FE-MODELING OF SPOTWELDS AND ADHESIVE JOINING FOR CRASHWORTHINESS ANALYSIS

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ABSTRACT:

The increasing demands with regard to the predictive capabilities and the exactness of crash simulations require more and more investigations into numerical models in order to capture the physical behavior reliably. Steps towards this goal are the usage of finer meshes which allow for a better geometrical representation and more sophisticated material models which allow better prediction of failure scenarios. Another important playground towards improved crash models is the area of connection modeling. Validation in this area is usually closely related to very detailed models which cannot be easily translated into a crash environment due to time step restrictions. Therefore, representative substitute models have to be developed and foremost validated. The aspect that failure of the connections has to be considered as well adds another dimension to the complexity of the task. The present paper highlights the conflict between predictive capability, capture of physical reality and manageable numerical handling. Another aspect of the paper is the attempt to raise the awareness of the topics verification and validation of numerical models in general. This concept is illustrated using latest developments for modeling of spotwelds and adhesive bonding in LS-DYNA.

KEYWORDS:

Spotwelds, Adhesives, Failure, Cohesive Elements, Explicit Finite Element Method

INTRODUCTION

In the past years the progress in the simulation methodologies and the increasing computer power changed the development process in the automotive industry constantly and significantly. Numerical predictions are much more reliable than before. However, with the increasing success of the simulation techniques also the expectance level has increased substantially.

Up to a couple of years ago, hardware prototypes had to be built and used for decision making in all development phases of a new vehicle, see [1] and [2]. Thereby, the first prototypes were built without an integrated numerical approach. The different simulation disciplines had more supporting character and rather seldom decision leading character. Numerical methods were used for detailed and rather isolated problems in order to indicate possible solution strategies. Its role was of accompanying nature.

DaimlerChrysler uses for its crash simulations the commercial Finite Element program LS-DYNA which is based on the explicit time integration scheme, [3] and [4]. The body in white is modeled to great detail which allows, together with the inclusion of aggregates and packaging details, to capture all effects and interactions.

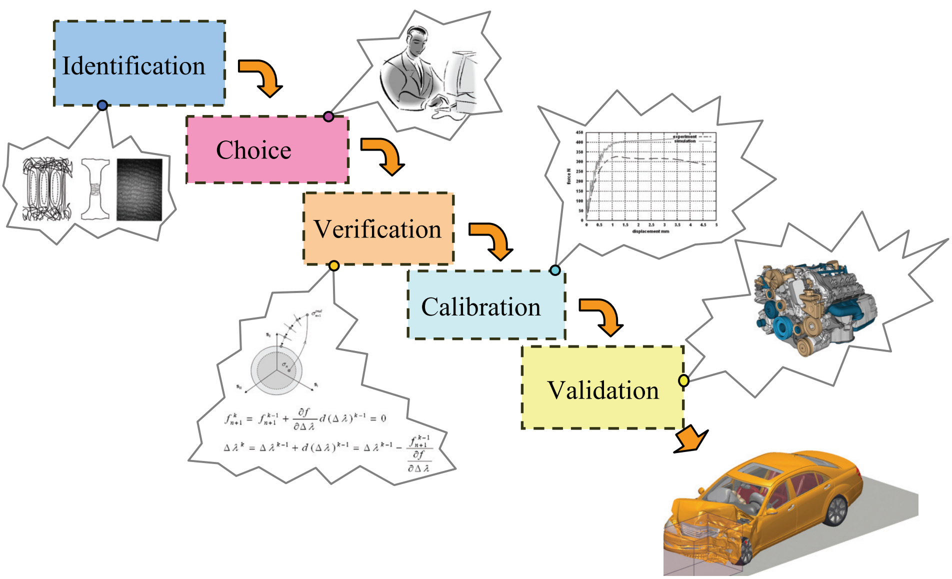

Figure 1: Verification and validation Process

A special challenge poses the prediction of failure in structural parts. This is particularly true for failure in metals or of connections (spotwelds and glued connections), and in plastic materials which all have been the focus of substantial efforts in the recent past.

The usage of new methodologies such as new material formulations and/or failure models is accompanied by a verification and validation phase (see [6] & [9]). The new method is released for usage in the overall development process only after the successful validation phase which secures the high predictive capability.

This procedure is depicted schematically in Figure 1 for the example of a new material formulation. Starting points are the determination of the characteristic material behavior and the analysis on how the microstructure influences the material behavior. This leads to the identification of the dominating mechanisms. Subsequently, the search for an appropriate material formulation begins or a new formulation is developed and implemented. The material law is verified by checking whether it can represent all effects of the characteristic mechanisms that were identified earlier.

The next step is the calibration of the material law, i.e. the determination of the material parameters. To this end simple experiments are used, e.g. tension tests. Local measurement data is very helpful in this case. Finally, the calibrated model is validated using component tests. Only after this verification and validation process the material model will be used in full car crash simulations.

STATUS QUO OF CONNECTION MODELING

The increasing usage of high strength and ultra high strength steels in car structures poses new challenges for the connection technology. As an example resistant spotwelding of hot formed steel sheets may be mentioned. Due to the heat induction the grain structure and the steel coating in the vicinity of the spotweld is influenced, leading sometimes to more brittle failure modes. As a result the strength of the spotweld is reduced; hence this effect has to be considered in the numerical modeling of the spotweld.

NEW SPOTWELD MODEL IN LS-DYNA (MAT_SPOTWELD_DAIMLERCHRYSLER)

In principle it is no particular challenge to model a spotweld connection with finite elements as long as one uses a fairly detailed model which includes the influence of the inevitable heat action and the resulting modification of grain size in the spotweld domain of the sheet metal, see Figure 2. If the characteristics of the various domains are known one could use e.g. the Gurson model and capture the overall behavior including the failure mechanism. However, such detailed modeling cannot be used in a crash environment due to time step restrictions. Considering an average spotweld diameter of 5 mm it becomes obvious that any substitute model is limited to one or very few elements in order to keep the time step of the explicit finite element model manageable.

Currently, one hexahedron element is used per spotweld, see Fig. 2 This spotweld element has to be able to capture the different failure modes (e.g. shear, bending and pure tension modes) properly. Therefore a hexahedron spotweld element is chosen to model the connection in contrast to the more traditional approach with beam elements. The advantage of the 3D-element is seen in a complete description of the stress state, hence it allows for a distinction between tensile, shear and peeling action.

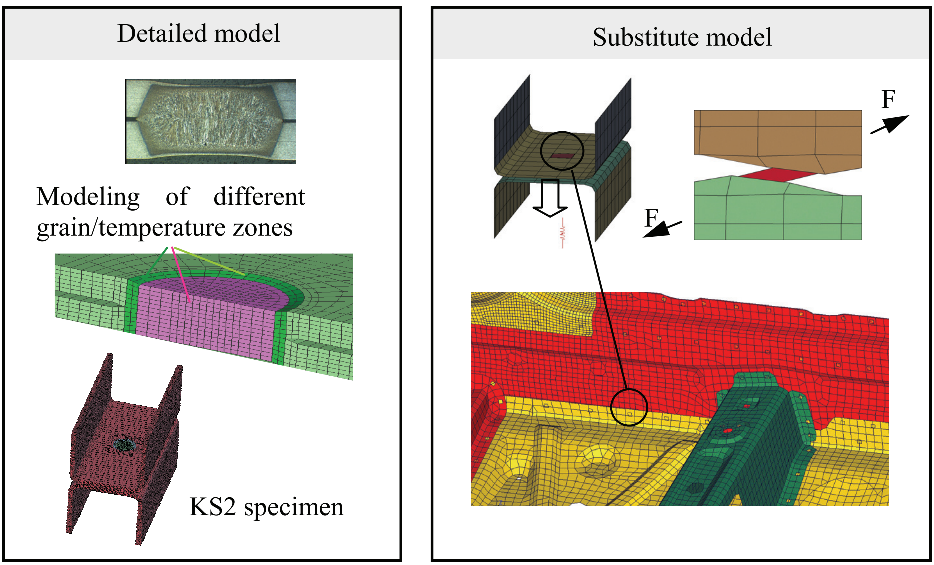

Figure 2: Detailed and substitute model of spotweld connection

The failure criterion has to be able to distinguish between these three different loading scenarios. As a result an elliptical failure criterion is chosen as depicted in Figure 3. A very similar failure criterion has been available in LS-DYNA for many years (MAT_SPOTWELD, opt=1). However, this criterion allows the distinction between tensile and shear components only. The new formulation (MAT_SPOTWELD_DAIM-

LERCHRYSLER) accounts also for the bending contribution as depicted by the red term in the equation in Figure 3.

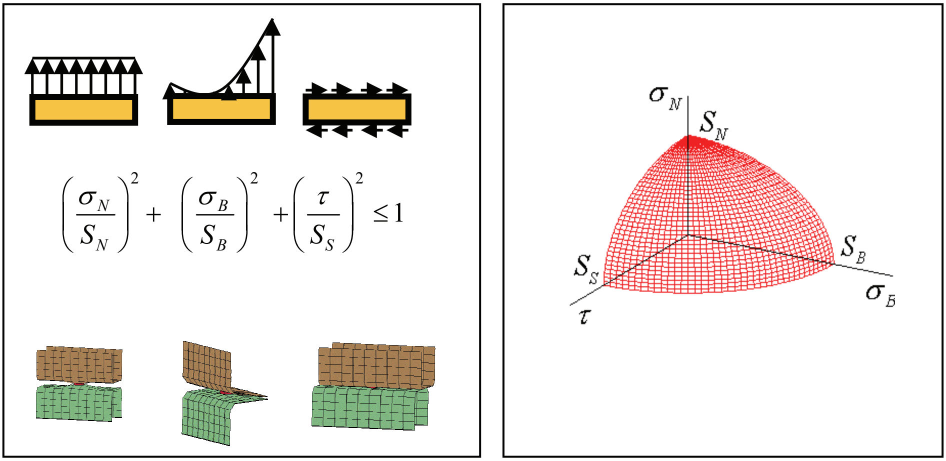

Figure 3: Failure criterion

Using this criterion results in qualitatively good results for the T-bar component test with vertical impact loading, see Figure 4. It must be emphasized though, that rigorous verification and validation procedures based on test data need to be applied in order to take advantage of this superior approach.

In order to capture the connection behavior in a reliable fashion not only the material and failure formulation is of importance. Moreover, in order to avoid unrealistic high contact forces in the vicinity of the spotweld the contact formulation has to be adjusted. Introducing the parameter SPOTTHIN [7] avoids the problem of premature failure in the spotweld due to high parasitic (i.e. non-physical) contact forces.

MODELING OF ADHESIVE CONNECTIONS

The usage of glued connections has increased significantly in recent times. The main reasons are the increased stiffness properties of glued structures and the increased connection strength of high strength parts. In this paper first steps towards the simulation of glued flat flanges are presented.

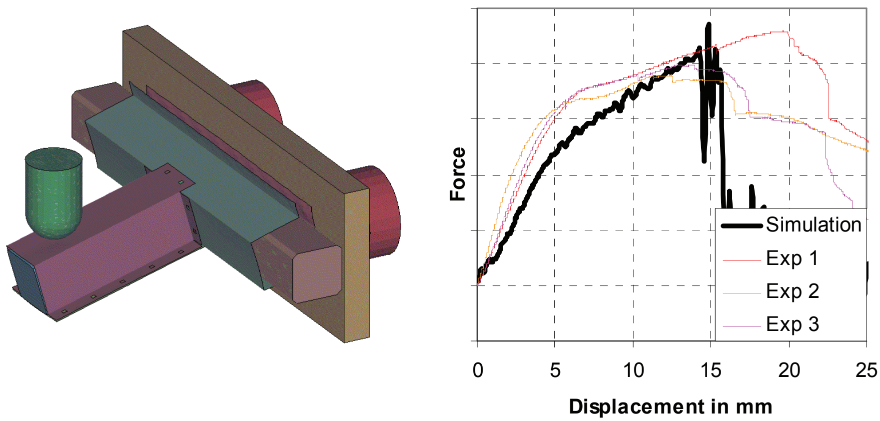

Figure 4: Validation of spotweld connection

The substitute model of structural adhesives, as applied in bodies in white, is naturally based on the two-dimensional character of adhesive joints. At DaimlerChrysler continuously connected hexahedron elements are used to model the adhesive connection. For validation KS2-, peel- and shear-tests are used for any material combination that may be of interest.

Contrary to the spotweld modeling technique a more detailed constitutive modeling of the adhesive connection is necessary. This is due to experimental results, which showed a strong dependency on the applied hydrostatic stress state. Hence, the substitute model needs to take this effect into account. This is particularly the case if the substitute model uses only one hexahedron element across the thickness direction and thus the compressibility characteristic of the material model is of uppermost importance due to the constraints enforce through the modeling technique.

In the present case the newly developed SAMP-model was applied, see [5, 6, 8]. Due to the high flexibility of the constitutive formulation and implementation in LS-DYNA, which allows direct usage of tension, shear and compression test data, its application is almost straight forward. The failure behavior may be adjusted through maximum plastic failure strain data that is dependent on the acting triaxiality. The results are depicted in Figure 5. A good correlation is observed between experimental investigations and the simulation runs. Meanwhile first experience was gained for full car crash analyses where SAMP is used for adhesive modeling. Again it is emphasized, that a rigorous verification and validation procedure needs to be applied in order to gain predictive results.

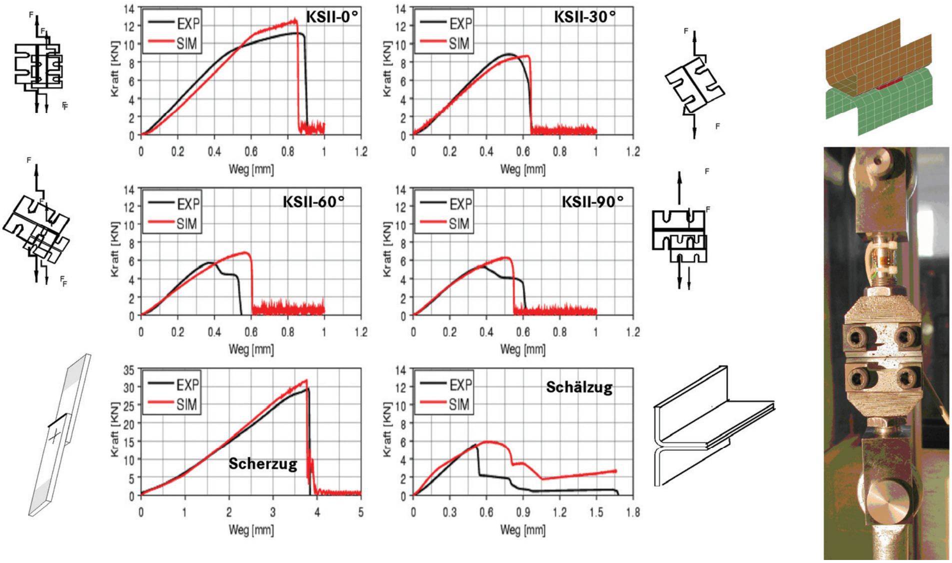

Figure 5: Validation of adhesive connections

SUMMARY AND OUTLOOK

This presentation illustrates some of the recent method development projects which were carried out at DaimlerChrysler in Sindelfingen in order to improve the predictive capabilities of crash simulations using LS-DYNA. Special emphasis was directed towards modeling techniques of spotweld connections and glued connections. The very high discretization effort and fine detailing of current crash models lead to good predictions of the structural behavior of the body in white. State of the art simulations allow detailed insight into construction and design variations during the different loading scenarios. Discretization and idealization limits lead to substitute models that replace and mimic the detailed mechanical behavior on the lower scale.

More reliable predictions during the car development cycle require significant efforts in component testing to ensure rigorous verification and validation of newly developed simulation techniques for failure of different connection types. The illustrated verification and validation procedure is very elaborate and requires data from many different tests.

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