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PLASTICITY EFFECTS IN SUBSEQUENT SIMULATIONS OF CAR STRUCTURES

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Abstract. *In order to further reduce the weight of car components while at the same time maintaining performance and safe life it is necessary to enhance the simulation process. This is especially important for chassis parts which have not only a high dynamic load but are also partly undamped. To reach this goal, the logical step is to couple the successive operations of forming, assembly and virtual performance testing.*

The objective is a complete determination of the mechanical state of the (sub-)assemblies. It is therefore necessary to consider all forming and joining processes a part has previously undergone and to consider them in the virtual model. This virtual model is ideally suited for virtual prototyping (e.g. structural analysis, fatigue, crash) because the complete history of every part is contained. In contrast to standard models, the changed thickness of sheet metal parts and residual stresses due to forming and joining as well as the new material state at every point are known prior to any external loading. This results in a more reliable prediction of product performance.

Using a relatively simple part it is demonstrated how the performance of chassis parts changes with the inclusion of plastic forming effects as compared to the exclusion of these effects. The transfer of the results of the forming process to the comprehensive model is shown first. Hereafter the model is subjected to static and dynamic external loads. The results are compared to calculations that use a standard model and show clearly that the inclusion of the plastic history has a significant influence on the product performance.

1 INTRODUCTION

In order to enhance the performance-to-weight ratio of cars it is desirable to make use of every positive effect while, at the same time, not neglecting any contrary effects. This is especially true for structural parts which have not only to deliver static and dynamic stiffness but also have to offer crash safety. In the case of chassis parts further restrictions are imposed by the minimum safe-life and the package design. The weight of the undampened masses is also critical. It is well known that the yield stress of steel increases in the deep drawing process. There are also strong indications that the fatigue life is enhanced due to the plastic strain that the material encounters during the deep drawing process[i]. However, in addition to these positive effects deep drawing also leads to a diminished sheet thickness thus reducing static stiffness and adding residual stresses. This is the reason why the simulation of every stage of the development process has to become as exact as possible. Added to this there is a strong demand for a considerable shortening of the development cycles. To unify these two goals it is necessary not only to develop new tools for simulation but also to represent the complete manufacturing process in the performance analysis.

In this paper the general procedure for including the effects of plasticity in subsequent simulations is discussed first. An example to illustrate this follows. The paper closes with an overview of future research directions and suggests which developments should be prioritized.

2 PLASTICITY IN THE PROCESS CHAIN

The production of car parts generally starts with a plastic deformation of the basic material. This can be casting, bulk forming or sheet forming (such as deep drawing or hydroforming). Here we restrict ourselves to evaluating deep drawn parts. This process is thoroughly understood and its simulation is based on phenomenological laws which are known to give results of satisfactory quality.

It is known that the material state is changed by every step in the production process. Thus the behavior of the final part depends on every previous step. Until now, this was not considered in the standard simulation of the structure (static and dynamic analysis), fatigue life or crash. Obviously, the inclusion of the plastic history from forming and joining can improve the quality of the product performance simulation. Figure 1 shows the subsequent steps that have to be performed.

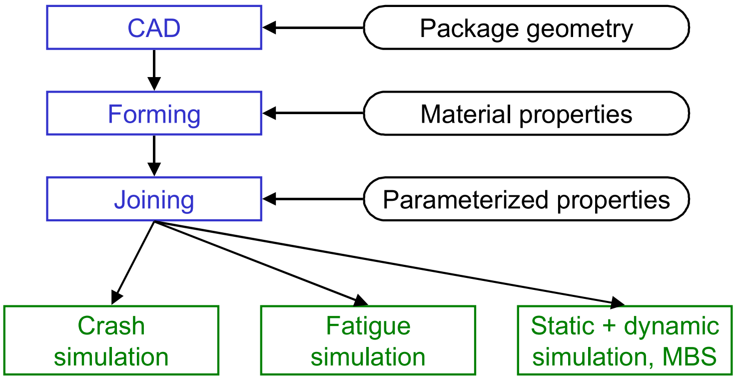

Figure 1: Simulation chain

The geometry of the part is determined by the CAD construction, which has to obey the given package geometry. Together with the basic material properties this is the basis for the forming simulation (deep drawing, casting etc). Following this, the thickness of the sheet metal, the material properties and the stress state are all changed. Next to forming, the joining of single parts to complex sub-assemblies can have a significant but unwanted effect on the geometry as well as the stress state. The simulation of joining (e.g. welding or riveting) is very time-consuming. Therefore the properties of the joints have to be included in a parameterized way. The result is a virtual model, which includes the complete plastic history. The material state variables and stress state are known for every point. These kinds of highly detailed models are new in car development. This allows for a more accurate prediction of product performance, such as crash, fatigue and structural behavior. They can also improve the elastic multi-body-simulation (MBS).

The forming simulation usually needs a very detailed and fine mesh. In subsequent simulations with an assembly of parts these fine meshes would lead to long computation times. A mapping procedure is therefore required. One straightforward way to achieve this is to map the results of the forming simulation onto a mesh which has been made using CAD-geometry. This new mesh can have regular elements of very similar size opposite to the mesh used in the forming simulation. Unfortunately, this process unavoidably loses valuable information. If, for example, emphasis is placed on keeping the integral forces and stresses in equilibrium, peaks will get lost. If, on the other hand, emphasis is placed on keeping the peak values then the inner and outer forces will be out of equilibrium following the mapping procedure. A third way, which is easy to implement and often used, has no preferences but also no especially strong points. Here the state variables of the integration points in the new mesh get the values of the nearest integration point in the old mesh. This method is used in this paper.

In the application of the process coupling as proposed in this paper it is desirable to use consistent data. This means that for every simulation all effects from previous steps are taken into account. For example, it can be misleading to regard solely the hardening resulting from deep drawing. The thinning of the material has a contrary effect on the strength and could outweigh the effect of hardening.

3 EXAMPLE

As an example of the discussed method the upper shell of a steering knuckle is considered, see figure 2. It is deep drawn from thick steel sheet (St14, 2 mm), in one stage.

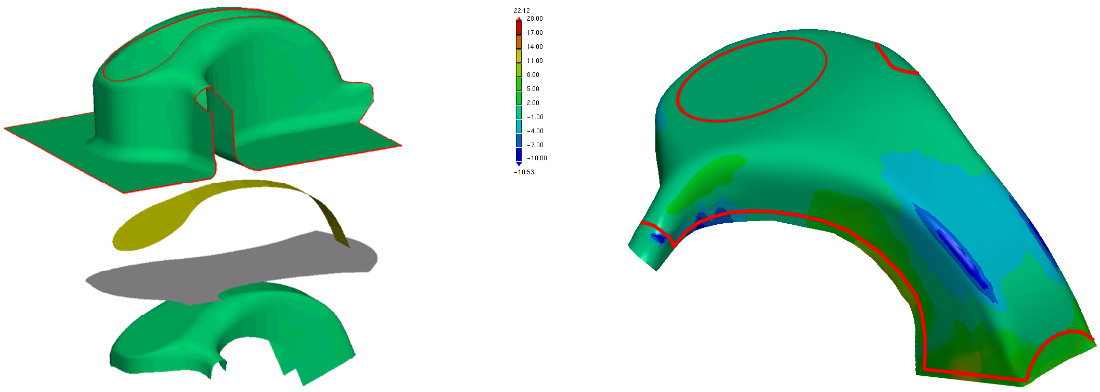

Figure 2: Upper shell of a steering knuckle - tooling and simulated thickness with INDEED

Due to the thick material and the double curvature, this is considered to be a complicated part. After deep drawing the part is trimmed and unloaded. The state variables of the material, thickness and the residual stress after springback are now mapped on a typically coarse mesh in a program for structural calculations. For this purpose ABAQUS was used.

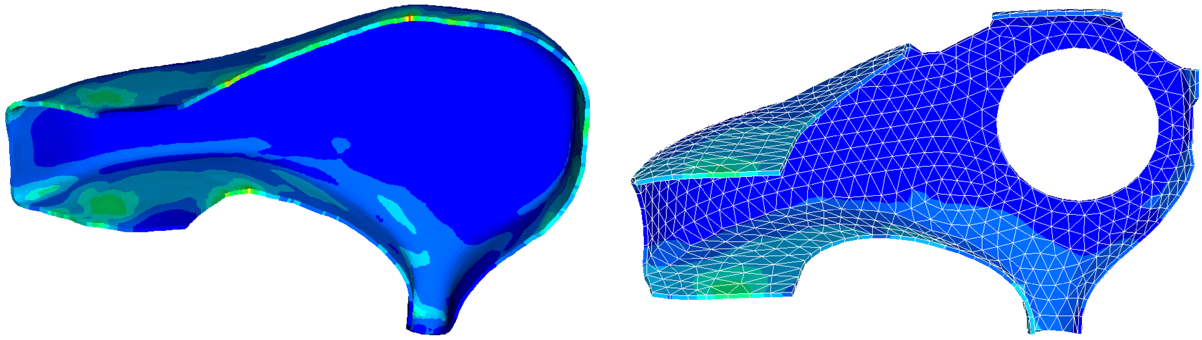

Figure 3: Mapping of the state variables onto a coarse mesh

The plastic strain is needed to ensure that the onset of yielding in the structural calculation is correct. Next a load case is defined that is typical for the in-service behavior.

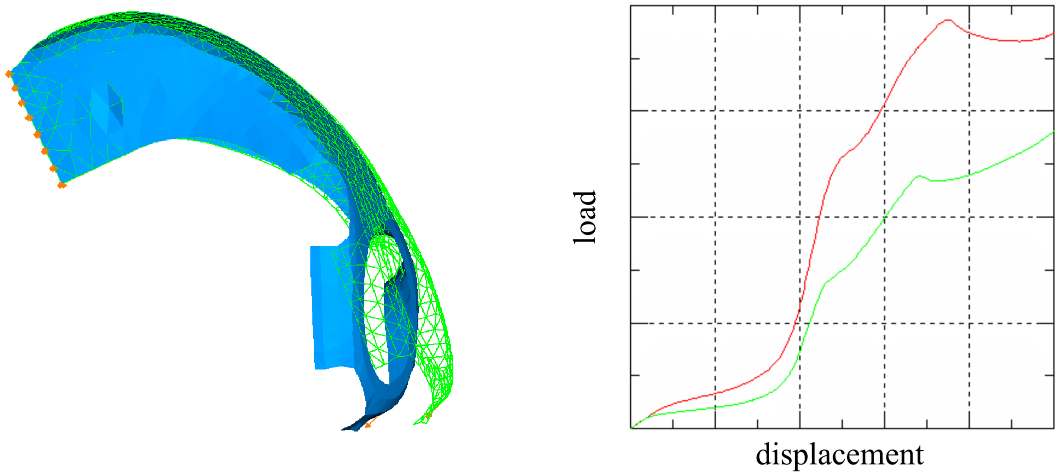

Figure 4: Load case and simulated load-displacement curves with (red) and without (green) plastic history

In the load-displacement curves of figure 4 it can be easily seen that the inclusion of the forming history has a significant effect on the strength of the part. In this example the deviation is about 30 percent. These large amounts are not unusual in practice in comparing standard simulations (without history) with experiments. Therefore, the inclusion of plastic history in these types of calculations will lead to an improvement in the accuracy of the predictions.

Next to the structural simulations fatigue-life calculations are also standard in product development. Here the considered part is analyzed with FEMFAT, with and without the inclusion of plastic history. It is based on the ABAQUS geometry and history of figure 3. Thus, thickness, total plastic strain and stresses are taken into account. According to Masendorf[i] and Rupp[ii] the fatigue life of a specimen increases with the application of a certain amount of total plastic strain.

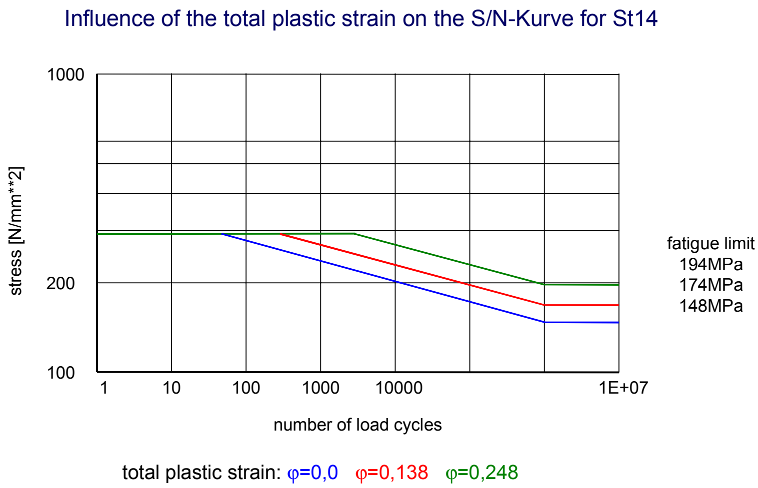

Figure 5: S/N curves as a function of total plastic strain[i]

Figure 5 shows how the fatigue life of steel St14 (DC04) depends on the total plastic strain. With increasing strain both the fatigue limit and the number of load cycles a specimen can endure under a given load increase. These measurements indicate that a pre-deformation has a positive effect on fatigue life.

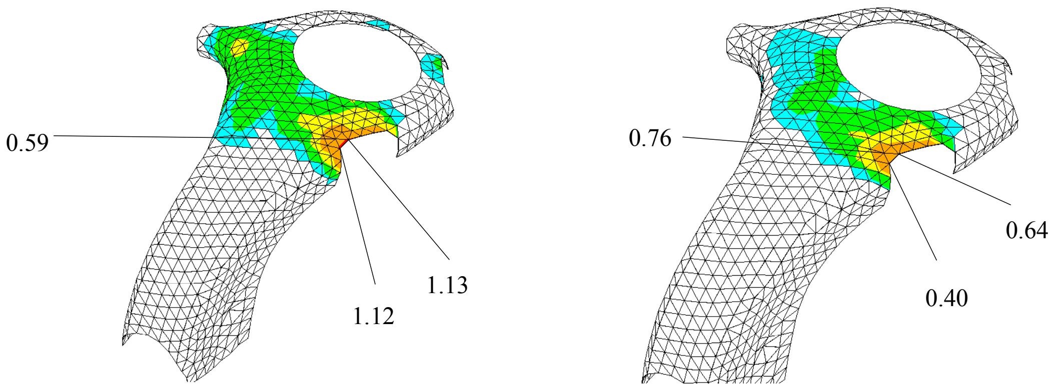

Figure 6: Calculated damage without (left) and with (right) inclusion of plastic history and residual stress

Figure 6 shows the simulated damage distributions with and without the inclusion of the plastic history of the part. At the critical spot the amount of damage has clearly decreased compared to the standard calculations. In practice this would mean that parts might be constructed with less weight. Nonetheless, care should still be taken.

4 FUTURE RESEARCH

A follow-up step in the current research would be simplified models for seam welds. Since seam welding is the most important joining technique for chassis parts, these models allow for the complete simulation from forming to virtual testing with the inclusion of the plastic history. Measurements on real parts also have to be made in order to verify the results of this research. For an accurate prediction of the fatigue life of assemblies more data on the basic materials is required. Concretely speaking, these are the S/N for more basic materials gained by actual measurements as well as S/N curves for different pre-deformations.

Given the appropriate interfaces, the forming history can be considered in crash simulations[vi].

A final step could be the inclusion of deviations between CAD and actual geometry as a result from springback. This would have an effect on the mapping procedure and on the assembly. Parts that are to be joined must be loaded to enable the joining procedure. This results in extra assembly-stresses that can have a significant influence on the product's performance.

5 CONCLUSIONS

This paper demonstrates how the inclusion of the plastic history of parts affects the product performance with respect to strength, fatigue life and crash. The plastic history involves the total plastic strain, the thickness change and the residual stresses from deep drawing and joining. After the mapping of these variables onto the typically coarse meshes used for static and dynamic analysis, the product is ready for the virtual test. As an example of the complete chain the upper shell of a steering knuckle was used. In addition to a static structural calculation the fatigue life was also simulated. Both results were compared with the ones gained through the exclusion of plastic history.

Generally speaking, the accuracy of the performance predictions will increase. With the coupling of the virtual production processes and the virtual prototypes presented in this paper the virtual process chain is closed. This leads to a reduction in cost and development times.

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