simplifications several try-out loops are needed. These try-out loops are labour and time intensive and therefore costly exercises. A method to more effectively conduct these try-out loops is to identify which parameters influence the result most and to identify how sensitive the result is. A method both a series of simulations and a series of experiments have been performed while varying identified parameters. First, series of simulations have turned out the have the most influence on the result of stamping a B-Pillar. Three parameters turned out the have the most influence. While varying the above mentioned parameters. For performed. The trends obtained from simulation and possible to define guidelines describing which parameters indeed in order to identify influence and sensitivity on the stamping process. Corus was able to deliver material for the experimental validation, and the University of Twente was able to recruit a master student to perform most numerical simulations. With that the consortium for this project was born.

1 INTRODUCTION

Sheet metal forming simulations are on a high accuracy level nowadays. However, the step from simulation to reality, at the first time faced at the tool try-out, is not always a one-to-one conversion. Because of various assumptions and simplifications several try-out loops are needed. These try-out loops are labour and time intensive and therefore costly exercises. A method to conduct these try-out loops more effectively is to identify which parameters influence the result most and to identify how sensitive the result is on those parameters.

This paper describes a project in order to validate this method. The objective of this project was to validate whether influence of design parameters and the sensitivity of the result found in numerical simulation could be seen in experiments as well. A B-Pillar reinforcement was chosen as the part for this project (Figure 1). AutoForm Engineering owns the drawing tools of the part which originally have been designed for an external research project [1]. AutoForm also has software tools to easily identify influence and sensitivity on the stamping process. Corus was able to deliver material for the experimental validation, and the University of Twente was able to recruit a master student to perform most numerical simulations. With that the consortium for this project was born.

Figure 1: First drawing of the B-Pillar (Photograph)

Section 2 describes the series of simulations that have been performed to identify the parameters having the most influence on the result of stamping the B-Pillar. For three parameters, blankholder force and two blank shape parameters, separate parameter studies have been performed. Section 3 describes the series of experiments that has been performed while varying the above

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mentioned parameters. For result evaluation thickness measurements have been carried out. In section 4, the experiments have been validated whereas section 5 gives an outlook on future applications of this method.

2 SIMULATIONS

The stamping simulation of the B-pillar has been run with AutoForm-Incremental; for the influence and sensitivity studies AutoForm-Sigma has been used. Two main series of simulations have been carried out. First a screening-run (section 2.1) and afterwards some parameter studies were computed (section 2.2). The simulations have been performed with the material description of a high strength zinc coated steel (H340LAD) with an initial sheet thickness of 1.458 mm.

2.1 SCREENING

The choice of the parameters for the screening analysis has been based on some pre-studies on the stamping of the B-Pillar [2]. These studies showed that blank shape parameters X5 and X6 have a big influence on the stamping result (Figure 2), as well as the blankholder force.

![Figure 2: Blank with shape parameters X5 and X6.](image)

The blank position in both x- and y-direction has been varied as well in order to evaluate its influence. In Table 1, all parameters for the screening analysis are listed. 120 simulations have been performed while automatically varying all parameters within the defined ranges.

**Table 1: Parameter settings for the screening analysis**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blankholder force</td>
<td>1100 - 3300 kN</td>
</tr>
<tr>
<td>Blank X5 mm</td>
<td>0 - 20</td>
</tr>
<tr>
<td>Blank X6 mm</td>
<td>0 - 20</td>
</tr>
<tr>
<td>Position X mm</td>
<td>-2 - +2</td>
</tr>
<tr>
<td>Position Y mm</td>
<td>-2 - +2</td>
</tr>
</tbody>
</table>

Figure 3 shows the simulated B-Pillar with 2 zones indicated with a small white spot. These two zones have been used for result validation throughout the rest of the paper.

![Figure 3: The simulated B-Pillar with definition of zone A and zone B.](image)

Figure 4 shows a histogram of the thickness variation of the screening analysis. The bars indicate the frequency a thickness value occurs in the different simulations of the screening analysis. The thick vertical black line indicates the original sheet thickness of 1.458 mm. The variation in zone A shows that the thickness reduces to a median value of 1.24 mm with a relatively symmetrical distribution between 1.14 mm and 1.33 mm. For zone B the median value is 1.45 with an unsymmetrical distribution with a maximum value of 1.49 and a minimum value of 1.35.

![Figure 4: Result variation in zone A and B of the screening simulation.](image)

Figure 5 shows the sensitivity plot of the simulation. The size of the circles indicates the influence parameters have on the thickness in the defined zones A and B.

![Figure 5: Sensitivity plot for zone A and B of the screening simulation.](image)

For X5, X6 and the blankholder force separate parameter studies have been carried out in order to study the influences individually.

2.2 PARAMETER STUDIES

2.2.1 Blankholder Force

In this study the blankholder force has been varied from 1000 to 4000 kN. The blank shape parameters X5 and X6 are put on 0, which means the full blank is used. Figure 6 shows the variation of the thickness versus the blankholder force for zone A and zone B. The two horizontal lines are reference lines at a thickness of 1.458 mm (the original sheet thickness) and of 1.1 mm.

It can clearly be seen that zone A reacts more sensitive on the blankholder force variation than
zone B. The sensitivity circle diagram of the screening analysis (Figure 5) already showed this response.

**Figure 6**: Scatter plot for thickness in zone A and B as function of the blank holder force.

### 2.2.2 Blank Shape X5

In this study the blank shape parameter X5 has been varied from 0 to 35 mm. Keep in mind this is a bigger range than in the screening analysis. The blankholder force was set to 2200kN and the shape parameters X6 was set to 0. Figure 7 shows the variation of the thickness as function of the blank shape parameter X5 for zone A and zone B respectively. The two horizontal lines are reference lines at a thickness of 1.458 mm and of 1.1 mm. The blank shape parameter has been parameterized, a value of 0 corresponds to a value of 0 mm whereas a value of 1 corresponds to a value of 35 mm. Also with respect to the variation of the blank shape parameter X5, the thickness in zone A reacts much more sensitive than in zone B.

**Figure 7**: Scatter plot for thickness in zone A and B as function of the blank shape parameter X5.

### 2.2.3 Blank Shape X6

In this study the blank shape parameter X5 has been varied from 0 to 35 mm. Again a bigger range than in the screening analysis is applied. The blankholder force was set to 2200kN and the shape parameters X5 was set to 0. Figure 8 shows the variation of the thickness versus the blank shape parameter X6 for zone A and zone B. The two horizontal lines are reference lines at a thickness of 1.458 mm and of 1.1 mm.

For the variation of the blank shape parameter X6 zone B reacts more sensitive than zone A. The screening analysis showed the same response although one has to be carefully comparing the screening analysis and the parameter study since different parameter ranges have been used.

**Figure 8**: Scatter plot of thickness for zone A and B as function of the blank shape parameter X6.

### 2.3 Simulations Discussion

The scatter plots shown in section 2.2 are a good basis for experimental validation. However, the thickness distribution is not representative for judging the forming process being successful. Figure 9 shows the variation of the max failure value. The result variable max failure is defined as the ratio between the major strain and the major strain forming limit curve value at constant minor strain. The black horizontal line indicates a failure value of 1.0 which corresponds exactly to the FLC. As can be seen for blankholder forces larger than 3200kN the part will split. This information must certainly be taken into account when performing the experiments.

**Figure 9**: Scatter plot for max failure in an area below zone A as function of the blank holder force (BLHF).

Figure 10 shows the maximum draw-in target as function of the blank shape parameter X6. In case the draw-in is that large during stamping that it passes the part boundary line the draw-in target has been violated and becomes larger than 0. Out of Figure 10 one can distinguish that a large value of the blank shape parameter X6 results is too much draw-in. One can distinguish that for values larger than 0.6 the draw-in target value strongly increases.

**Figure 10**: Scatter plot for draw-in target as function of the blank shape parameters X6.
So, the general evaluation showed that the blankholder force should not exceed 3200 kN otherwise the part will split. The blank shape parameter X6 should not be too large since otherwise the blank edge will run into the final part geometry. The sensitivity circle diagram shows that the thickness values in zone A and B are relatively insensitive for the parameter PosX (blank position in length direction) but sensitive for the parameter PosY (blank position in width direction). These results have been considered when performing the experiments as will be described in the next section.

3 EXPERIMENTS

The experiments were executed at the IUL at the University of Dortmund on their hydraulic deep drawing press. The blanks were prepared on their laser cell in order to generate the different blank geometries. Based on the simulations as described in section 2 the experiments have been carried out, the parameter ranges have been defined as listed in table 2.

Table 2: Parameter settings for the experiments

<table>
<thead>
<tr>
<th>Parameter Variations</th>
<th>500-1000</th>
<th>1000-1400</th>
<th>2000-2600</th>
<th>3400-3600</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blankholder force kN</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Blank X5 mm 0 – 10</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Blank X6 mm 0 – 10</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

3.1 EXPERIMENTAL RESULTS

After stamping the part, the thickness has been measured using an ultrasonic device for validation purposes. The measurement points in zone A and B can be seen in Figure 11. For zone A measurement point 2 has been measured.

Figure 11: Definition of the zones for the thickness measurements.

Figure 12 shows the measured thickness of zone A and B versus the blankholder force. The experiments are performed with a full blank, blank shape parameters X5 and X6 are both 0. As can be seen, the thickness variation for zone A is much more sensitive for the blankholder force variation as for zone B.

Figure 12: Thickness of zone A and B versus blankholder force.

For the largest blankholder force value of 3400 kN, the part splits. Figure 13 shows the B-Pillar with the split in the vertical wall close to zone B.

Figure 13: B-Pillar with split in vertical wall for a blankholder force of 3400 kN.

Figure 14 shows the measured thickness of zone A and B versus the blank shape parameter X6. The blank shape parameter X6 is 0 and the blankholder force is 2200 kN. For both zone A and B, the thickness variation is very limited. The variation for zone A is between 1.24 and 1.28 and for zone B between 1.45 and 1.47. The experiments show no clear trend under the consideration of the given experimental scatter.

Figure 14: Thickness of zone A and B versus blank shape parameter X6.
Figure 14: Thickness of zone A and B versus blank shape parameters X5.

Figure 15 shows the measured thickness of zone A and B versus the blank shape parameter X6. The blank shape parameter X5 is 0 and the blankholder force is 2200 kN.

For both zone A and B, the thickness variation is very limited. The variation for zone A is between 1.26 and 1.30 and for zone B between 1.45 and 1.47. For the blank shape values of 10 and 20 mm, two experiments have been carried out. The variation of the experiments with equal blank shape is larger than the variation between the experiments for different blank shape due to splits in the part. For blank shape parameter X6 larger than zero no good parts have been produced.

Figure 15: Thickness for zone A and B for versus blank shape parameters X6.

4 VALIDATION

In this section the simulation results and the experimental results are compared. We have already seen in section 3 that for identical experiments, different thickness values have been measured. The thickness has been measured with an ultrasonic device with a probe with a diameter of 10 mm. The zones in the simulations have also been defined as area with a diameter of 10 mm. As can be seen in Figure 16, zone B consists of several elements. Due to adaptive refinement, the smallest element of zone B has an element side length of 2.5 mm. So, one can presume that the thickness varies in the zone as well.

Figure 16: Definition of zone B which exists of several elements.

The in-zone variation for zone A and B is plotted in Figure 17. Zone A shows a relatively small thickness variation, the range only varies between 1.25 mm and 1.26 mm. Zone B shows a larger variation. The range varies between 1.43 mm and 1.47 mm resulting in an average value of 1.45 mm. So, one can imagine that a small shift of position of zone B directly results in another average thickness value.

Figure 17: In-zone variation of thickness values in zone A and zone B.

The experimental scatter shown in Figure 12 and Figure 15 as well as the averaging of the thickness values as indicated in Figure 17 must be considered when experiment and simulation are compared.

In the following sub-sections the results of the experiments are compared with the results of the simulation parameter studies.

4.1 BLANKHOLDER FORCE

Figure 18 shows the scatter plot of the thickness of zone A and Zone B versus the blankholder force with the experimental results included in the figures. In this figure one can see that the trends of simulations and experiments coincide very well. For zone A as well as for zone B the absolute values also coincide very well.

Figure 18: Scatter plot of thickness of zone A and B versus the blankholder force with experimental results (black circles) from Figure 12.
4.2 BLANK SHAPE X5

Figure 19 shows the scatter plot of the thickness of zone A and B versus the blank shape parameter X5 with the experimental results included in the figures. In this figure one can see that the trends of simulations and experiments coincide.

For zone B the values coincide very well. For zone A the experimental data show relatively equal values whereas the simulations show a step at a blank shape parameter of 0.5 (18 mm blank cut out). The experiment with a cut out of 20 mm does not show that jump.

For small X5 values (large blank) as indicated with a in Figure 19, the material draw-in does not pass the die-radius as can be seen in Figure 20. For case b it just passes the die-radius and for case c it easily passes the die-radius and even the addendum radius. In this case the restraining of the blank is only very limited and only little thinning occurs. In the experiments that point of passing the die radius has not been achieved which explains why the jump in the thickness variation is not seen.

Figure 19: Scatter plot of thickness of zone A and B versus the blank shape parameter X5 with experimental results (black circles) from Figure 14.

Figure 20: Draw-in close to zone A for three different values of blank shape parameter X5 as indicated in Figure 19.

4.3 BLANK SHAPE X6

Figure 21 shows the scatter plot of the thickness of zone A and B versus the blank shape parameter X6 with the experimental results included in the figures. In this figure one can see that the trends of simulations and experiments do not coincide well.

As well in the simulation as in the experiments splits were observed for X6 values larger than 5 mm (simulation parameter 0.2). These splits make both measurements and simulations not reproducible anymore.

Figure 21: Scatter plot of thickness of zone A and B versus the blank shape parameter X6 with experimental results (black circles) from Figure 15.

5 CONCLUSIONS & OUTLOOK

Screening analysis and parameter studies showed clear trends in thickness distributions of the B-Pillar. Experimental validation showed identical trends and in most cases identical values.

In case one can identify the influence of several parameters on a result and one can understand the sensitivity of the result due to parameter variation, than this information can be used in tool try-out. Knowing these influences and sensitivities, guidelines describing which parameters must be varied by how much can be defined to adjust try-out results. So, a try-out map can be defined in order to more effectively perform the tool try-out and reduce the costly try-out time.

6 ACKNOWLEDGEMENT

The authors kindly thank the employees of the IUL of the University of Dortmund for their excellent support and contribution in performing the experiments. Many thanks also to Martijn Bonte and Rick ter Wijlen who both did a lot of work in the pre-studies and experiments.

7 REFERENCES
