Simulation of Sheet Metal Forming using Elastic Stamping Dies

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1 Abstract

Simulation of sheet metal forming is one of the major applications of LS-DYNA. Today, a majority of the forming industry is using Finite Element models to design the stamping dies in order to prevent excessive thinning, wrinkling and producing parts within tolerance by compensating for springback deformation. All these simulations are made using the assumption of rigid forming surfaces. Depending on the type of press, tool design and sheet metal part, this assumption could prove to be incorrect which yields a forming result that depends on the elastic deformation of the stamping die and in some cases the entire stamping press. Such deformations are usually compensated during die try-out by manual rework which is costly and time consuming.

This paper presents the result of a study performed at Volvo Cars press shop in Olofström, Sweden, aiming at determining computational methods to introduce elastic stamping dies in the sheet metal forming simulations in order to minimize manual rework by performing a virtual tryout of the stamping die. The methodology to model the stamping die and the forming surfaces in LS-DYNA are presented and a simulation model is gradually improved from using nominal rigid CAD surfaces through scanned tool surfaces and finishing with an elastic model of the stamping die assembly. The part used in the study is the side door inner for Volvo XC90 and comparisons are continuously made between simulations results and measurements on parts from running production.

2 Introduction

The car industry is a very challenging area to compete within, and the complexity and speed is constantly increasing. To be able to compete it is key to use reliable virtual tools for design, prediction, and testing of products instead of physical prototypes. One of the areas where simulations are used extensively is sheet metal forming, both for finding viable designs of metal parts and design of the stamping dies. This has led to a drastic decrease in lead times for new stamping dies.

Even though the simulations have improved the manufacturing process of stamping dies a lot, there is still a large room for reduction in lead time. One of the bottle necks in the car projects of today is the manual rework required for every new die. The rework process is further described by Lingbeek [1] and Pilthammar [2], and it consists to a large degree of compensating the forming surfaces against elastic deformations of stamping dies and presses. These elastic deformations are not considered in the vast majority of industrial sheet metal forming simulations. To simplify the modelling and reduce solver time an assumption is made that only the blank exhibits elastic and plastic deformations visualized in Fig.1.

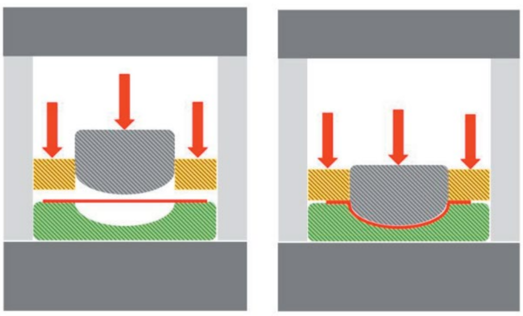

Fig.1: Sheet metal forming in a double action press with rigid die and press structure [3].

In reality both the stamping die and press is behaving as elastic bodies. Even though these deformations are relatively small, often on a sub millimetre scale, they have a vast impact on the forming process and causes a lot of time consuming and manual rework.

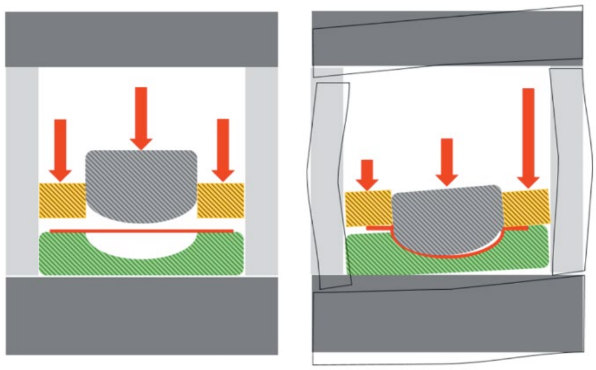

Fig.2: Sheet metal forming in a double action press with elastic die and press structure [3].

The current development and manufacturing flow of a stamping die is visualized in Fig. 3. Since a manual rework is performed on the physical die it is not certain that the geometry of the final forming surfaces are represented in the final CAD-geometry of the die, unless a detailed scanning and accurate update of the CAD-model is performed. This can limit the possibility for production support later on during the life of the die.

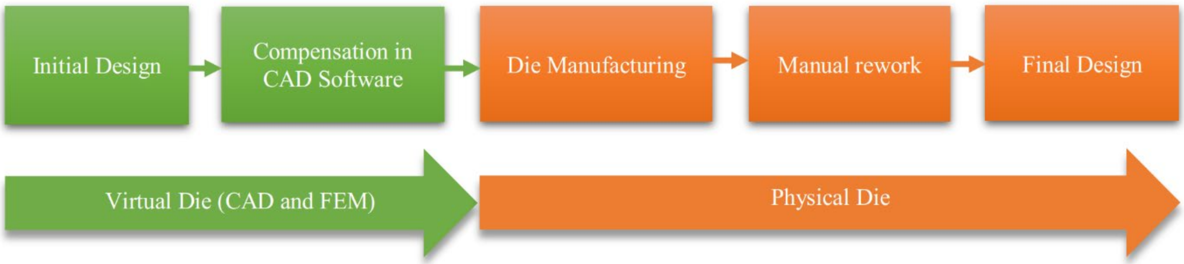

Fig.3: Sheet metal forming in a double action press with elastic die and press structure [3].

The aim of this study is to setup and analyse a model of sheet metal forming with a complete elastic stamping die and press cushion. The part that is studied is a front inner door for Volvo XC90, produced in a single action stamping die. Models of this size is not used in car projects due to their complexity in modelling and simulation times. However, if the solver time can be reduced and the modelling made relatively simple, these simulations can have a large impact on the lead time for stamping dies. The following questions are meant to be answered by this study, see Lind and Sjöblom [4]:

- Is it possible to model a sheet metal forming operation of a Volvo XC90 inner door using elastic stamping dies?
- What can be a suitable sheet metal forming and structural analysis combination to continuously include stamping die deformations?
- Can predicted major strain results from a forming simulation with scanned stamping die surfaces correspond to major strain measurements of a blank used in production?
- Can a sheet metal forming process be simulated with low computational time and acceptable results using complete elastic stamping die?

3 Method Description and FE-model setup

As mentioned previously, the purpose of the study is to investigate whether introducing elastic stamping die parts in the sheet metal forming simulations will lead to an increased accuracy when simulation results are compared to measurements from production. It is evident that the contact surfaces will have an effect on how the forming forces are applied. Thus, when doing this type of comparison it is of outmost importance to know the geometry of the forming surfaces. The forming surfaces are milled using nominal surfaces from CAD but the actual forming surfaces in the tooling could differ due to manual reworking during die try-out or due to wear. Further, shims are applied to the blank holder kissing blocks in order to balance out the die during try out. This will of course affect the forces in the tooling and consequently the tool deformations.

In this paper, two different geometry scenarios together with two modelling assumptions will be presented in the chapter were simulation and measurement results are compared. Firstly, nominal CAD surfaces and rigid tools are used as a reference simulation since this is often the only information of the forming surface geometry available when comparing simulations and measurements results. This model will then also be simulated with an elastic stamping die and the results compared with reference model to study the effects by this modification. In order to take manual rework into account, the actual forming surfaces are 3D-scanned to create a second variant of tooling geometry but still assuming a rigid tooling. The final simulation set-up is to use the scanned surface and also assume that the die structure is elastic. In the FE-models using scanned forming surfaces, the scanned contact surfaces of the kissing blocks in die and blank holder are also included in the model.

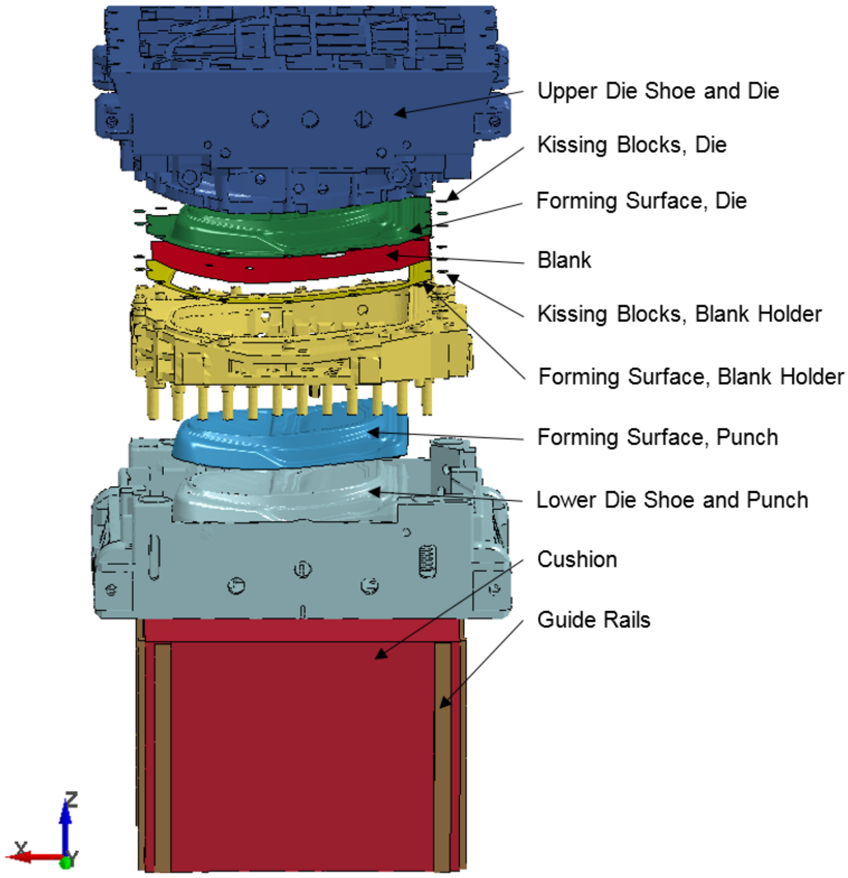

Fig.4: Exploded view of a complete model using scanned shims and forming surfaces.

The sheet metal forming simulation is preceded by a gravity simulation which is done using the implicit solver and imported into the explicit forming simulation. In a single action die, the punch is bolted to the press table which is static. This is modelled by constraining the translations of bottom of the shoe. The die part is connected to the moving upper press slide. To accommodate this, a prescribed motion to a node set at the upper die shoe are used, see Fig. 5-6.

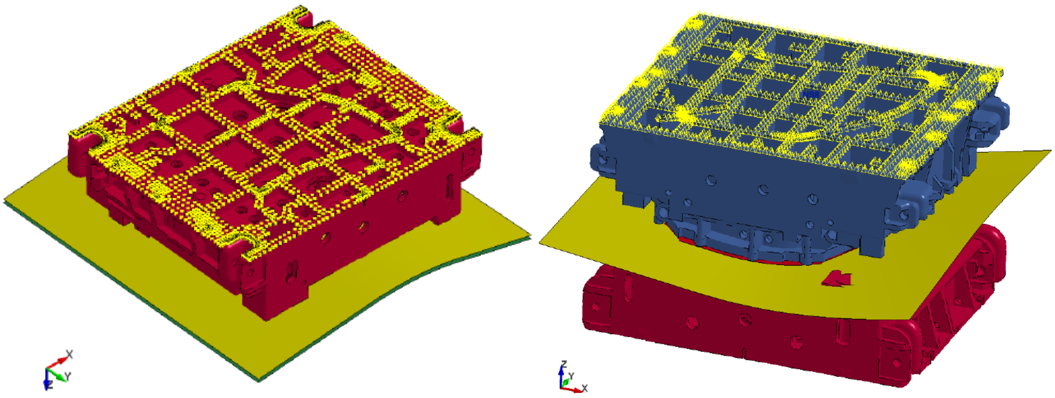

Fig.5: Constrained punch surface and prescribed motion node set on upper die shoe

The blank holder is resting on pins that are located at top of the press cushion. The total blank holder force of 1.5 MN is applied in the two points where the hydraulic cylinders are mounted to the bottom part of the cushion in the real press. The movement of the blank holder is not constrained in any direction, but in order to limit its movement in the xy-plane of the die coordinate system, contact between its wear plates and the punch and lower die shoe is defined, see Fig. 6.

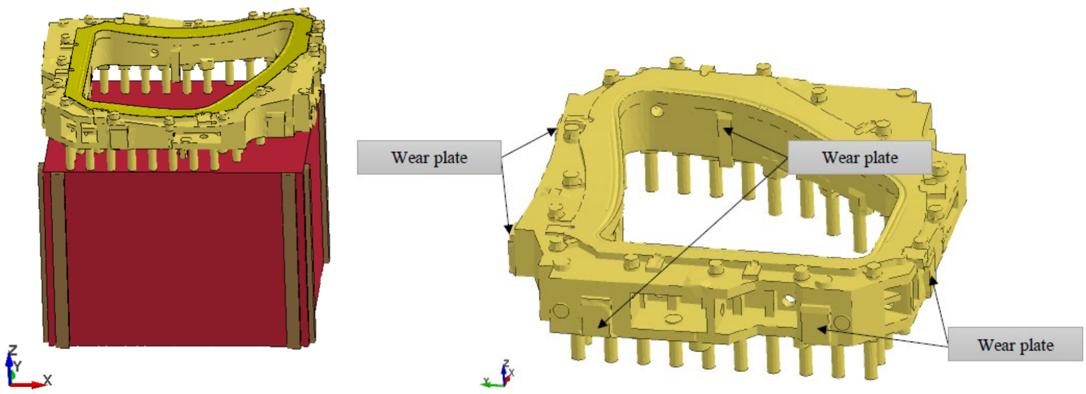

Fig.6: Blank holder on press cushion and position of wear plates.

The stamping die material is assumed to be elastic using nodular iron material data, see Table 1. The blank material is VDA239 CR4-GI with a thickness of 0.7 mm. It is modelled using shell elements and the YLD 2000 material model, see Table 1 for material anisotropy data and Fig 7 presents the material hardening curve.

	Blank material (YLD 2000)	**Stamping die material (Elastic)**
Density [kg/m^3]	7800	7200
Young's Modulus [GPa]	210	180
Poisson's ratio	0.3	0.28
Sig00 [MPa]	156.6	-
Sig45 [MPa]	160.0	-
Sig90 [MPa]	156.0	-
R00	1.805	-
R45	1.336	-
R90	1.876	-
SIGXX [MPa]	187.0	-
SIGYY [MPa]	187.0	-
DXX	1.000	-
DYY	-0.982	-
A	4.5	-

Table 1: Material data

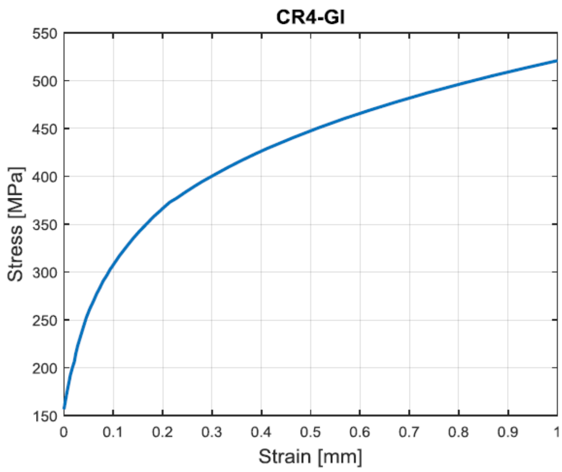

Fig.7: CR4-GI material hardening

In order to reduce the simulation time, both time and mass scaling is used in explicit FE technology. The time-step is limited by the minimum ratio of the speed of sound and the element length. Mass scaling involves raising the mass on an element level and by this decreasing the speed of sound in order to meet the Courant timestep. Also, time scaling is used which means increasing the speed of the press ram. The ram speed in the FE-model is typically in the range of 2000-5000 mm/s compared to the maximum ram velocity in the press line for this part which is 280 mm/s. Unfortunately, this introduces dynamics into the system which affects the results. In this work, a ram velocity of 500 mm/s proved to give a quasi-static solution. However, by decreasing the density of the blank holder and the cushion, it was possible to increase the speed to 2500 mm/s and significantly reducing the simulation time.

4 Modelling of elastic dies in LS-DYNA

One of the main issues when simulating deformable stamping dies is the solid modelling of the tooling. Often e.g. die radii and draw beads are in the range of a few millimetres while the global size of the stamping die could be several meters. This contradiction makes the meshing of the stamping die a huge task and also generating very large models with long simulation times. One way to remedy this is to use a separate shell element mesh for the forming surface which requires a very high dense mesh in order to model the contact between the sheet and the die accurately, and a coarser solid element mesh for the tooling to capture a more global structural behaviour as proposed by Haufe et al [5]. The idea is to use a fine surface mesh with **`*MAT_NULL`** and tie it to a coarser solid tool mesh by **`*CONTACT_TIED_NODES_TO_SURFACE_CONSTRAINED_OFFSET`**, see Fig 8.

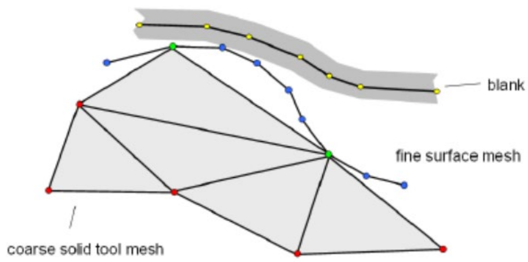

Fig.8: Idea of tying a shell surface mesh to a solid mesh, see Haufe et al [5]

The benefit of this approach is obviously that the number of solid elements can be minimized and the time spent on meshing the stamping die structure is limited. Another benefit is that it is fairly easy to modify the forming surfaces since it only requires changing the shell mesh and not the entire stamping die structure. In this study, the same solid mesh was used for all tooling surface scenarios. The tooling was meshed using LS-PREPOST and tetrahedron element 13. The element size varied between 20 mm and 6 mm depending on the geometry. Fig. 9 show the mesh of the blank holder mesh and Table 2 the model size.

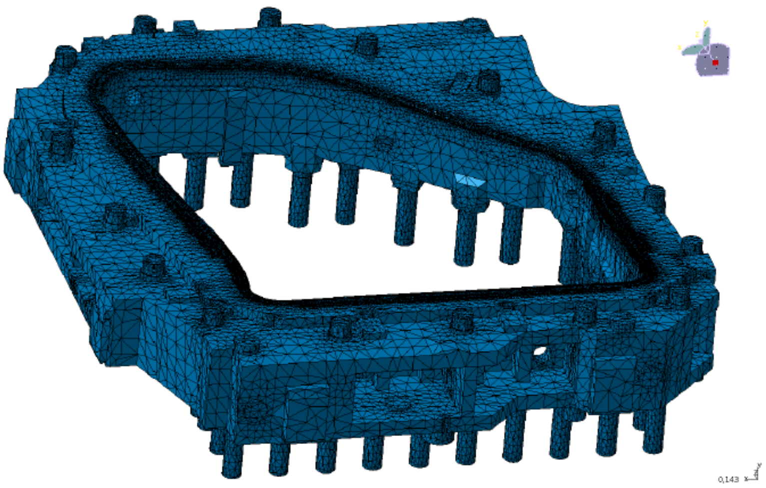

Fig.9: Blank holder mesh

Blank	Blank holder		Die		Punch		Total
	Solids	Shell	Solids	Shell	Solids	Shell	
1817747	280665	781648	1519259	2947989	641526	1793429	9972551

Table 2: Model size

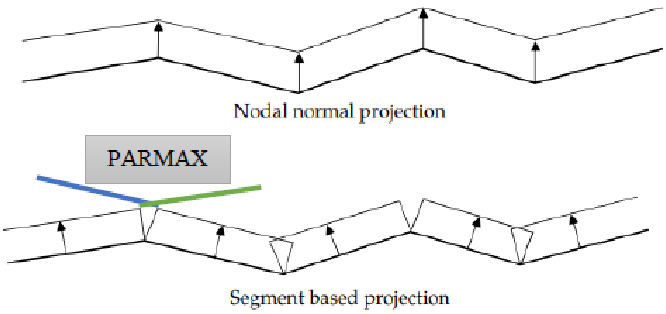

Fig.10: Contact segment extension using option …_MPP and PARMAX

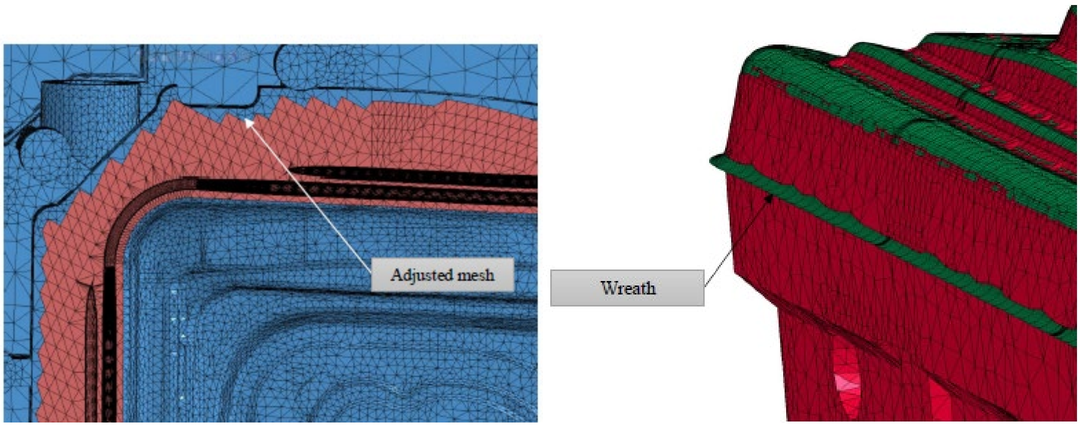

Fig.11: Null shell contact segments tied to a solid tool mesh

When tying the null shell nodes to the solid mesh it is of outmost importance that all the nodes are tied to the solid surfaces. In this study, two contact parameters were used to ensure that all the nodes were tied to a corresponding segment. Firstly, the search depth of the …`_TIED` contact can be set by a negative value in the SST/MST parameter. Secondly, due to the relatively coarse solid mesh and the thickness offset, the segment based projection could result in a gap between the segments resulting in that the node will not find a contact segment. By using option …`_MPP` it is possible to extend the contact segment by the PARMAX parameter, see Fig 10. The shell mesh was manually trimmed and elements that were not likely to contact with the blank was left out, see Fig 11.

5 Results

5.1 Measurements in production

Draw-in and strain measurements were performed on parts produced under production conditions in the press line normally used for stamping the Volvo XC90 door inner parts. These measurements was done together with the steel material supplier for this part, Tata Steel. The draw-in was determined by scanning of parts after both blank holder closing as well as after the first forming operation. The strain measurements was made by etching a grid with 2 mm grid size on a number of areas of the blank before the stamping of the part. After the stamping of the gridded blanks, the strain field was determined by the ARAMIS system from GOM. The same system was also used for the comparison between major strain from simulations and the measured values presented in Fig 12-14.

5.2 Simulation results using nominal forming surfaces and a rigid stamping die

To the left in Fig 12, the predicted part shape after forming is presented together with the edge from the scanned part. Along the top and bottom part of the door inner, the agreement between the predicted edge and the measured one is quite good. However, along the front and rear side of the door, the predicted draw-in is much lower than measured one.

The right part of Fig 12 displays the difference in major strain between the forming simulation prediction and the strain measurements. The smaller this difference is, i.e. in the green areas of the plot, the more accurate the simulation results is. If the presented value is positive as in the red areas of the plot, the simulation overpredicts the major strain and if the simulation results underpredict the strains, the presented value is negative, i.e. the blue areas of the plot. Figure 12 shows that using the nominal surfaces and rigid dies overpredict the strains in large areas of the door inner. This is to some extent unexpected since the draw-in is relatively well predicted.

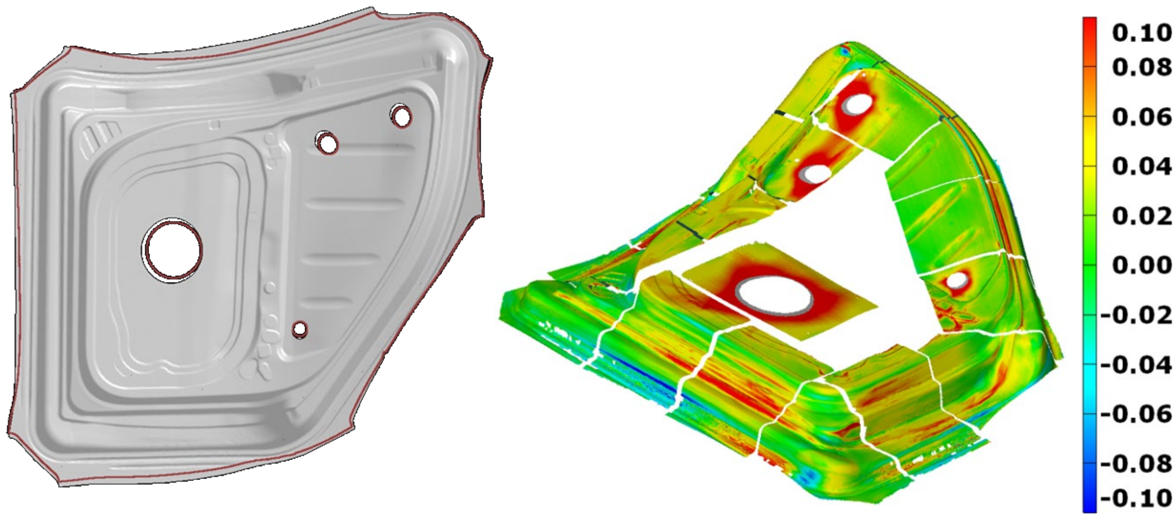

Fig.12: Comparison between simulation results with nominal forming surfaces and a rigid stamping die.
To the left: Part shape from simulation after forming (grey part) together measured edge from real parts (red curve). To the right: Difference in major strain between simulation and the measured ones in the real part.

5.3 Simulation results using nominal forming surfaces and an elastic stamping die

The only difference between this model and the previous one is that in this case the stamping die structure is assumed to be elastic and modelled with solids. The draw-in and major strain comparison is presented in Fig 13. This modification improves accuracy of both the draw-in and major strain prediction.

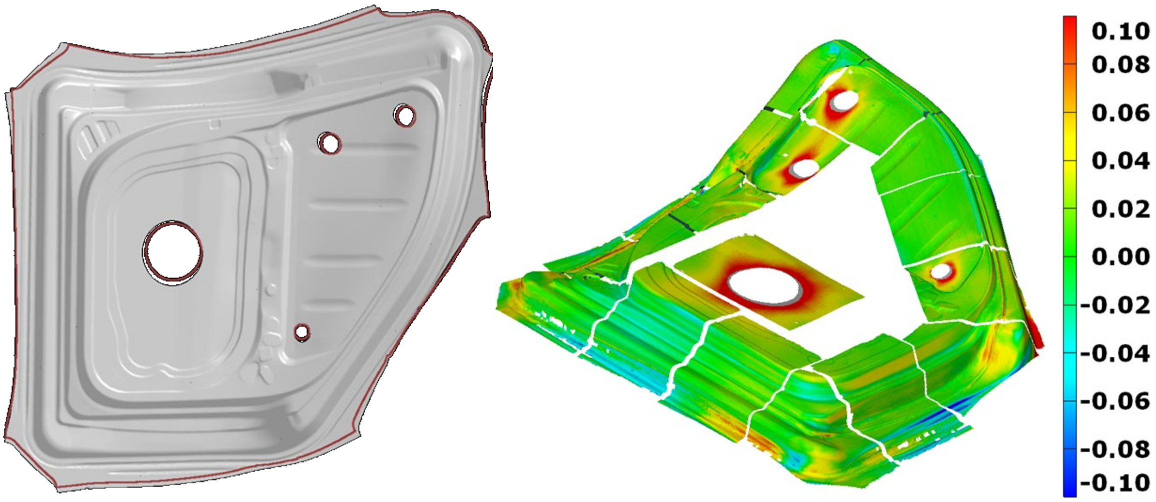

Fig.13: Comparison between simulation results with nominal forming surfaces and an elastic stamping die. To the left: Part shape from simulation after forming (grey part) together measured edge from real parts (red curve). To the right: Difference in major strain between simulation and the measured ones in the real part

5.4 Simulation results using scanned forming surfaces and a rigid stamping die

As have been described earlier in this paper, generally there is a lot of manual rework of the forming surfaces during the try-out of a new die set. In order to take these modifications into account, the forming surfaces of the die, punch and blank holder together with the contact surfaces of the kissing blocks in the die and blank holder of the studied die was scanned. The resulting surfaces was then used in the second set-up to the forming simulations. Fig 14 presents the draw-in and strain comparison for this FE-model.

This simulation set-up is generally overestimating the draw-in, see the left picture in Fig 14. There are also large wrinkles in the corners of the part in the simulation that was not present in the real part. The overprediction of the draw-in will then lead to an underprediction of the major strain in the forming simulation as presented in the plot to the right in Fig 14. The conclusion is that even if the forming surfaces are more accurately described in this FE-model, the accuracy of the model is not improved compared to using the nominal surfaces.

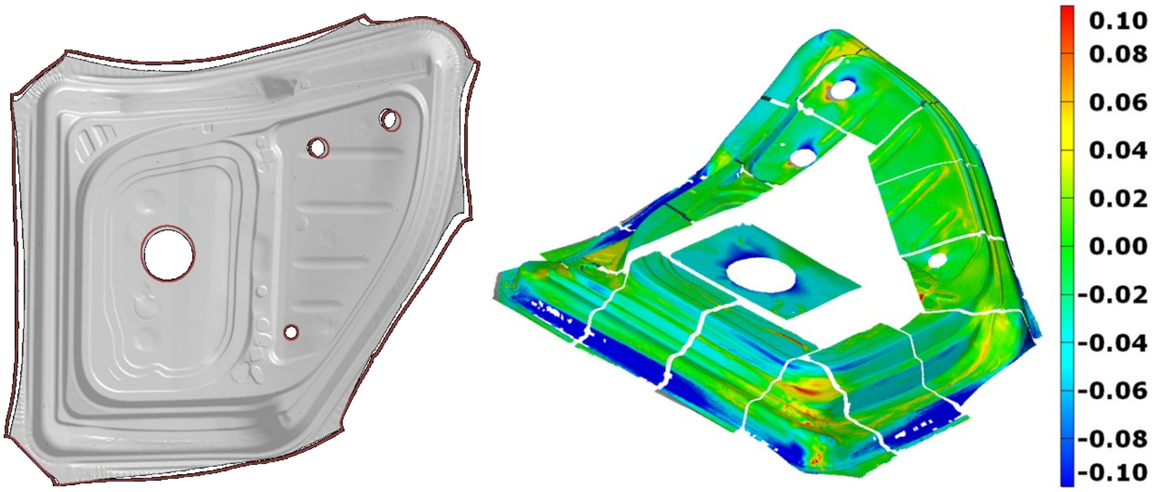

Fig.14: Comparison between simulation results with scanned forming surfaces and a rigid stamping die.
To the left: Part shape from simulation after forming (grey part) together measured edge from real parts (red curve). To the right: Difference in major strain between simulation and the measured major strain in the part.

5.5 Simulation results using scanned forming surfaces and an elastic stamping die

Since the results in the previous section was unsatisfactory, further refinements of the FE-model is needed to improve the accuracy. One improvement would be to assume that die structure has elastic material properties. The results from this model are presented in Fig 15. Both the draw-in and strain prediction accuracy has increased compared to the previous model and now both these results are accurately predicted.

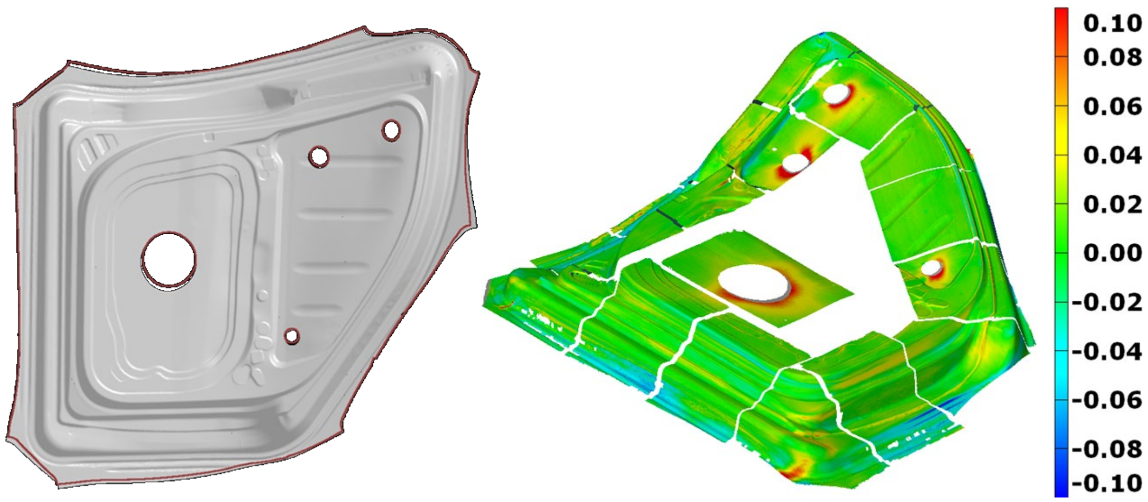

Fig.15: Comparison between simulation results with scanned forming surfaces and an elastic stamping die. To the left: Part shape from simulation after forming (grey part) together measured edge from real parts (red curve). To the right: Difference in major strain between simulation and the measured ones in the real part.

6 Summary and Future Work

The results presented in this paper clearly illustrate the effect on sheet metal forming results, in this particular case draw-in and major strain, of elastic deformations of the stamping die. However, this doesn't imply that other important parts of sheet metal forming can be modelled with a lower level of detail, if the stamping die is modelled elastically. The highest accuracy in this study was reached using both an accurate description of the forming surfaces and an elastic stamping die. Furthermore, a more advanced friction model, like the TriboForm model used in Sigvant et al [6], would probably increase the accuracy even more. In order to utilise the full potential of this friction model, the contact pressures must be accurately predicted by the simulation. This will in turn demand elastic stamping dies for the majority of sheet metal forming simulations, and also scanned surfaces if dies in running production are analysed.

The future work will focus on reducing the modelling work and simulation time for an FE-model simulating both the forming and the structural response of the stamping die simultaneously. One way to do this is only model the parts of the die structure that has the largest influence on the result as elastic. The blank holder is generally believed to be such a part, and future studies will look into if it is sufficient to only model this part as elastic and the other parts of the stamping die as rigid. When reasonable simulation times are reached, this will then open up for studies of the structural response of more die sets in Volvo Cars production. The conclusions from these studies can then be used to improve internal standards and working procedures for simulations, die tryout, and running production. In cases where the FE-model is a digital twin of a production line and should be used for production control, the elastic modelling of the stamping must be included to reach the desired accuracy.

7 Literature

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