Improved Product Design Using Mapping In Manufacturing Process Chains

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Summary:

Generally, the manufacturing of complex structures involves various processes that yield the final product. Simulation methods are often used to optimize each single process step. When the manufacturing levels involve different physical disciplines usually diverse discretizations have to be used. Hence, if a result of a simulation has an influence on the simulation of the following processing step it needs to be transferred between possibly different domains. When chaining these process steps together in the simulation, software interfaces become necessary to realize an integrated virtual process chain. The Fraunhofer-Institute for Scientific Computing developed the software tool SCAIMapper as neutral data mapping interface in process chains supporting a wide range of different well-established FEM simulation software packages as LS-Dyna. The paper shows how the utilization of data mapping can help modeling manufacturing process chains as well as optimize material property parameters used in simulation by validation with experimental results. Therefore, among others, an example for improved failure prediction of a b-pillar in crash simulation applying data mapping from forming simulation and also a new evaluation method increasing the analysis quality in sheet metal forming applications is presented.

Keywords:

Manufacturing process chain, data mapping, forming simulation, crash analysis, forming analysis, parameter optimization

1 Introduction

Prediction of quality and behavior of a product arising from a multi-stage manufacturing process is a presently given task in engineering. Using the instrument of simulation for each process step is a well established proceeding in todays product development cycle. In general each process step has more or less effects on the material properties or behavior of the product and thus may influence the following steps leading to the final product. For instance in crash simulation of vehicle components (e.g. formed metal sheets) among others local thickness distribution, plastic strain or material properties have a big influence on the crash result. The initial parameters of the undeformed component obtain a variation by the forming process resulting in different structural properties. As a natural conclusion, the resulting distributions should be considered as new initial conditions of the following step of the process chain. In general, it is not possible to perform all simulations on the same discrete representation of the component. Hence, the results need to be interpolated respectively mapped between different discretizations. The crash behavior of relevant components does not only depend on design geometry and material properties, but is also influenced by manufacturing history. A failure can be caused by local thickness reduction or residual stress peaks which are a result of the stamping process. This failure can limit the functionality of the entire component.

2 Problem Definition

For identical discretizations the interpolation method is obtained by copying the physical entities. As each manufacturing step is modeled with a proper simulation tool, the topology, the geometry, the element formulation, the entity location, or the material models may change. A robust data interface solution therefore has to deal with distinct data models. In addition to the different geometry of source and target model, the global coordinate systems also can be dissimilar. For instance when dealing with data interpolation between deep-drawing and crash analysis in automotive industry applications, the crash model will be located at the dedicated position in the car body which can't be predetermined for deep-drawing. Taken together with the interpolation problem itself a mapping procedure is partitioned in two tasks:

1. Identification of data relationships by geometrical analysis; e.g. computation of neighborhood relation
2. Interpolation of entities using the precomputed neighborhood relation; e.g. data mapping

Well-established methods for interpolation between different geometric datasets are based on the assumption that a function at an unknown point can be approximated by given known distribution of geometrically close points or elements. For instance the Shepard algorithm [4] (cf. Figure 1) uses weighted neighboring data information for interpolation resulting in a smoothed distribution on the target. The utilization only of weighted neighboring data makes the Shepard algorithm very robust and produces satisfying results as long as the resolutions of source and target discretization is similar.
To obtain efficient mapping algorithms based on the neighboring data approach it is crucial to work with efficient neighborhood computation schemes. A suitable and theoretically runtime optimal technique for randomly distributed data is the usage of spatial search trees. For the determination of neighborhoods in arbitrary distributed point clouds a single search request can be done in logarithmic complexity depending on the point clouds size.

3 Realization of data mapping in SCAIMapper

As mentioned in the previous section a mapping procedure between two different representations of a domain using the neighboring approach can be divided in two different parts; the neighborhood determination and a mapping prescription based on neighboring data. When dealing with different coordinate systems for the source and the target representation a rotation and a translation of the source towards the target model has to be determined in a preprocessing step. Therefore SCAIMapper, apart from manual interaction, offers two semi-automatic methods to adjust the geometries. The first method attempts

to achieve a 'rough alignment' by comparing the principal axes of inertia tensors of coarsened representations to fit the orientation of each model. In a second 'fine alignment' step, least square methods minimize the overall distance between the models.
Having aligned models, the neighborhood computation using spatial search trees can be done. For this purpose SCAIMapper operates with a high performance three-dimensional search tree which can handle points, elements as well as code-specific integration points in elements. A relation between different models containing several hundreds of thousands nodes and elements can be obtained in a few seconds.
The SCAIMapper provides accurate and high performance methods for interpolation of scalar, vector and also tensor quantities like strains and stresses. A modified Shephard algorithm has been implemented allowing a conservative and orientation conserving transfer especially for tensor data. It can also handle models with different numbers of shell layers and allows code-specific usage of integration points in shell elements.
After the mapping progress has finished SCAIMapper offers methods for checking the quality of mapped results. The concept of validation is to compare the original values from the source mesh with those values which were mapped from source to target mesh and back again onto the source mesh. Local differences on the source mesh can be calculated and visualized. Additionally the validation functionality includes methods to calculate and visualize the association and nodal distances between the coupled meshes to examine and evaluate differences in geometry and discretization.

4 SCAIMapper mapping features for LS-Dyna

- Linear shell element types with different number integration points and layers
- Mapping of scalar and tensor data (thickness, plastic strain, strain, stress and history variables)
- Examination of major, minor and equivalent strain and comparison to forming analysis data at surface layers
- Handling of different mesh geometries and coordinate systems
- Permutation of history variables for extended material model GISSMO

5 Application cases

As first application field the SCAIMapper was used as simple mapping tool that simplified the process of mapping forming results to crash models [2]. Later in a study the SCAIMapper helped to prove how local rigidity of crash-relevant side rails made of multi-phase steels can be improved by local hardening and thus avoiding an increase of the cross section [1] (cf. Figure 2). Currently the tool is applied in several newer projects studying more complex manufacturing process chains as forming-welding-lacquering-crash [8] or related ones like casting to crash for casted vehicle components [6].

5.1 Forming-Heating-Crash and Forming-Crash

In automotive manufacturing there is an increasing request for lightweight construction and safety which leads to an intensified use of high-strength multi-phase steel such as dual phase (DP) or transformation induced plasticity (TRIP) steel. The required stiffness of crash relevant body parts can differ locally. These demands have motivated the use of locally optimized components. The research project 171 N of the Forschungsvereinigung Automobiltechnik e.V. (FAT) and the Arbeitsgemeinschaft Wärmebehandlung und Werkstofftechnik e.V. (AWT) was funded by the program Industriellen Gemeinschaftsförderung (IGF) by the Federal Ministry for Economics and Technology through the AiF.

This study shows how local rigidity of crash-relevant side rails made of multi-phase steels can be improved by local hardening and thus avoiding an increase of the cross section (cf. Figure 3). This method could be named as 'tailored microstructure' [7]. At the same time simulation process chains were completed and results validated by experiments. The SCAIMapper as dedicated software tool for the coupling of a wide range of commercially available FEM software products was utilized.

Another study dealing with the process chain forming to crash was the Fraunhofer CAROD project (Computer Aided Robust Design) where unsafe manufacturing and operating conditions should be quantitatively and qualitatively detected to establish an improved design process which from the first considers tolerances in material properties and the production process. Efficient, novel methods were proposed and employed for sensitivity analysis of simulation results on fine grids depending on parameter variations, for a reduction of the design space and the simulation results as well as for mapping an appropriately constructed data base of most influencing trends, not only comprised of thicknesses and strains, but also damage information. Including the latter turned out to be a crucial point [3] (cf. Figure 4 and 5).

5.2 Validation of Process Chains using the example of high-qualtity steel

High-quality steel is one of the most important materials in industrial production today. In particular in car manufacturing modern steel grades allow the engineers a wide range of simulation based optimization for car body structures. Due to the high requirements with respect to feasibility, stability and crash performance, exact CAE methods and models for the estimation of material behaviour are required. One component in the validation process is the comparison of different simulation results or experiments with each other.

Although the basic functionality of the SCAIMapper lies in coupling process steps, the tool can also help improving a single simulation step by comparing simulation with experimental data by mapping. For the application of material behavior prediction in crash simulation the engineers require exact material models with an optimized description of the forming behaviour for the simulation program applied. The calibration of the material model consumes a larger amount of time and money. If the chosen material model differs from the real material behaviour, expensive costs may arise for the adjustment of critical areas of the stamping tool.

Using the SCAIMapper in the chain of material description optimization for new materials, where the material properties are inproper known, the tool can help finding best matching material models reflecting the real behavior (Figure 6). The influence of various simulation and material parameters can be displayed by mapping and following difference computation. If any deviations in the comparison of sheet thickness or strain distribution become apparent, an adjustment of the material model can be made or the best fitting parameter set can be selected (Figure 7 and 8).

6 Literature

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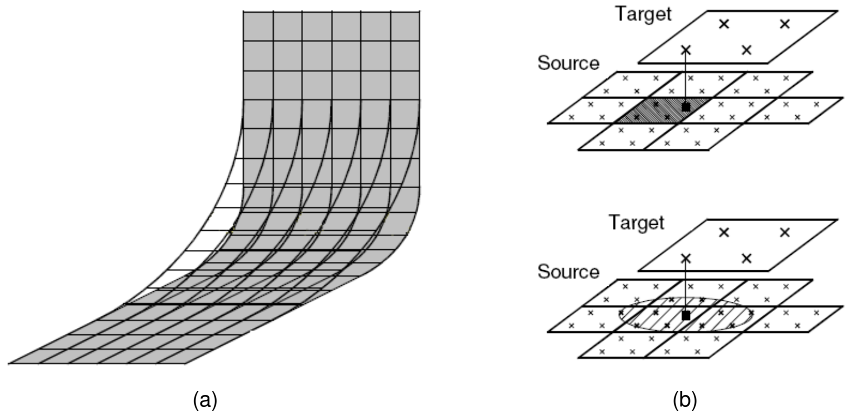

Figure 1: (a) Mapping between non-overlapping structures (b) Element section for the interpolation basis - modified Shepard algorithm [4] (bottom) in relation to element-based interpolation(top)

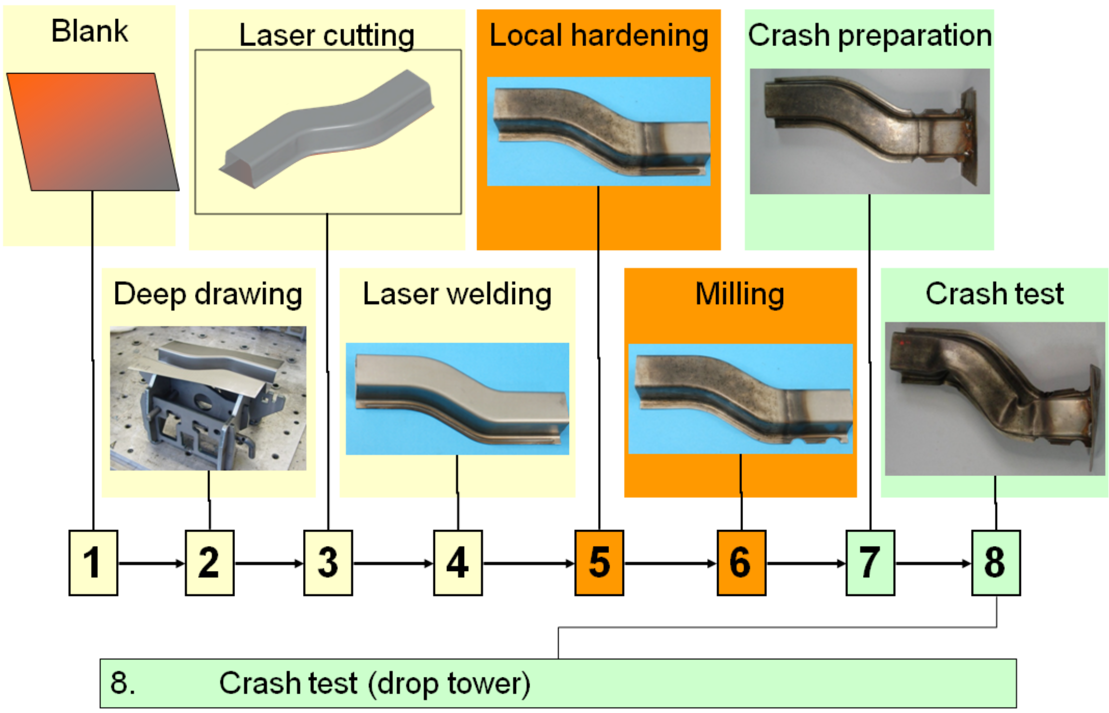

Figure 2: Manufacturing process from undeformed multi-phase steel sheet to locally hardened side rail in experimental crash test.

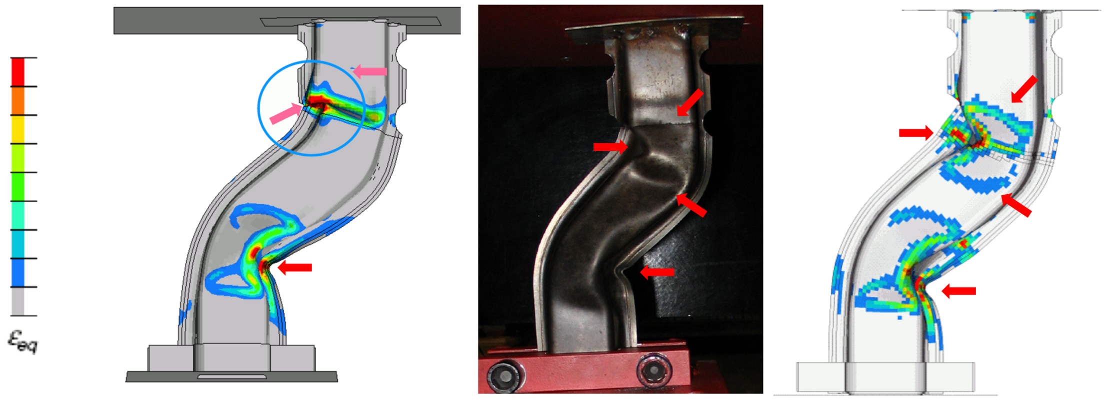

Figure 3: Comparison of crash simulation results of non-mapped (left), mapped (right) with experimental crash test (middle) [1]. It shows that the crash simulation without mapped results from forming and heating has a significant different behavior in the upper transition area compared to the experiment. The non-mapped simulation reveals a folding at the left side of the rail instead of buckling. In contrast to this the simulation using mapped data from forming and heating simulation shows a better agreement with the experiment.

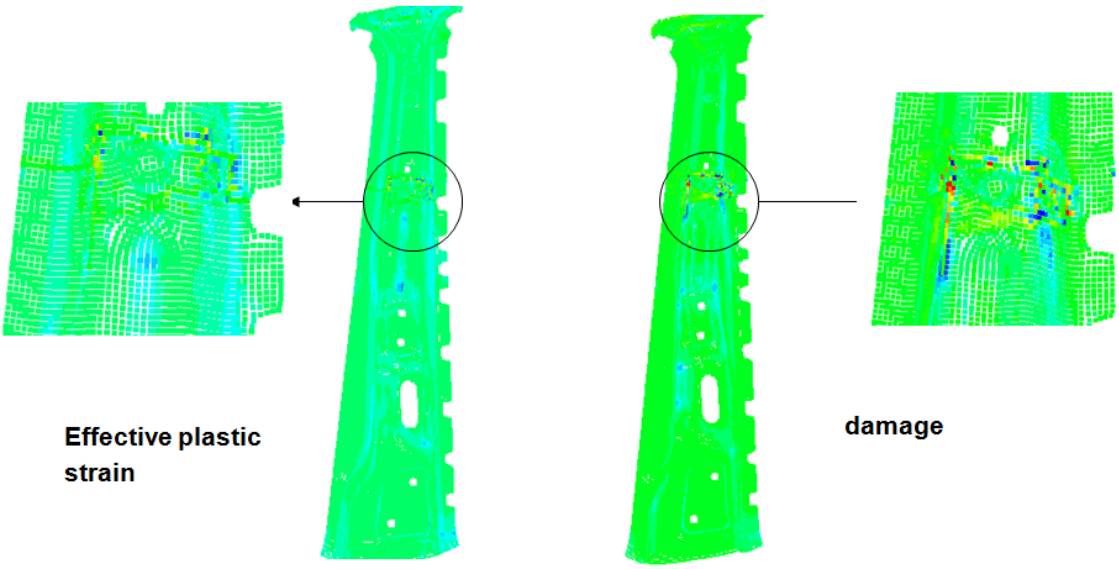

Figure 4: Differences of crash simulation with and without mapping at effective plastic strain and damage for a ZStE340 metal blank of a B-pillar.

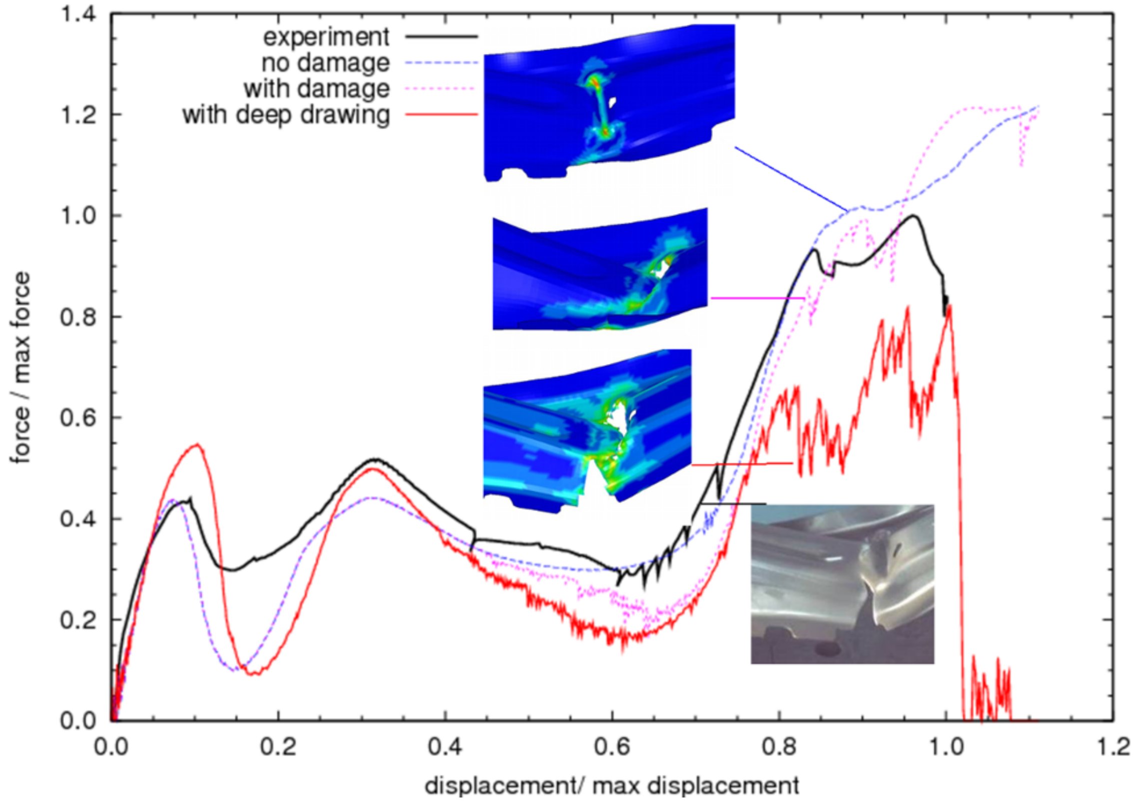

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Figure 5: Failure behavior in crash simulation of B-pillars with and without mapping compared to experimental measured data [3]. The comparison of experimental data and the varying mapped initial data for crash simulation reveals that the utilization of mapped results from forming simulation allows to reproduce the occured crack initiation from the experiment.

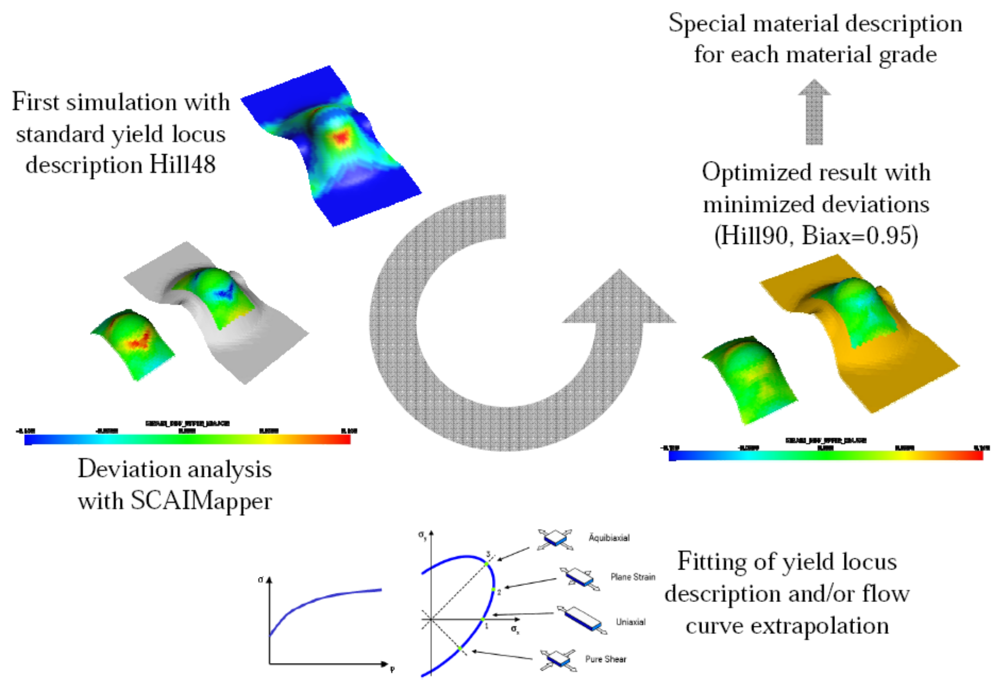

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Figure 6: Chain of material description optimization

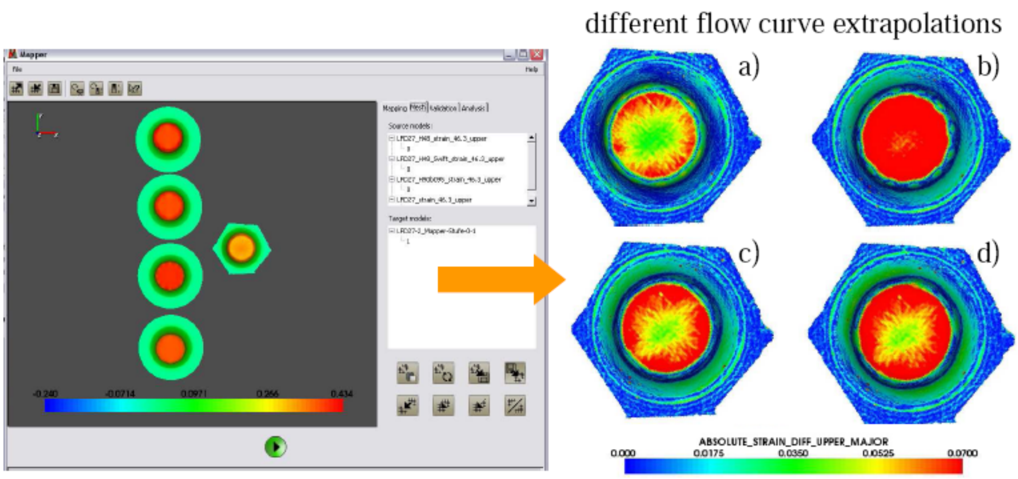

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Figure 7: Different simulation results (LS-Dyna) mapped and compared to one experimental result (ARGUS)

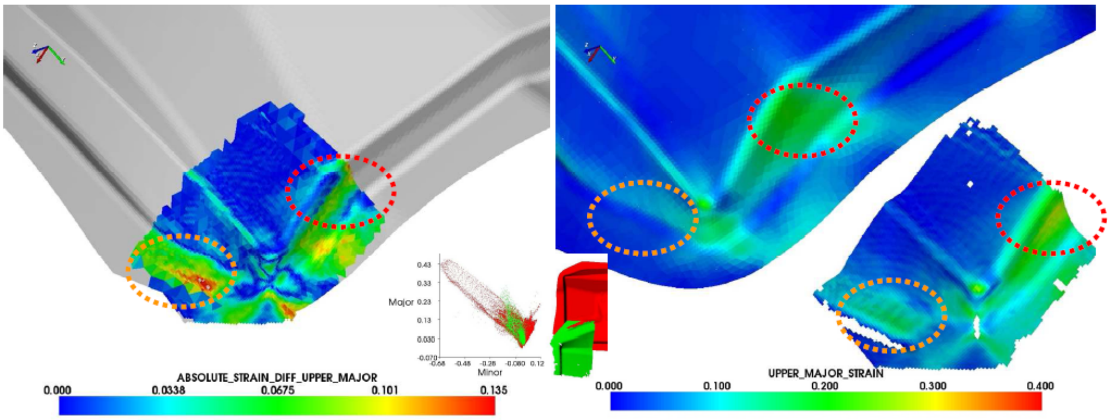

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Figure 8: Difference and major strain for the front wall of a car body structure. Simulation done by LS-Dyna and experimental measurement with ARGUS.