Modelling of Weld and Adhesive Connections in Crashworthiness Applications with LS-DYNA

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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 behaviour 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 modelling. 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 modelling of spotwelds and adhesive bonding in LS-DYNA.

Keywords:

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

1 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. 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.
Daimler uses for its crash simulations the commercial Finite Element program LS-DYNA which is based on the explicit time integration scheme, [1] and [2]. The body in white is nowadays modelled to great detail which allows, together with the inclusion of aggregates and packaging details, to capture all necessary structural effects and interactions.

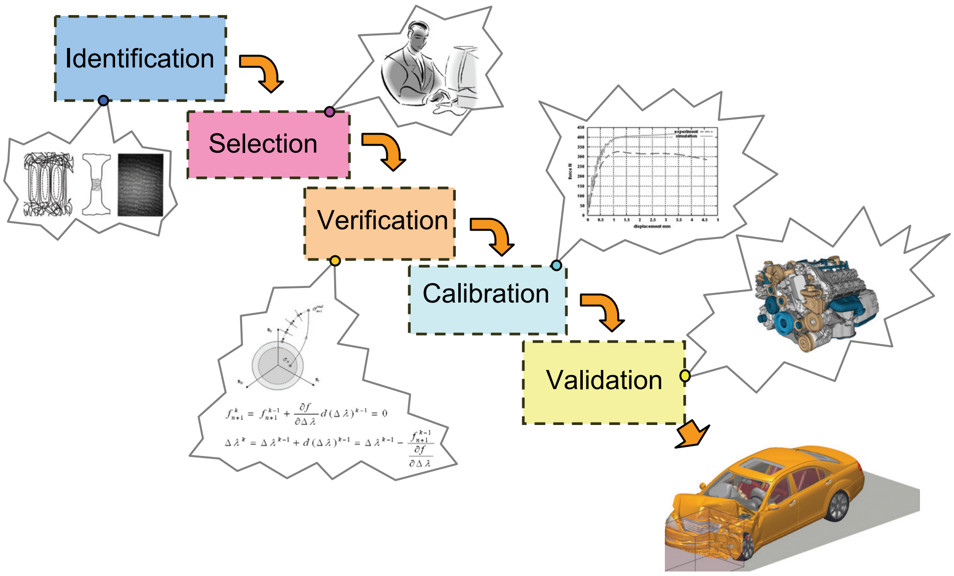

Figure 1: Verification and validation Process

A special challenge poses the prediction of failure in structural parts. This is particularly true for failure in metals or disintegration of connections. Here spotwelds and bonded connections are discussed.
The usage of new methodologies such as new material formulations and/or failure models is accompanied by a verification and validation phase (see [3] & [5]). A new method is released for usage in the overall development process only after a successful validation phase which secures highly predictive capabilities of the models.
This procedure is exemplified schematically in Fig. 1 for the development of a new constitutive formulation. Starting points are the determination of a characteristic material behaviour and the analysis on how the microstructure of the material affects the global material response. This leads to the identification of the dominating mechanisms. Subsequently the search for an appropriate material formulation begins or a new formulation has to be 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. standard tension tests. Local measurement data from optical systems 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.

2 Status Quo of Connection Modelling

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 modelling of the spotweld.

2.1 An example for modelling spotwelds in LS-DYNA

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 Fig. 2. If the characteristics of the various domains are known one could use e.g. the Gurson model and capture the overall behaviour including the failure mechanism. However, such detailed modelling cannot be used in a crash environment due to the well known restrictions within the explicit time integration scheme. 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 often 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. In the past few years more complicated modelling techniques as for example multiple hexahedron elements sometimes based on cohesive constitutive formulations have been introduced as well as pointwise defined cohesive relationships.

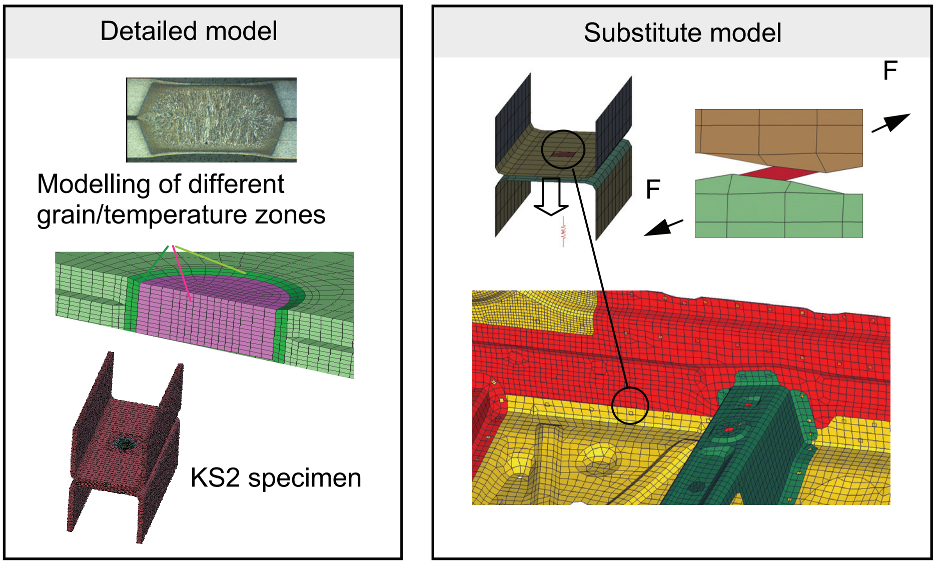

Figure 2: Detailed and substitute model of spotweld connection

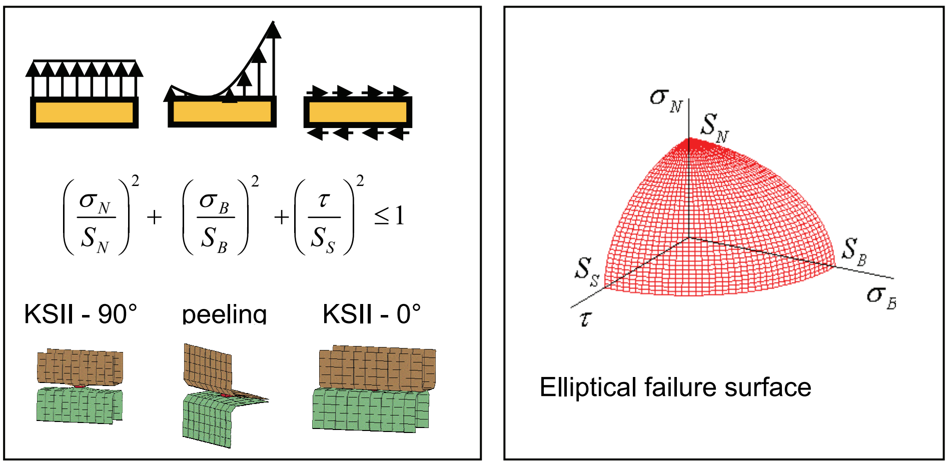

Figure 3: Failure criterion

The failure criterion has to be able to distinguish between the aforementioned three different loading scenarios. As a result an elliptical failure criterion may be chosen as for instance depicted in Fig. 3. A very similar failure criterion has been available in LS-DYNA for many years (MAT_SPOTWELD, opt=1). However, it criterion allows the distinction between tensile and shear components only. The new formulation (MAT_SPOTWELD_DAIMLERCHRYSLER) accounts also for the bending contribution as depicted by the second term in the equation in Fig. 3.

Using this criterion with calibrated data from KS2-specimen leads to qualitatively sound validation results for the T-component test. It must be emphasized though, that a rigorous verification and validation procedure based on test data needs to be applied in order to take advantage of this superior approach.
In order to capture the connection behaviour 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 [4] avoids the problem of premature failure in the spotweld due to high parasitic (i.e. non-physical) contact forces.

2.2 An example for modelling adhesives in LS-DYNA

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.

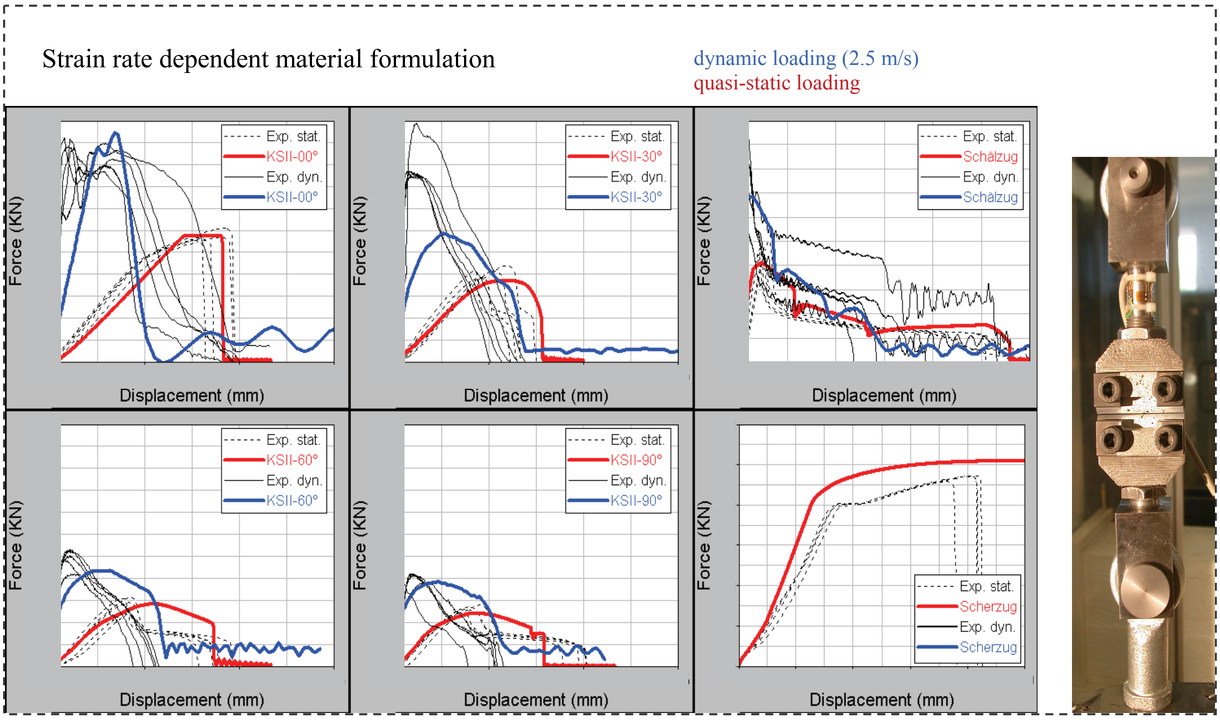

Figure 4: Calibration of adhesive connection

The substitute model of structural adhesives, as applied in bodies in white, is naturally based on the two-dimensional character of adhesive joints. At Daimler 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 modelling technique a more detailed constitutive modelling 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 enforced through the modelling technique.

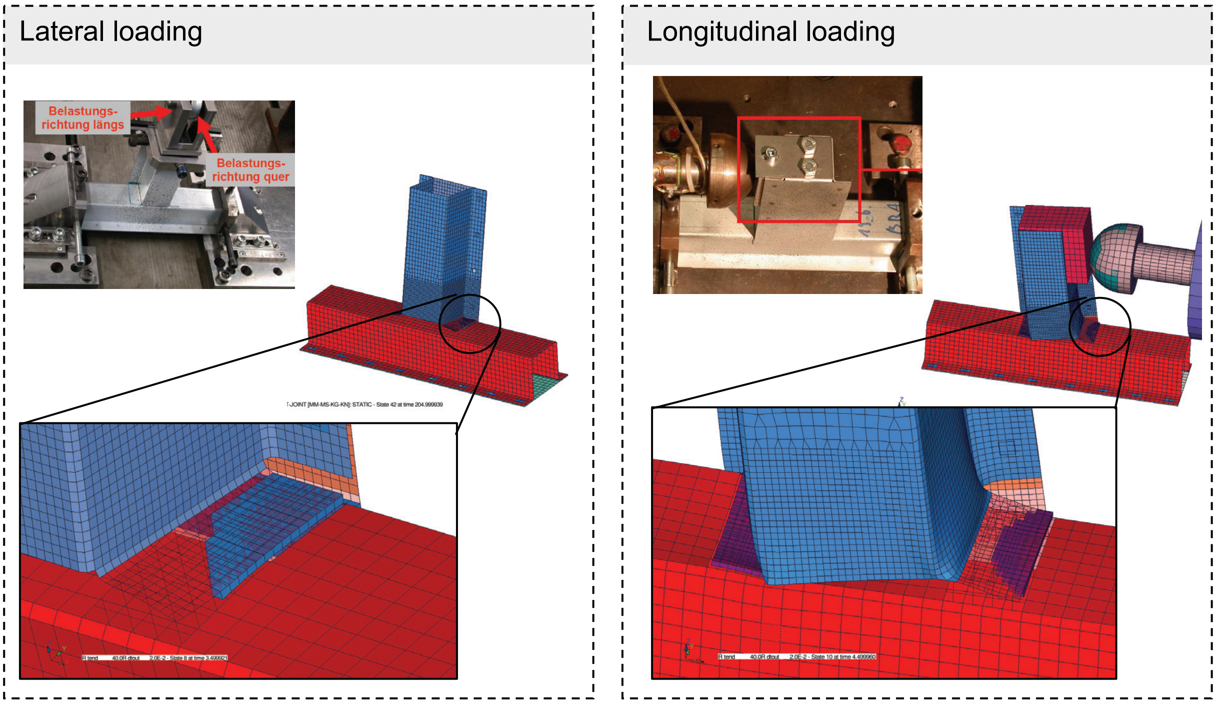

Figure 5: Test setup and validation finite element model of T-section

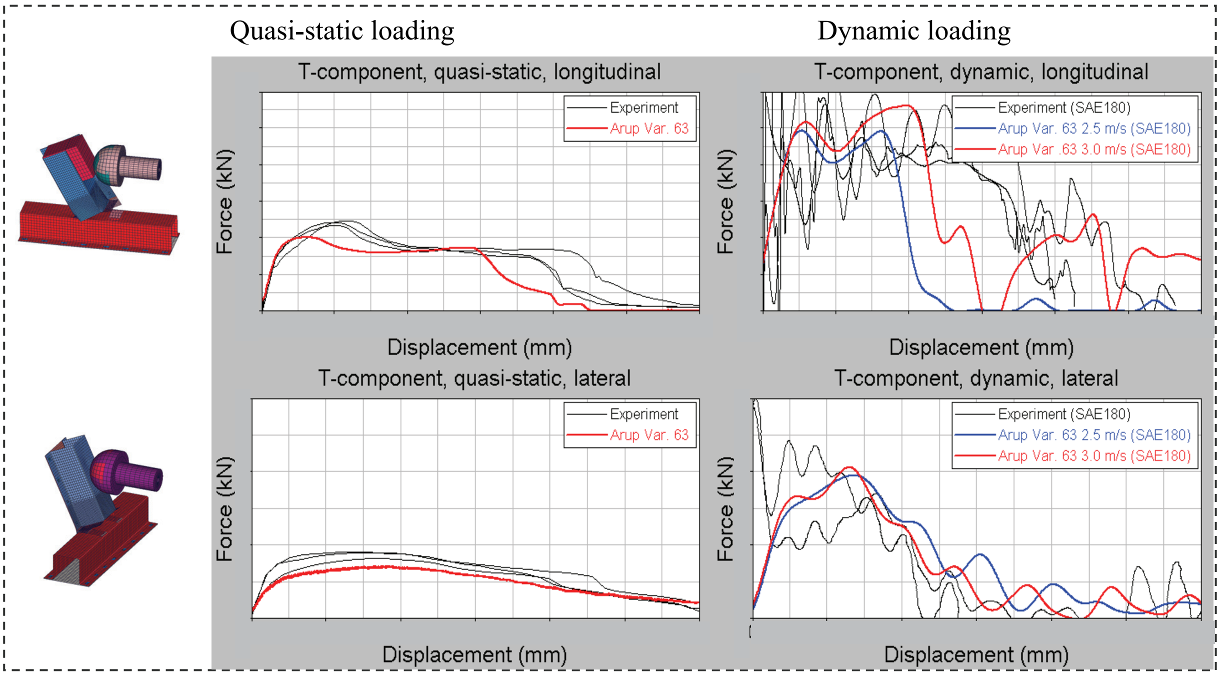

Figure 6: Validation results of adhesive connection

In the present case the ARUP-model was applied, see [6, 7], that allows fro independent parameters In shear and pure tension loading on the basis of a cohesive-like formulation. The model is capable of taking strain rate dependent parameters into account and shows also good agreements for mixed loading. The failure behaviour may be adjusted through parameters that correspond to crack width opening measures. Calibration is done by KS2-specimen as depicted in picture 4 while Fig. 5 shows the typical modelling of a component test. A good correlation is observed between experimental investigations and the simulation runs as shown by the validating results depicted in Fig. 6. Again it is emphasized, that a rigorous verification and validation procedure needs to be applied in order to gain predictive results.

3 Summary

This presentation illustrates some of the day-by-day applied methods to modelling connection failure within crashworthiness simulations at Daimler in Sindelfingen. Continuous improvements are made in order to enhance the predictive capabilities of the models available in LS-DYNA. The very high discretization effort and fine detailing of current crash models leads to good prediction capabilities of the structural behaviour of the body in white. State of the art simulations allow detailed insight into construction and design variations during the different loading scenarios. But discretization and idealization limits still lead to substitute models that replace and mimic the detailed mechanical behaviour on the lower scale.

The demand for even more reliable prediction capabilities during the car development cycle require significant efforts in component testing to ensure a rigorous verification and validation effort of these newly developed or enhanced modelling techniques. This effort must be even higher if a sound failure prediction of the many different connection types is sought after. The illustrated verification and validation procedure is very elaborate and requires data from many different tests.

4 Literature

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