Comparison of sheet-metal-forming simulation and try-out tools in the design of a forming tool

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Comparison of sheet-metal-forming simulation and try-out tools in the design of a forming tool

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Abstract

Today, sheet-metal-forming simulation is a powerful technique for predicting the formability of automotive parts. Compared with traditional methods such as the use of try-out tools, sheet-metal-forming simulation enables a significant increase in the number of tool designs that can be tested before hard tools are manufactured. Another advantage of sheet-metal-forming simulation is the possibility to use it at an early stage of the design process, for example in the preliminary design phase. Today the accuracy of the results in sheet-metal-forming simulation is high enough to replace the use of try-out tools to a great extent. At Volvo Car Corporation, Body Components (VCBC), where this study has been done, sheet-metal-forming simulation is used as an integrated part in the process of tool design and tool production.

Key words: Sheet-metal forming, Simulation, Finite element method, Try-out tool

1 Introduction

Traditionally, try-out tools are used in order to verify that a certain tool design will produce parts of the required quality. The try-out tools are often made of a cheaper material, e.g. kirksite, than production tools in order to reduce the try-out costs. This is a very time- and cost consuming method. However, today another more efficient technique is available – sheet-metal-forming simulation. This new technique is based on the simulation of the forming process, and could result in a cost reduction of factor 10 and a time reduction of factor 15 for each hard tool.

Sheet-metal-forming simulation technology is constantly developing and the results of the simulations are more and more accurate. In the future it will also be possible to analyse more processes using sheet-metal-forming simulations. Today the accuracy of the results in sheet-metal-forming simulation is high enough to replace the use of try-out tools to a great extent.

2 Method

The purpose of this study is to analyse and compare the benefits and drawbacks of the use of sheet-metal-forming simulation and try-out tools in the design of forming tools. The method employed in this study is based on the Production Reliability Matrix (Rundqvist and Ståhl, 2001) together with a Process Correspondence Matrix which has been developed especially for this study. The Production Reliability Matrix (PSM) is a matrix that categorises the effects of different factors (parameters) in the process into different factor groups. The effect of each factor (parameter) is then assessed according to a scale of 0-3. Based on the results of the matrix, the parameters that have the most considerable effects on the production process can be extracted and a priority list for neutralising or minimising these effects can be made. The Process Correspondence Matrix (PCM) has been developed through extensive interviews of senior experts in automotive component forming to analyse the correspondence between the results of sheet-metal-forming simulations, the try-out tool and the quality of produced parts in actual production.

3 Process for designing a forming tool

Figure 1 shows a simplified flow of the production process of developing a forming tool at VCBC.

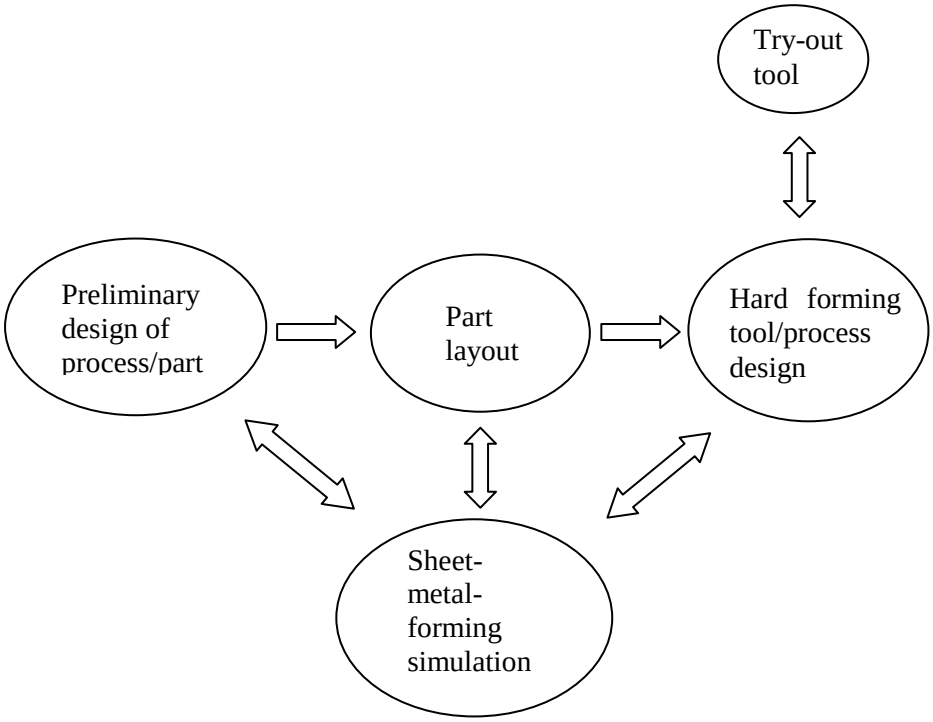

Figure 1: *Process for designing a forming tool at VCBC.*

The process of the design of a forming tool includes a try-out phase where different designs of the tool are tested. This is a very important stage in the tool design process, in order to verify that the part will fulfil the required quality. It is very difficult to predict the result of a forming operation, but by using sheet-metal-forming simulation there is a possibility to gain valuable insight into the outcome of the forming operation.

3.1 Use of sheet-metal-forming simulation

Sheet-metal-forming simulation can be used in several stages of a tool design process:

- Early in the preliminary design phase, to enable rapid verification of different proposals for the design of automotive components.
- To predict and verify the forming process.
- To improve an existing process.

3.1.1 Requirements for sheet-metal-forming simulation

Sheet-metal-forming simulation requires the following :

- Simulation software.
- A CAD-model of the part layout or a CAD model of the forming surfaces of the tool.
- Parameters for description of the specified sheet-metal material.
- Process parameters.
- Workstations (Today the development of the PC's is rapidly advancing so that PC's will be a strong alternative in the future).
- A competent staff who can handle the software and analyse the results of the simulation.

Simulation software
Today there is a variety of commercial software available on the market. In order to find suitable software the area of use must be analysed. The software package is different with regard to user-friendliness and flexibility.

At VCBC, where this study was performed, two different software packages are used. One is Autoform (2001) which is user-friendly and provides fast results. This software is used for the iterative process of finding the proper tool geometry. The other software is LS-DYNA, which is used at VCBC to verify the results of Autoform.

CAD-model
In order to analyse a part or a tool design using sheet-metal-forming simulation, a CAD-model of the part or tool is needed. This model can be created in most CAD-programs, for instance CATIA, which is used at VCBC. Different simulation software demand different qualities of the CAD-models.

Material parameters
Uniaxial tensile tests are used to describe the material parameters. There is also a need for describing the risk of fracture in the material. Data regarding risk for fracture are obtained by creating a forming limit curve (FLC). The

FLC is a curve in the plane of principal strains that indicates the maximum allowed strain values before fracture occurs. A more thorough description is presented in Pearce (1991).

Process parameters
Sheet-metal-forming simulation requires proper process parameters e.g. drawbeads.

Workstations
The simulation models that are used in sheet-metal-forming simulation are generally so large that they require a workstation in order to achieve reasonable calculation times. However the development of PC's enables the clustering of several PC's which can be an alternative to workstations.

Competent personnel
In order to interpret the results of a sheet-metal-forming simulation it is necessary to enter the correct input data, and possess the ability to understand the results. This requires competent personnel. The competence should consist of both forming knowledge and simulation knowledge since that gives a natural connection between the production process and the interpretation of the results.

3.2 Results of a sheet-metal-forming simulation

Sheet-metal-forming simulation enables the study of:

- Thickness distribution.
- Risk of fracture.
- Draw lines.
- Wrinkles.
- Drawbeads/Blankholder pressure.
- Surface defects.
- Stability of the surface.
- Springback.
- Material behaviour.
- Process surveillance.
- Draw in.
- Forming window.
- Forces (Punch, Blankholder).

In order to demonstrate possible results, a simulation of a Body Side Outer from a Volvo S80 has been studied. The material used for this automotive component is a mild steel with good formability (V-1158). Material data can be found in table 1.

Table 1: *Material data for V-1158.*

Thickness (mm)	Rp0.2 (MPa)	Rm (MPa)	n-value (average)	R-value (average)
0.8	140	329	0.243	1.76

Thickness distribution
The sheet-metal-forming simulation can provide a good approximation of the thickness distribution for a part, see appendix 1 figure 2. In the automotive industry there are requirements concerning the maximum allowable reduction in thickness, in order to ensure safety margins in the event of a crash.

Risk for fracture
Risk for fracture during the forming process could be evaluated by means of a forming limit curve, which is described earlier in this section. An example can be seen in appendix 1 figure 3.

Draw lines
Draw lines occur when a section of an part has been gliding over a radius during forming. A plot of how a point on the part surface moves during the simulation (see appendix 1, figure 4) illustrates these lines. Draw lines are not acceptable on a visible surface on an exterior part

Wrinkles
Visible wrinkles are not allowed on a part. These can be detected with sheet-metal-forming simulation, see appendix 1 figure 6.

Forces
In order to dimension the process in an accurate way it is necessary to know which forces are necessary to form the part. The data for these forces can be obtained from the results of a sheet-metal-forming simulation.

Surface defects
Exterior automotive parts are sensitive to deflections of the surface that can occur during forming. These deflections can be very small but can still be visible after the part is painted, which means that the part must be scrapped. The defects can be detected by the human hand as it moves gently across the surface. Sheet-metal-forming simulation can be used for detecting risk areas through analysis of the strain distribution.

Stability of the surface
Stable surfaces are required in order to increase the stiffness of the part to prevent the part from becoming unstable and vibrating. Sheet-metal-forming

simulation can be used for detecting risk areas through analysis of the strain distribution, see appendix 1 figure 6.

Process surveillance
In sheet-metal-forming simulation the process can be followed in detail by means of animations. Figure 6 in appendix 1 illustrates this.

Draw in
To minimise material consumption, it is important to optimise the shape of the blank. Sheet-metal-forming simulation can facilitate optimisation of the blank by analysing the draw in.

3.3 Use of try-out tools

Try-out tools are used when the design of the process shall be verified, see Figure 1. Based on this design the try-out tools are then cast in kirksite for example. Prototype parts are then produced from this try-out tool. There are several differences between a try-out tool and a production tool. One is that the try-out tool wears out much faster than a production tool. Therefore, it is not possible to produce so many parts in a try-out tool. Another difference is that a try-out tool is much cheaper than a production tool. However, since there are differences between the two types of tools there is no guarantee that the parts produced in the two types of tools will have the same quality.

4 Production Reliability Matrix

The Production Reliability Matrix (PSM) can be used to determine which parameters have significant effects on the stability of the process. It is also possible to determine the extent of an effect. This provides valuable help in the identification of the most severe problems. These severe problems are especially interesting since they are the most cost effective when solved. A more detailed description of the PSM is presented by Rundqvist and Ståhl (2001). An example where the PSM is applied is presented in Pettersson (1991) where the PSM is used to analyse different processes at VCBC.

5 Result

The technique of using try-out tools has been compared with the technique of using sheet-metal-forming simulation from two aspects. The first aspect is a comparison of the ability to predict the different parameters of the production process, mentioned in section 3. The second aspect is the ability to verify which process parameters should be studied.

5.1 Study of agreement of predicted process with production process

The Production Correspondence Matrix allows a clear comparison between try-out tools and simulation regarding correspondence with the production process. In table 2 the different fields of applications for the different techniques are listed together with the ability to predict behaviour in the production process. The values in table 2 have been determined through extensive interviews with senior forming experts.

Table 2: *Process Correspondence Matrix (PCM).*

Process	Thickness distribution	Risk for fracture	Fracture	Draw lines	Wrinkels	Surface defects	Stiffness in part	Springback	Material properties	Process surveillance	Draw in	Forces-punch	Drawbeads	Blankholder force	Forming window
Simulation	4	4	4	4	4	2	2	2	4	4	4	3	2	2	4
Try-out tool	3	3	4	3	4	4	4	3	2	3	4	3	4	3	3

In table 2 the following scale is used:

5 The results show perfect agreement with production process.

4 The results show good agreement with production process. Special cases can deviate.

3 The results show good agreement in most cases with production process.

2 The results show good agreement in certain cases with production process. Indirect interpretation of the results is needed.

1 The results show no agreement with production process. It can not be used for process prediction or verification.

Comments to table 2.

- The difference between risk for fracture and actual fracture is that risk for fracture shows areas which have not cracked but where necking has appeared.
- The parameter “Material characteristics” refers to the ability to predict the quality of the part depending on variation in the material quality.
- Process surveillance enables the monitoring of how different parameters change during the process.
- The forming window is an aid for detecting how sensitive the process is to disturbances.
- The values for the tool-forces are based on the assumption that it is possible to measure the forces in the try-out press.

5.2 Study of which factors in the production process are possible to analyse

The concept of grouping different factors that are typical for the production process into different factor groups has been used in this study according to the PSM-model. In a previous study, Andersson et al. 2001, different factors concerning the forming of aluminium were studied. This work has been modified in order to facilitate a comparison between the two techniques for prediction and verification considered in this study, namely, sheet-metal-forming simulation and try-out tools. See table 3 for the results.

Table 3: *Production Reliability Matrix (PSM).*

	Factor groups	Sheet-metal-forming simulation	Try-out tool
A	**Tooling**		
A1	Tool geometry	2	2
A2	Microgeometri/Surface	0	1
A3	Drawbeads	1	2
B	**Material**		
B1	Thickness distribution	2	2
B2	Risc for fracture	2	2
B3	Draw lines	2	2
B4	Wrinkels	2	2
B5	Surface defects	1	2
B7	Surface stability	1	2
B8	Springback	1	2
B9	Material properties	2	2
B10	Draw in	2	2
B11	Surface roughness/galling	0	2
C	**Process**		
C1	Press velocity	1	2
C2	Temperature	0	1
C3	Lubricant	1	2
C4	Forces - punch	2	2*
C5	Forces - blankholder	2	2*
C6	Forming window	2	2
D	**Human factor**		
D1	Control	1	2
D2	Change frequence	1	2
E	**Maintenance**		
E2	Press maintenance	1	1
F	**Special factors**		
F1	Tool cleaning	0	2
G	**Misc. equipment**		
G1	Handling equipment	1	3

** Assuming the possibility of measuring forces in the try-out tool*

In table 3 the following scale is used:
3 - The results show perfect prediction of production process.
2 – The results show direct prediction of production process.
1 – The results show indirect prediction of production process.
0 – The results cannot predict production process at all.

5.3 Restriction/expansion of test possibilities

An analysis of table 2 and table 3 shows several advantages of using sheet-metal-simulation in the tool design process. However one of the biggest advantages of sheet-metal-forming simulation is that it enables the testing of many different designs of the part, tool or process, which generates substantial savings in costs and time. In this respect, try-out tools are more limited and expensive, which means that only a minimum number of try-out tools are produced. The use of try-out tools contributes to a restriction of test possibilities while the use of sheet-metal-forming simulation contributes to an expansion in test possibilities.

6 Conclusions

The use of sheet-metal-forming simulation leads to a significant reduction in both cost and time compared with the use of try-out tools. The requirement is that the respective parameter for study (see section 3.1.2) demonstrates good correspondence between simulation and actual production processes. Sheet-metal-forming simulation is also superior to try-out tools with regard to predicting and verifying the forming process.

The investment requirements are relatively small when starting to implement sheet-metal-forming simulation. It is necessary to invest in a workstation and software, which cost about SEK 500,000. In addition it is necessary to have competent personal for handling the sheet-metal-forming simulation. Compared with the investment for one try-out tool (>SEK 500,000 per tool) it is clear that there is a lot to gain in reducing cost and time if sheet-metal-forming simulation is used when it is suitable.

As stated above, today the accuracy of the results in sheet-metal-forming simulation is high enough to replace the use of try-out tools to a great extent. The use of try-out tools in the tool design process may be necessary for some time to come to verify some process parameters, but the following advantages are closely associated with sheet-metal-forming simulation:

- deeper insight into the process at significantly earlier stages.
- greater flexibility in testing designs for the part, the tool and the process.
- greater understanding of when try-out tools should be used, making try-out tools much more cost-effective.
- greater potential to design cars with more daring designs.
- greater possibility to test new materials for the automotive parts.
- greater competitive advantage due to more daring designs, lower costs and shorter lead times.

7 Comments

At VCBC, where this study was done, sheet-metal-forming simulation is today a natural part of the tool design process. Sheet-metal-forming simulation has been used in manufacturing since 1995 and the experiences have been very good. Today all processes that are so complex that it is difficult to choose process conditions based on experience are simulated. During the development of the Volvo S80, which was the first car project to use simulation technology in full scale, it was established that there was a significant decrease in problems in the process when it was introduced in actual production for the first time.

Acknowledgement

I would like to express my gratitude to my colleagues at VCBC, who have contributed much valuable information and interesting discussions during this work. I would also like to thank Professor Jan-Eric Ståhl (Division of Production and Materials Engineering, Lund University) and Professor Kjell Mattiasson (Chalmers University of Technology) for their support and constructive criticism of the article.

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Appendix 1. Images from a sheet-metal-forming simulation

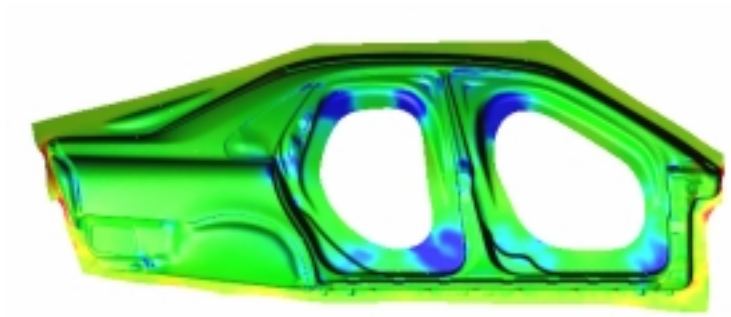


Figure 2: *Thickness distribution. The scale shows blue for 20% thinning and red for 10% thickening.*

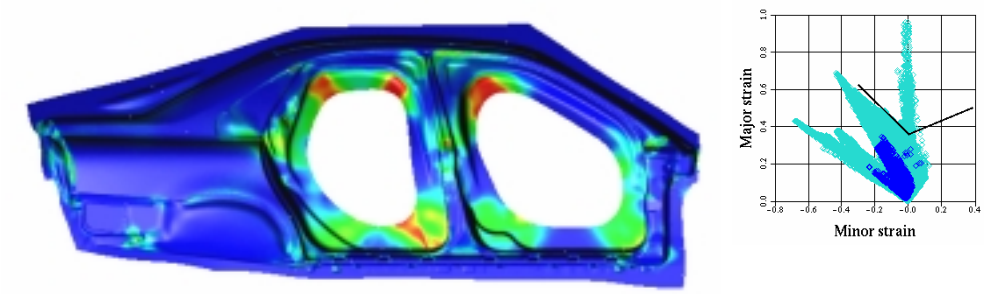


Figure 3: *Risk for fracture. In this image, cracks are shown in red. To the right is the forming limit curve represented by the black line. Shown also are the results of the simulations (blue points).*

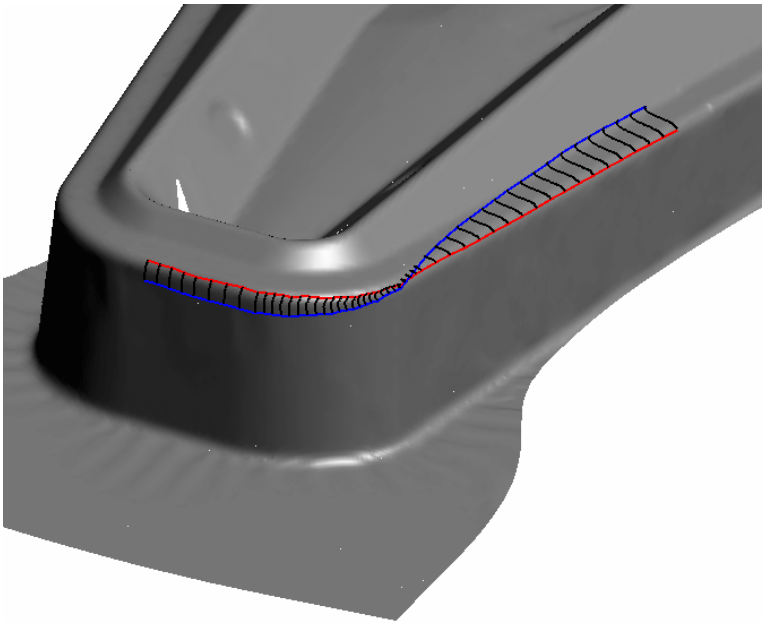
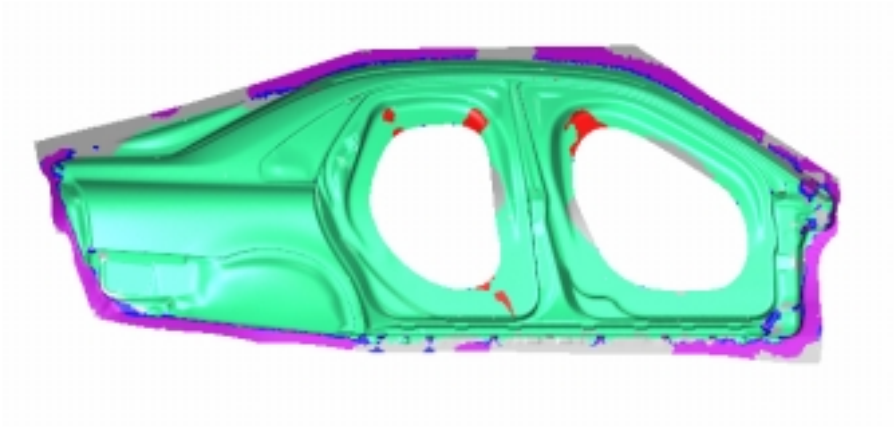


Figure 4: *The blue line in the image shows how the material has flowed during the forming operation. If the material has flowed over a radius, a draw line will appear on the part. If the draw line appears on a visible surface of an exterior part, the part will be rejected for quality reasons.*

Formability



Second principal strain

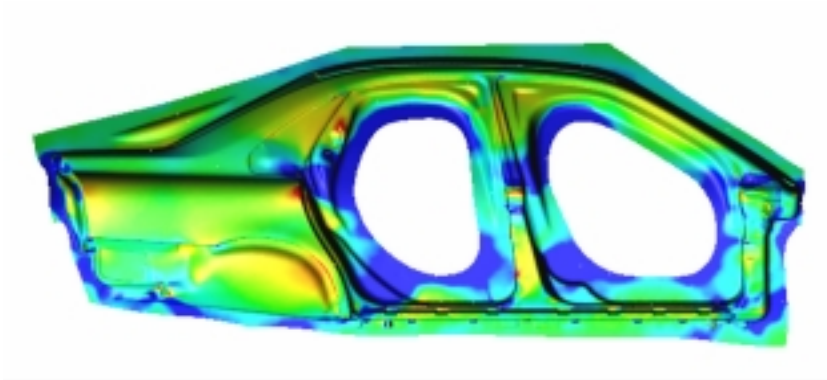


Figure 5: *In the images above, which describe formability, surfaces with enough strains to be stable can be seen. By studying these images together it is possible to estimate the stability of the surfaces. The upper image shows the formability. The grey areas in the lower image indicate unstable surfaces and the pink area indicates wrinkles. In the lower image the surfaces with small strains are marked with blue, which indicates compression. If these areas are located on a visible surface of an exterior part there is a risk for unstable areas.*

This is a simplified analysis. A more detailed analysis would include the interaction between stresses and strains for the complete part.

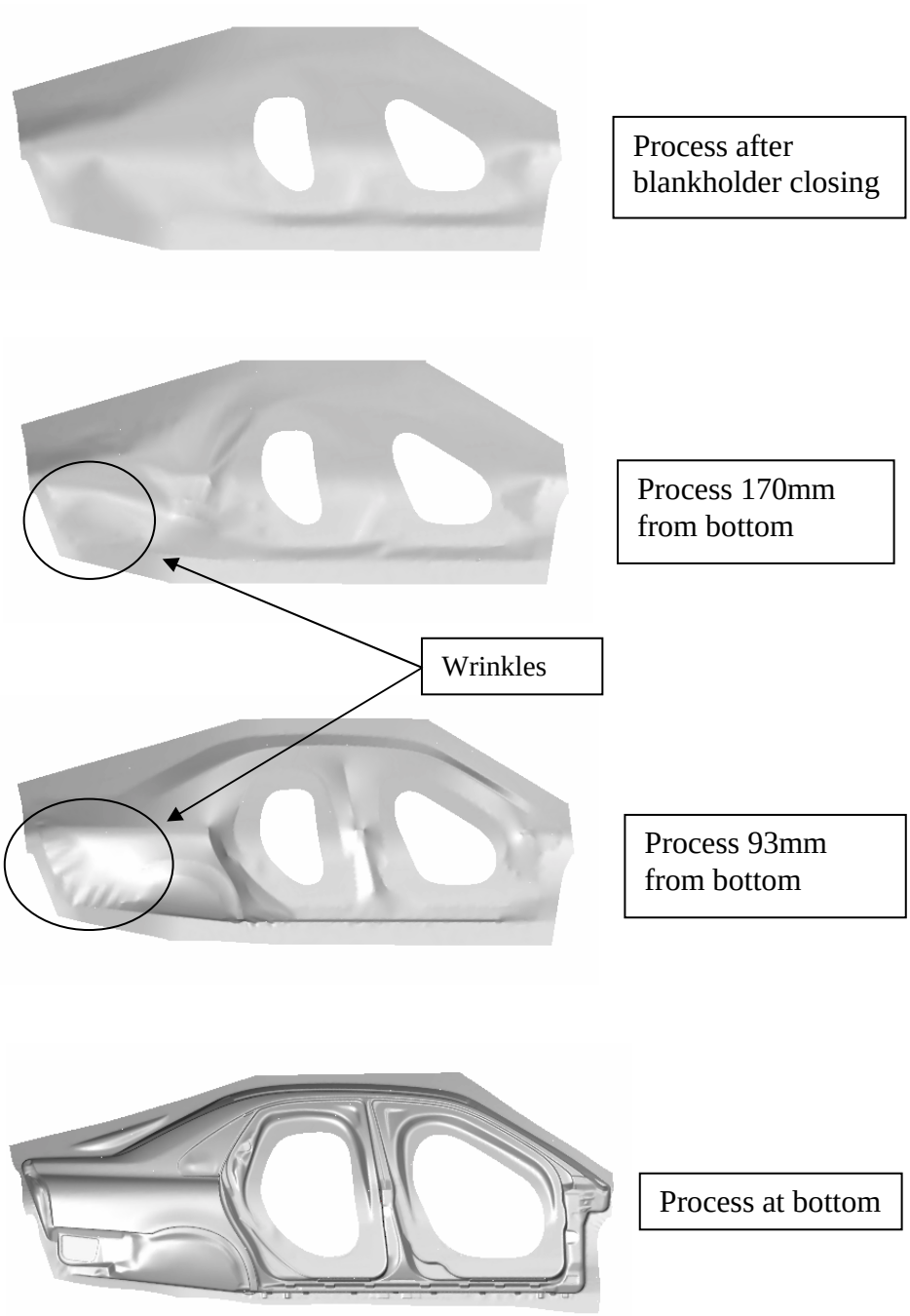


Figure 6: *The images show an example of surveillance of the process. It is easy to follow how the wrinkles develop during the forming process.*

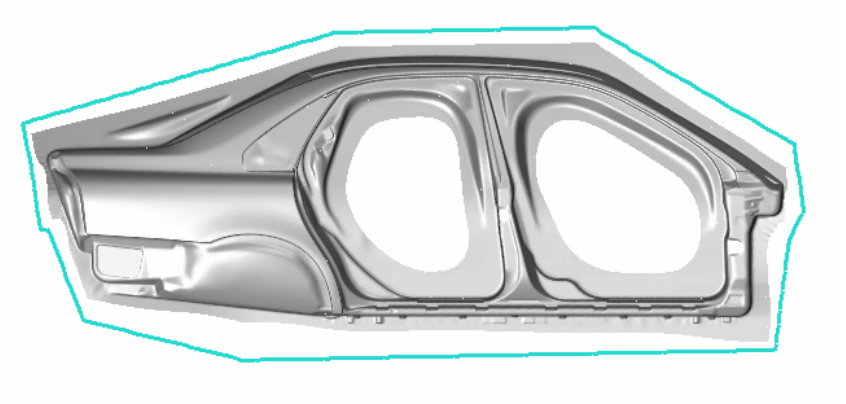


Figure 7: *The line shows the sheet position after blankholder closing. The draw in can then easily be measured by a comparison with the line in bottom position.*