Einsatz der Simulation in der Prozesskette Karosseriebau

Use of simulation in the process chain of car body manufacturing

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Abstract:

The industrial simulation methods used today is the result of a development process during the last two decades. A main focus of this process was the continuous optimization to characterize the material properties. The presentation will give an overview of the simulation technology challenges arising from the need to improve bridging of the gaps between material data and computational technology. Furthermore, an integrated technology pathway from the perspective of simulation requirements, material characterization needs, simulation technology innovations, and impacts of those requirements on the accuracy of practical applications in the automotive world is discussed.
Based on the Digital Factory project at Daimler, now we are integrating the forming simulation, joining simulation and welding simulation in our digital planning and review process of sheet metal part production and assembling. Particularly during the process of sheet-metal part production, planning times for press plants and tools can be drastically reduced by the introduction of digital planning and simulation methods. This applies to the application of standards, full data integration, defined planning processes (workflows) and the automation of planning tasks. Furthermore, planning quality is increased as well as the maturity of the planning results due to consistent digital review of each individual process step by means of simulation. In addition, effective areas and the benefit potential of the digital techniques with regard to the planning process can be identified. This would show how the implementation of the vision of a "virtual process chain" can help to resolve the challenges faced in the planning of systems and tools for manufacturing parts.

1 Vision of a simulation process chain

To facilitate fulfillment of the described requirements in future, Daimler is implementing a planning process supported by digital methods across all productive manufacturing stations. In this context, the Daimler vision for a process chain according to simulation, which is set to be implemented in a strategic production engineering project, no production facility will be designed, constructed, commissioned or operated without a (full) review being first carried out using digital planning methods. The review (see Figure 1) is to cover the entire factory layout and buildings as well as individual manufacturing stations, facilities and production lines through to the tools, operational steps and technical operations such as forming, welding and adhesive bonding, in accordance with an extensive multi-level information pyramid. The scope of manual workloads is also taken into consideration, particularly the interaction of workers with equipment and machines with regard to ergonomic aspects such as physical effort.
Viewed in isolation with regard to individual levels, this vision may not seem so different, as various digital planning and simulation methods have been used to support individual process stages in the past. However, it represents a new challenge if the entire system including all the individual aspects is to be linked in the form of continuous workflows and relevant digital tools with access to a central data management system.

2 Main Approaches for the Digital Factory

From our point of view, the digital planning methods for a digital factory will need to be based on the following four main approaches (see Figure 1) and it will be necessary to further develop these approaches consistently in order to realize the potential time and cost savings, referred to above, in the process as a whole [1].

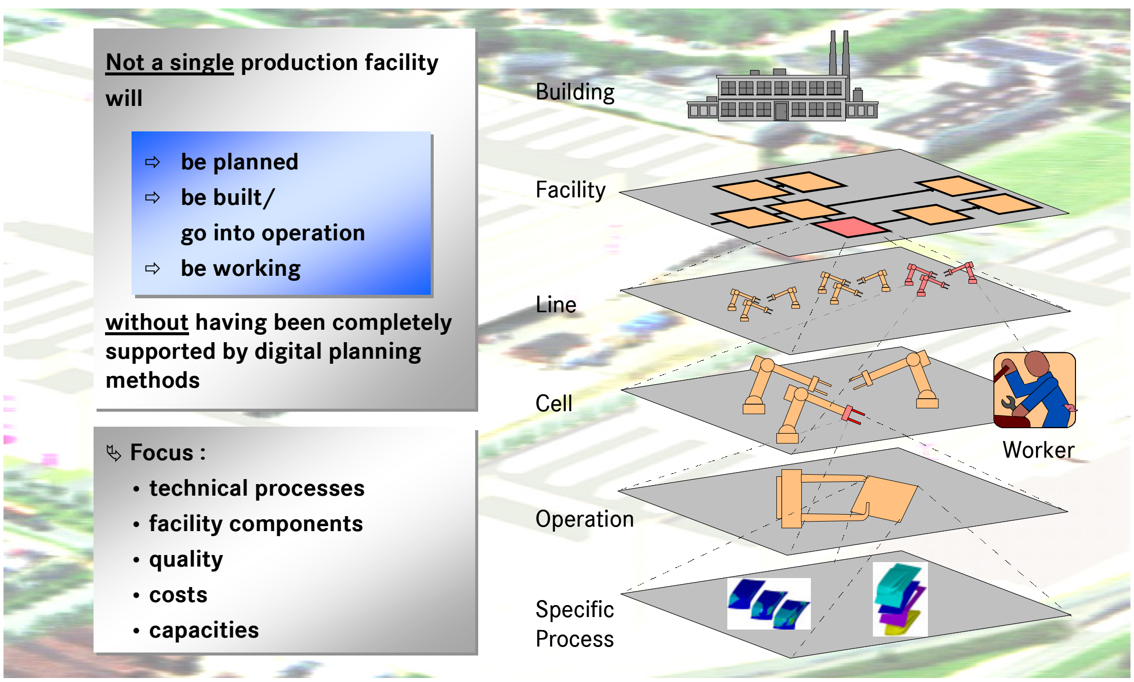

***Figure 1**: Vision of the digital factory*

In future, data integration will be necessary to replace the wide variety of individual databases currently used with a few data management systems. Each data record must only be recorded and saved once and the supplier of the data remains responsible for updating it. This applies to all data, including 3D product and factory data, tool and equipment data records, process and production plans and simulation results. This will call for certain obligatory changes in the approaches and working methods of developers and planners. This means that in the future, it will be necessary to save incomplete data and interim versions on the system and not just complete, reviewed results. In addition, all the information must be available worldwide. Furthermore, processes must be defined and integrated in the form of workflows so that the current sequential working methods can be replaced by a form of

meshed cooperation including revision management. The automation of repetitive routine planning tasks will relieve the workload on planners and ensure further benefits.
The duration of production engineering work on press plants and tools for sheet metal part production can be significantly reduced by using digital planning methods focusing on standardization, data integration, workflows and automation. In addition, the consistent digital verification of all process steps can significantly improve planning quality. These improvements result in a steady increase in the maturity of planning results and tool technology from the initial design through to commissioning. This shows how the digital factory will have a key role to play in overcoming the challenges posed and the introduction of digital planning methods will mean drastic changes in working practices. These developments will be driven by the need to design buildings, plants and tools for the production of pressed parts for a wide variety of new, attractive models as efficiently as possible.

3 Integration of simulation tools in the process chain

In the area of production planning nowadays all processes for manufacturing sheet metal parts are calculated upfront using efficient simulation software before actually producing the part. Thus, statements about the feasibility of certain components for future parts using certain materials can be done in an early design stage. In addition, tool geometries can be optimized in time.
Besides feasibility studies, basically processes that lead to changes in the material structure and for this reason to changes in the material properties are of special interest. So far the simulation calculations of each single process were usually done independently. A possible influence of a previous step in the process chain on the following step was not considered with this approach. Depending on the material examined the deformation history is, however, of crucial importance for the accuracy of the simulation results. Therefore, great efforts are taken to close up the digital processing chain for manufacturing sheet metal parts holistically.
The digital process chain for manufacturing sheet metal parts can be roughly divided into the simulation packages casting, rolling, annealing, forming, joining, durability analysis respectively crash. At present each individual component (module) is been worked on with the objective of closing the process chain in reference to calculating the component properties. Figure 2 shows a schematic overview of the future simulation environment.
To simulate all steps in this environment we have to solve some problems:

- Each simulation method (static, crash, etc.) needs its "own" FE - Program (exception Forming - Crash with explicit codes)
  - Each simulation method (static, crash, etc.) needs its „own“ FE - Mesh
  - Each simulation method has "own" material and failure models
  - Data must be mapped between the programs statically and kinematically compatibly.
  - Today it is only possible to interpolate Scalars such as thickness, plastic strain, etc.
  - Which influence does the "damage" have by the mapping process on the characteristics of the component?
  - With the extrapolation of tensors still many questions are open (e.g. can an equilibrium be achieved with mapping?)

Nowadays, FE-simulations for calculating the crash behaviour of component parts are mainly built up using CAD data that only contain geometrical information on the component or component assembly neglecting the deformation history. In the past years so called mapping algorithms were developed, which allowed to transmit certain parameters (element thickness, strain) from the results of the forming simulations to the starting mesh of the crash simulation. This poses a big challenge because the FE-meshes used for forming simulations, which are done for each part separately, are much finer than the FE-meshes used for crash simulations, which are done for a whole vehicle. Thus, a wise mapping algorithm has to be able to transform result parameters obtained from many fine forming elements to a rougher element of the mesh used for crash simulation. Such a method is already being used for certain crash calculations but it does not represent the common approach.
Many commercial finite element programs are today capable of reliably forecasting possible crack and tear formation and the sheet thickness and form changes of conventional sheet-metal materials. In the past ten years, a number of studies have been made of sheet-metal forming process simulation [2,3,4], based on a very broad range of approaches, where, in addition to implicit and explicit processes, what are known as “one-step procedures” (often also known as inverse procedures) are also on the market.

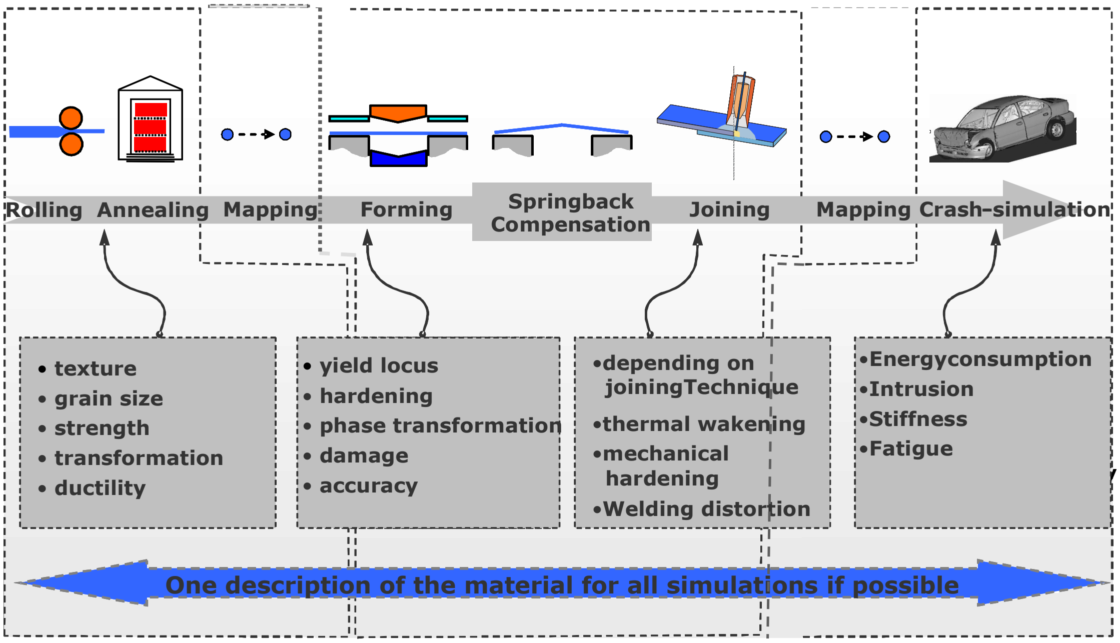

Figure 2: *Schematic overview of the future simulation environment [5]*

With increasing requirements on crashworthiness, and light-weight car body structures being a central issue in future automotive development, the use of high strength steel qualities has become widespread in modern cars. Since these materials often show significantly lower ductility than conventional steels, it is of great importance to precisely predict failure under crash loading conditions. Hence constitutive models in crashworthiness applications need to be initialized with correctly determined internal variables mapped from a corresponding sheet metal forming simulation. Here two principle ways could be used theoretically: On the one hand different understanding of damage and failure in crashworthiness and sheet metal forming applications may be unified by a generalized incremental stress state dependent damage model. This approach can be considered as an attempt to replace the currently used Forming Limit Diagram (FLD) for the failure description in forming simulations. Furthermore, an advantage would be the inherent ability to account for load-path dependent failure behaviour. On the other hand the already applied Gurson model in crash simulations may be fed by an estimation of the internal damage value from the forming simulation. The idea here would be to perform the forming simulation with a state-of-the-art anisotropic material model like e.g. the Barlat model, with a simultaneously executed estimation of Gurson's damage evolution law. First results are shown in Figure 3 [6].

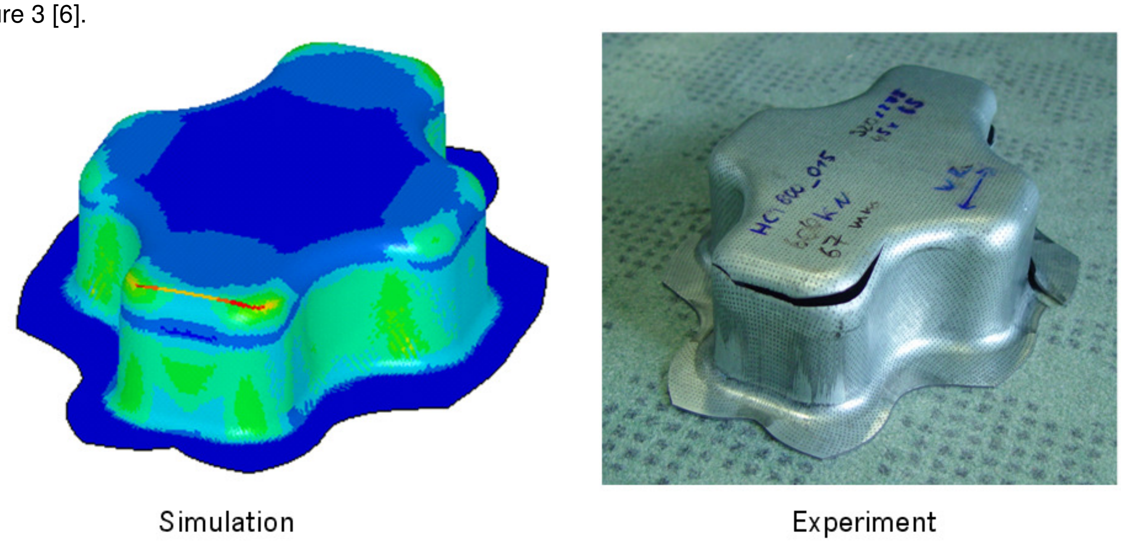

Figure 3: *Prediction of Failure using Barlat-Model with a Generalized Incremental Stress State Dependent Damage Model [6]*

The described possibilities for determination and transfer of local pre-damage data from forming to crash simulations show a promising potential to make crack prediction in crash simulations more accurate in the future. Both options proposed, for the combination of a material model for forming simulations (like Barlat89), with a crash damage model, can be improved by implementing the described extensions to the damage models. As some unintended, but very welcome "side-effect", the damage models also show promising results in predicting ductile failure in forming simulations. The use of these damage models could therefore also lead to an improved failure prediction in forming simulations.

4 Simulation of different joining methods

One of the most important joining steps of body-in-white is hemming. Hemming is applied in the process chain after forming and assembling of body parts (see Figure 2). Prediction and minimization of hemming defects and an improved understanding of the roller hemming process are essential for the dimensional quality of roller hemmed hang-on-parts. The successful application of the finite element analysis (FEA) code LS-DYNA to model the roller hemming of sheet metal specimens with flat surface and straight edge was demonstrated in preceding studies which was presented in [7]. The results showed that diameter and geometry of the hemming roller are significant for achieving a good quality of the hemmed flange and finished assembly.
To achieve realistic results from the simulation, the model of an experimental tool with configuration curved surface and curved edge/straight edge is developed and validated against experimental results. Beside the aspect of validation, the adaptation of the roller hemming simulation model to generic three-dimensional problems is the most important point to be able to run subsequent formability simulations. The simulation models for the roller hemming joining process shall contribute to increasing the process understanding and support the process interpretation.

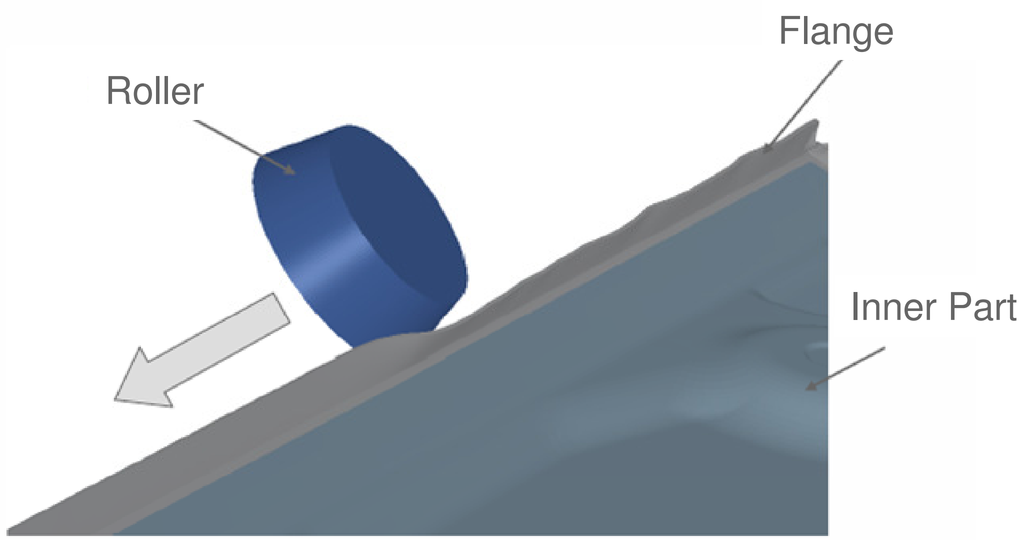

Figure 4: *Description of the roller hemming process [8]*

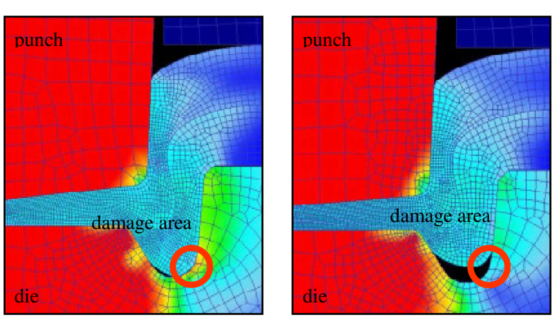

Figure 5: *Simulation of clinching [9]*

Clinching and self-piercing riveting are established, efficient mechanical joining processes, which become more important for those applications [9]
The simulation of those clinching processes provides a more detailed understanding of the process. The reason is the constant monitoring of the joining sequence. It is necessary to analyze the punching and clinching effects in combination with influences caused by the materials of the parts to be joined.
Another benefit of using the simulation is the possibility of analyzing the tool loads during the

clinching. This advantage is already used for conventional clinching applications. Figure 5 shows the previous and the optimized die stresses of such a testing. This makes it possible to avoid broken dies by changing the punch diameter.

5 Use forming results in fatigue respective crash analyses

The digital process chain for sheet metal parts is divided roughly into the simulation packages casting, rolling, annealing, forming, joining, fatigue respective crash. Currently there is a lot of work on these topics going on with the goal to take over the results and subsequently close the process chain.
Figure 2 shows the concept of the proposed digital process [5].
For example the simulation of vehicle crash behaviour today mainly calculated using initial and perfect CAD data (geometrical shape and material behaviour). But the reality is not “perfect”. Due to the manufacturing process of deep drawing the material behaviour (thickness and strain distribution) changes in local areas of the parts. In recent years, so-called mapping algorithms [10] have been developed that allow certain parameters (element thickness, effective plastic strain) transfer results from a forming simulation to the mesh of the crash simulation. The challenge here is that the very fine and adaptive element meshes for forming simulation, which are calculated per component have to be transferred on the much coarser element meshes simulating the full vehicle. This procedure is now in certain crash calculations already used, but is still not the normal practice.
Alternatively to the mapping process currently is working on a method which carries out the essential failure criterion for crash simulations even at the forming process.
Unlike in conventional forming simulation, there is a so-called damage variable used in crash analyses (e.g. Gurson model) in order to decide whether the deformation of the finite element is in accordance to the real deformation behaviour of the material.
The important factor is the multiaxial stress condition - a scalar, which describes the ratio of the mean element normal stress after von Mises. Depending on the multiaxial condition the elongation after fracture is determined therefore also the damage parameter.
If these damage parameter reaches the limit, the referred element from the FE mesh was removed, creating a hole at this point, and in the next simulation increment the previously forces be moved to the surrounding elements. In this way the crack of the material grows up.
In current crash simulations the "initial" damage value is zero. With slight modifications of the forming simulation – that means including the same damage model - it is possible to be carried out the damage value already in the forming simulation step. In this way you can use a more realistic
pre-damage value due to deep drawing manufacturing like the "initial" damage value of zero. [11, 12].
Figure 6 shows result after crash mapping of 64 parts in a car body

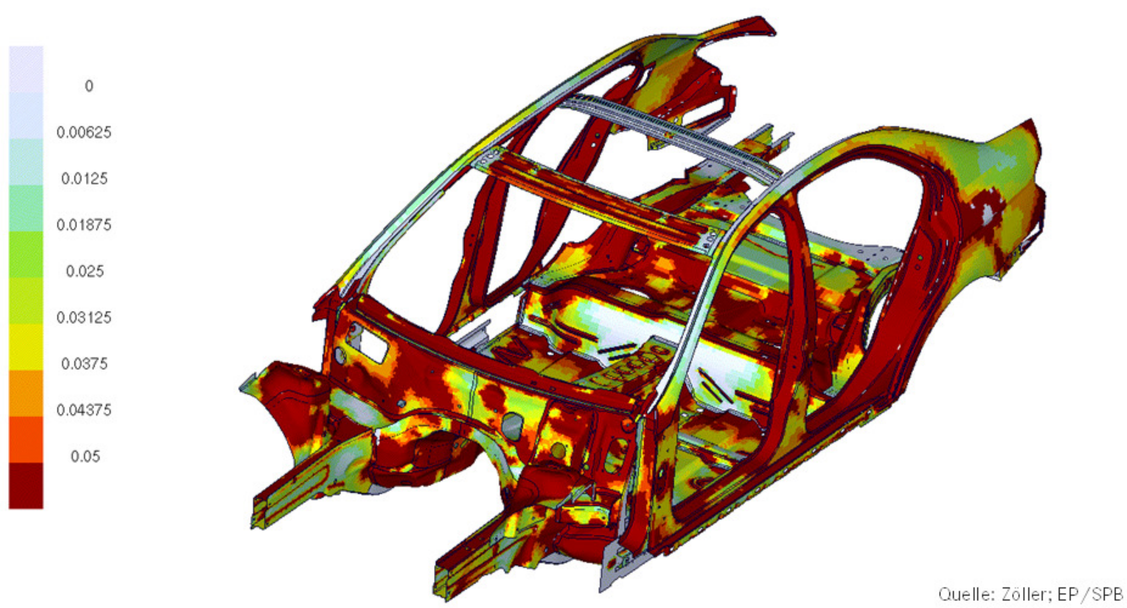

Figure 6: Result after c*rash mapping of 64 parts in a car body*

6 Literature

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