Consideration of Manufacturing Effects to Improve Crash Simulation Accuracy

Authors:

Curd-Sigmund Böttcher, Steffen Frik
Adam Opel AG, ITDC, Rüsselsheim, Germany

Correspondence:

Curd-Sigmund Böttcher
Adam Opel AG, ITDC
VD&S Vehicle Simulation, IPC 80-18
D-65423 Rüsselsheim
Germany

Tel: +49-(0)6142-773183
Fax: +49-(0)6142-775719
e-mail: curd-sigmund.boettcher@de.opel.com

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ABSTRACT

The confidence level of crash simulations is mainly determined by a well-defined finite element representation of the vehicle structure, correct modelling of the kinematics, and the material properties being applied. In the past, materials were described by quasistatic – or, if available – dynamic stress-strain characteristics. Besides this, each sheet metal part was assumed to have a uniform gage and material characteristics.

However, it is a well-known effect that the physical properties of steel can alter significantly during the manufacturing process. This comprises an increase of material stiffness due to plastic deformation as well as gage changes. The amount of these changes is of very local nature and cannot be covered by simply scaling material properties and gages. In the past, crash software tools didn't support the introduction of these local effects, so that they couldn't be taken into account.

In the meanwhile LS-DYNA has the capability to import information provided by stamping tools such as PAMSTAMP or AutoForm. Thereby a very important part of the material properties can be introduced into the crash simulation models, leading to a significantly increased correlation to test results. The impact of this effect on crash performance was analysed for a recent vehicle project and will be discussed in detail.

INTRODUCTION

The development of new passenger cars is characterized by an ever-increasing number and severity of crashworthiness requirements. The increased demand for improvements regarding low speed crash performance requires very stiff front rails in order to restrict the deformation zone, leading to competitive insurance classifications. On the other side, the same structure must be deformable to fulfil high-speed crash requirements e.g. for ODB tests. In order to develop a vehicle structure for these contradictory targets, the individual structural properties must be balanced very well. This leads to high requirements for the applied simulation methods in order to achieve simulation results with the necessary level of accuracy.

During the development of a recent vehicle, it turned out, that crash simulation results showed a much weaker structural behaviour than ongoing high-speed crash tests. For example, the front rails remained almost undeformed after the crash tests whereas crash simulations showed significant deformations.

At first, the material strength was scaled in order to match potential manufacturing deviations. However, even a scaling by a factor of 1.5, that is no more justified by material property scattering between different coils of sheet metal, did not resolve the deviation.

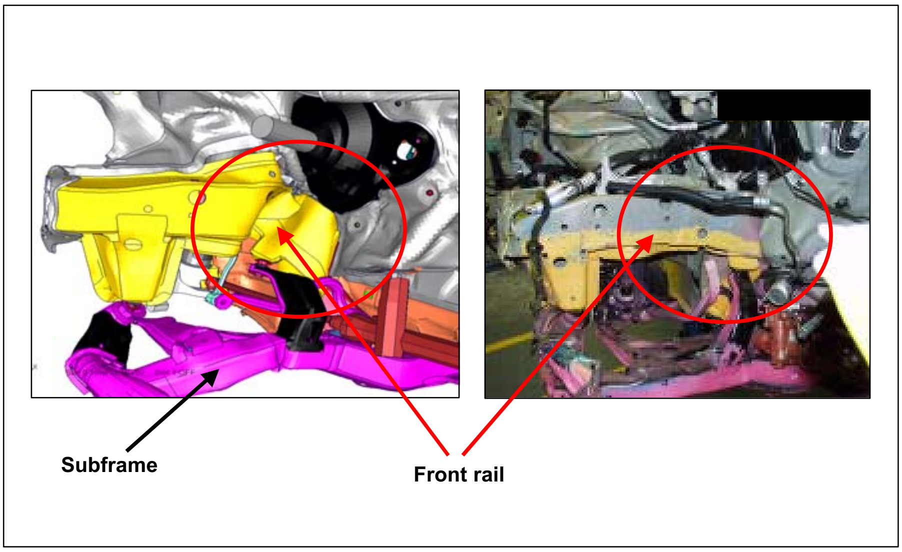

Figure 1 Simulation and test results for a prototype front ODB crash

At that point, systematic analyses were performed to detect potential reasons for this deviation. It turned out, that the material for the front rails was changed to high strength steels (DP: dual phase) in order to achieve the required crash performance and weight targets. It is a well-known effect, that these materials show a significant impact of plastic pre-deformations on the strength. As an example, Figure 2 shows the stress-strain characteristics of two respective steels.

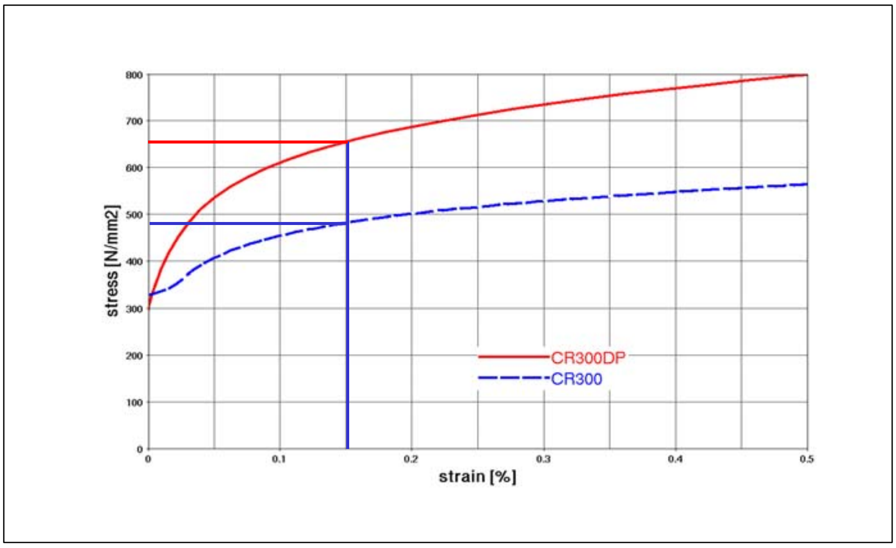

Figure 2 Stress-strain properties for CR-300DP (DP500) and CR-300

It is obvious, that even moderate plastic deformations being applied during the forming process lead to a significant hardening of the DP steel that could explain the deviation between the simulated and measured crash performance.

In order to analyse these effects for a complete vehicle, a collaboration project between the stamping and crash simulation groups was initiated to provide the required forming simulation results.

STAMPING SIMULATION

During the last years, stamping simulations were introduced into the vehicle and die development process at Opel. In the meanwhile formability simulations are carried out for almost all sheet metal parts. This progress was enabled by improvements of the simulation software and a consequent switch towards a math-based tooling development process [1].

Today, AutoForm DieDesigner is used to check formability and to drive design changes, if necessary. Figure 3 explains the individual tasks that need to be performed to achieve the die form.

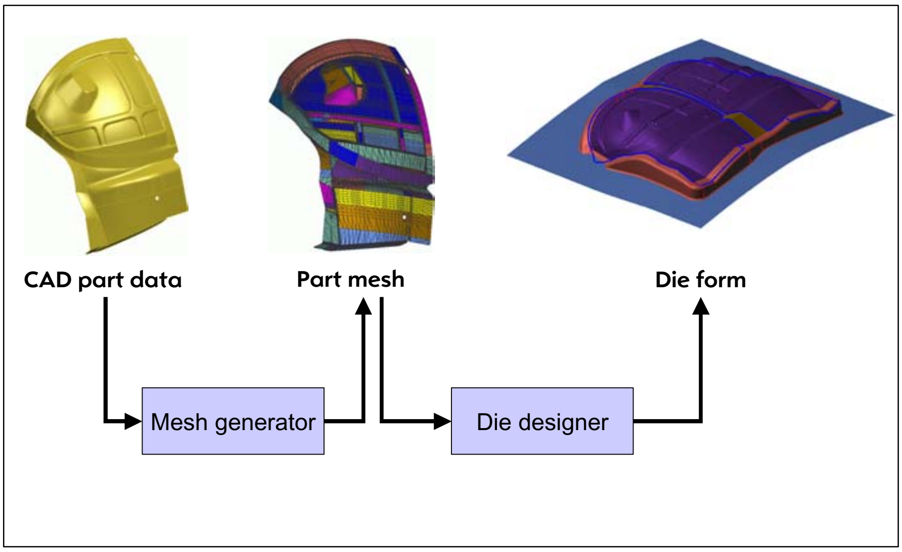

Figure 3 Stamping simulation with AutoForm DieDesigner

Besides this, AutoForm also provides maps of the local sheet metal thickness and strain after the stamping process, because these values are important indicators for the manufacturability and quality of the part. For example, local strains are used as an indicator for potential cracks occurring during the stamping.

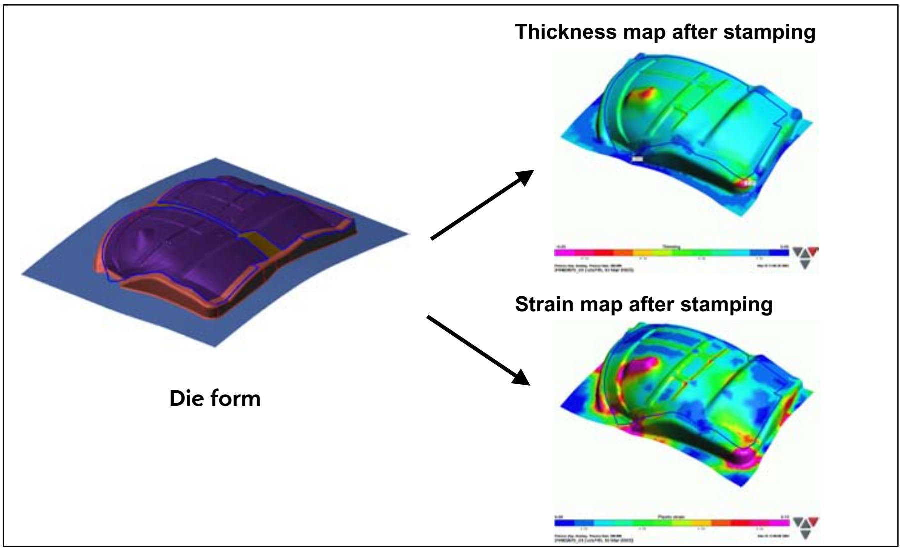

Figure 4 AutoForm simulation results

As already mentioned, the crash simulation results showed a significantly different behaviour of the front rails compared to the test. Therefore an AutoForm analysis was run to show the impact of the deep draw forming on the properties of these parts. Figure 5 shows the gage change and plastic strains for a front rail segment.

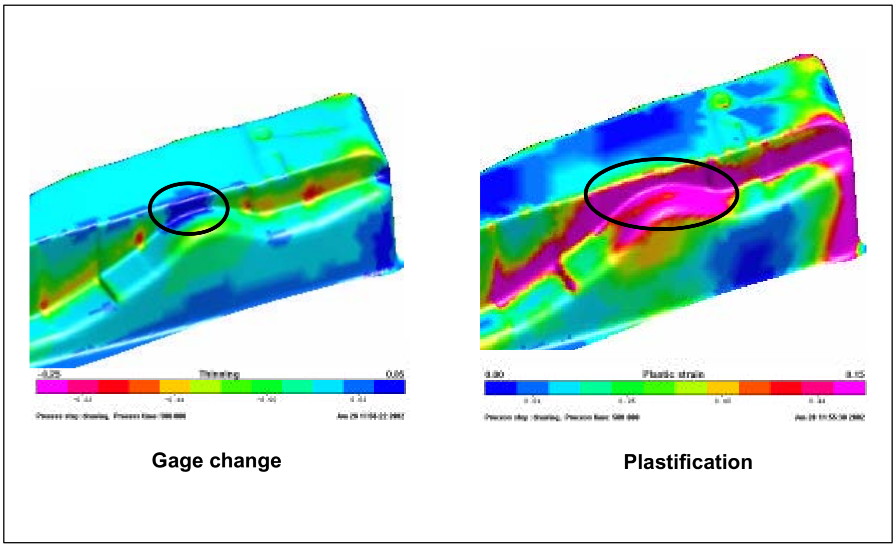

Figure 5 Deep draw simulation results for the front rails

It turned out, that there was no material thinning in the critical areas, but even an increase of about 5% (Figure 5). Besides this, there was also a residual strain of about 15% in the same area. According to the stress-strain relation in Figure 2, this leads to a 120% increase of the material stiffness. Combining these two impacts, there is an enormous hardening effect of the front rails.

In order to capture this tremendous deviation of the material properties, deep draw simulation results were applied to front crash simulations. The effort for providing mapping information can vary significantly. Whereas a simple part can be simulated within two hours after receiving perfect CAD data, it needs several days to perform the analysis for a more complex part such as a side panel.

The information coming from AutoForm can be added to the LS-DYNA input deck by simple include statements [2]. As AutoForm models are described in a tool reference frame it must be assured that the mapping information is available in the vehicle reference frame so that the data can be mapped directly on the crash simulation model. Otherwise the mapping data must be transformed in a preceding step. The mapping is then performed after initiating the run.

Figure 6 shows the calculated gage and strain distribution of a front rail and the mapped information included into the LS-DYNA model.

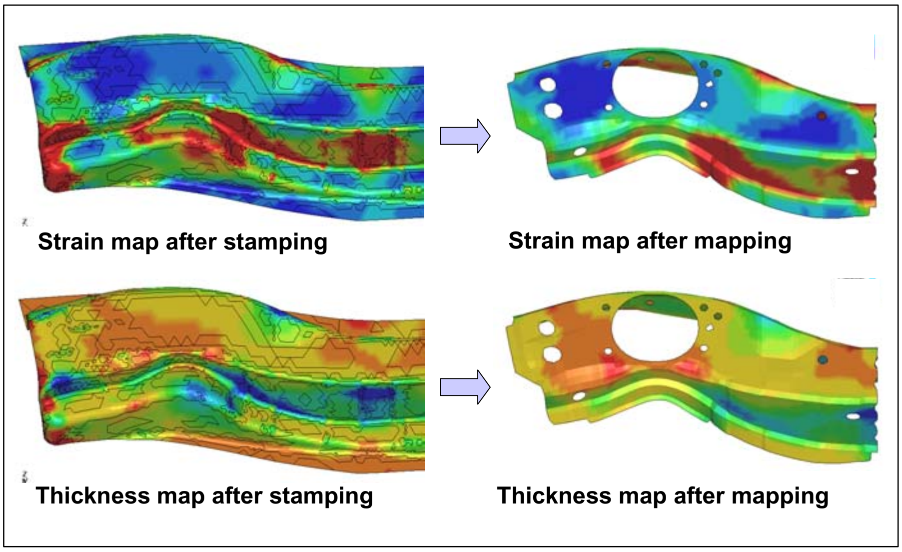

Figure 6 Mapping gage and strain information for the front rail panels

After applying this information for the front rail panels, a front crash simulation was performed. As it can be seen in Figure 7, the front rail deformation behaviour now shows a much better correlation to the test results.

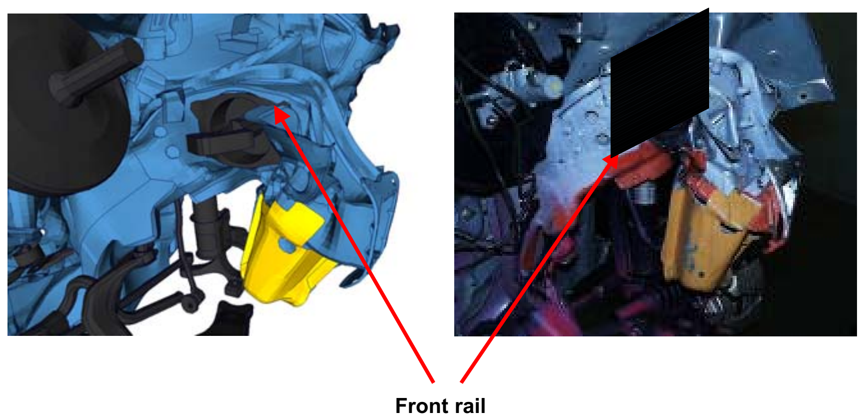

Figure 7 Simulation and test results for a prototype front ODB crash test (with deep draw results)

As this measure led to a tremendous improvement of the simulation results, all parts that build up the main load paths and being made of high strength steel are simulated with forming simulation results. In the meantime this procedure was extended to all crash loadcases. However, not all of them showed the same amount of improvement regarding the correlation to test results. This is mainly caused by the different material that is applied for the respective loadpaths for these loadcases. As their strength characteristics is not that sensitive to pre-deformations, the impact of mapping deep drawing results is significantly lower. Nevertheless, all cases that have been analysed so far show a better correlation to test results.

The additional effort of mapping the deep drawing information is considerably low. It takes some simple statements in the DYNA input deck to include the mapping results. For the current number of parts that are provided with mapping information, the additional computing effort is about 3% of the total computing time. Thus it can also be a very efficient measure to improve the correlation to hardware test results.

SUMMARY AND CONCLUSIONS

Crash performance and lightweight requirements are increasing constantly, leading to an ever higher need to use high strength steels. As their material properties alter significantly during the manufacturing process, profound skills are required to predict their correct performance during crash impacts in order to enable an optimum material choice.

The analysis demonstrates that especially the application of dual phase steel creates a need for including metal forming information into the crash simulation models. In all cases, adding stamping information improved the correlation of the computational model to the test. Of course, the amount of improvement was influenced by the sensitivity of the strength of the applied materials to plastic deformations.

According to the experience that has been achieved so far, mapping data should be used starting from the earliest possible stage of the vehicle development process. Experiencing how wide the range of material properties of one part can be, a correct survey of all vital areas (especially all load paths) is of crucial importance.

A good stamping analysis, together with an extensive knowledge of steel properties and a well working mapping algorithm are basic requirements. In order to improve the available mapping algorithms, a joint project was initiated by FAT, the research consortium of German car manufacturers. The purpose of this project is to create

- a neutral data format to allow and ease data exchange between the software codes,
- an improved mapping tool, able to deal with spring-back effects or other small geometric variations,
- and a quality checking tool, that allows to compare the mapped data with the original data in order to make sure that no important information was lost by the mapping process.

Further improvements should be achieved to allow mapping strain data for elements with more than one integration point. Thus, the described approach could be extended to processing the respective data from folding operations as preferably used for very high strength steel.

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