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INTERACTION CHAINS OF ENERGY ABSORPTION

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The occupant protection and especially the pedestrian protection are getting more and more important since several years. The reason is the insufficient safety of the pedestrian against severe injuries during the impact with vehicles. For the reduction of injuries and their severity, design changes within the frontal structure are necessary to absorb energy and to reduce the forces and accelerations on pedestrians. Therefore more and more of such structures for energy absorption are considered that are often designed with different materials like highly porous foams as well as energy absorbers with plastic deformation behaviour such as egg-box structures. Combinations of such parts are interacting under crash load e.g. the bumper system. For the layout of new protection systems, it is necessary to predict deformation behaviour and force level of these "interaction chains".

The main purpose of the present study is, together with Institute for composites in Kaiser-slautern, to detect and quantify the interactions among structural components in complicated systems, which take place during low-energy-impact events. Since these interactions often lead to deviation between experimental and simulation results, the accuracy of forecast of the crash simulations will be increased as a consequence of this investigations.

The energy absorbing system, investigated in this study, represents an interaction chain of different constituent components: EPP foam, a polymer eggbox structure, steel and alumi-num sheets. This interaction chain and its constituent components are investigated experi-mentally and further modelled with finite element code LS-Dyna. Own experimental material data is used to validate the material models.

Keywords: Materials engineering, Composites, EPP-foam, Eggbox, Numerical simulation, Energy ab-sorption, Validation, Modelling, Test, Pedestrian protection, Complex impact processes

INTRODUCTION

Besides the occupants protection, the pedestrian protection especially gained importance within the last few years. By now pedestrians stand for more than 15 % of all casualties of the European road traffic [BUN03]. In order to improve pedestrian safety, Phase I of the EU Directive 2003/102/EC came into effect on the 1st October 2005, which regulates a test of the structure behaviour of the vehicle front, whilst using a body impact testing procedure. On 14th January 2009 a further regulation 2009/78 EC was started with aggravated requirements. In order to reduce the injuries of pedestrians, constructive changes in the vehicle front struc-ture are necessary, to absorb energy and to decrease the forces and accelerations that have an impact on the pedestrian. For these reasons, the usage of energy absorbed structures is required, these are mostly accomplished in multi-material-design. Next to highly porous foams, components with distinctive malleable deformation behaviour are used, to which the so called eggbox structure belongs to. Combinations of such structures correlate with each other when attaching crash encumbrances. It is necessary to be able to predict the deforma-tion behaviour and strength level of these interactions, in order to design new protective systems. Although those single components were validated in the simulation and are easy to describe, it is common that notable differences occur between calculation and test for the whole interaction chain, due to the very different stiff-

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ness of the components. Impact proc-esses with interaction of various components on a low energy level are in particular hard to describe.

MOTIVATION

Throughout the car are areas, where various materials contribute jointly to the energy ab-sorption. In this project, an impact chain is defined as a combination of at least two compo-nents that interact. An example of an impact chain, consisting of four components, can be seen in Figure 1. This is constructed of EPP-foam (Neopolen P from BASF AG), a sheet of aluminium, an eggbox structure consisting of Acrylnitril-Styrol-Acrylester (ASA) and a steel plate. Exemplary for a realization, is the energy absorbed impact chain on the right side, which made of a steel cross member, a foam and a plastic covering.

At almost all collusion scenarios the described impact chains occur, when the single compo-nents of the whole chain lie partly parallel partly serial in the distribution of forces. During the impact process, the arrangements, thus the interactions can change between the involved components.

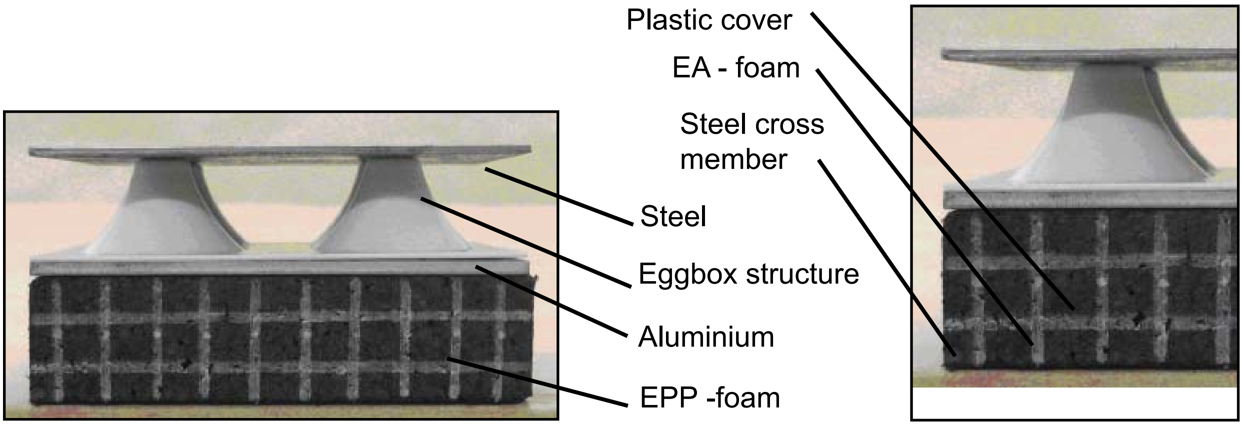


Figure 1. Architecture of an impact chain (left), Example of a vehicle front [ERN00] (right)

Aim of the conducted research within the DFG-project “Evaluation of the cross impacts of structure elements of complex impact processes” was to determine the interactions between adjacent components, which occurred during the impact processes, to improve the predict-ability of FE-simulations with a comparison of corresponding tests, and to grasp coinciden-tally the boundaries of the calculation for suitable comparable loading conditions. For the analysis a simplified scenario was considered, which is likely to occur with a leg impact against a bumper or a head impact on the bonnet.

CHARACTERISATION OF THE MECHANICAL FEATURES

The state of the art enables a simulation of the material features of a single component with the precision, which corresponds to the accuracy of measurement of the material test. How-ever, this precision of the depiction of the material features, is not directly contained in the FEM-codes, but refers to an adequate precise selection and calibration of the material mod-els, which are available to the FEM-codes. A comparison between the simulation and test requires experimental data. As a very precise depiction was aimed at in the described pro-ject, basic literature was not sufficient. The single components were instead examined with help of the following loading cases.

Material modelling

The steel and aluminium material parameters were recorded with the aid of tensile tests for various strain rates, and afterwards depicted with the, for these materials, common material model 24 “MAT_PIECEWISE_LINEAR_PLASTICITY”. The validation of the tensile test took place in a LS-DYNA tensile test model.

The eggbox was manufactured through thermoforming out of Acrylnitril-Styrol-Acrylester (ASA) with a thin top coat of Polycarbonat. As material model the material “MAT_PLASTICITY_¬COMPRESSION_¬TENSION” was chosen by the research partner IVW, in order to depict tensile and pressure curves separately. The needed material parameters of the EPP-foam for the simulation were evaluated at the ika. The validation is described as follows.

At first the appropriate material models for the simulation of the foam material are chosen and are compared to each other. Most of the available models in LS-Dyna are merely for very specific applications. Whereas others represent more general models, which can be used for a various number of materials. For the EPP foam the LS-Dyna material model 83 “MAT_FU_CHANG_FOAM” was chosen. The direct input opportunity of the suspense-strain-curves for different strain rates were one reason for choosing the latter. With this model, the strain rate dependency of the foam material can be considered without restraints. From the experimental researches, results both from quasi-static suspense tests with the strain rates 0,01 1/s, 0,1 1/s and 1 1/s and from dynamic suspense tests with strain the rates 50 1/s, 100 1/s and 180 1/s were available.

The measured raw data in the first instance conditioned for the simulation. Afterwards the tests were simulated for all six strain rates and then validated. Because the strain rates were chosen in a spectrum of quasi-static and highly dynamic weighs, the numeric calculation was able to be conducted with LS-DYNA, which provides both a implicit and a explicit FE-Solver. The material parameters were chosen for a joint model in such a way, which made the ag-gregate deviation minimal in the single simulations. Figure 2 compares exemplary the defer-ment behaviour of the basic alternative and the final alternative after the validation of the deferment behaviour within the test for a strain rate of 50 1/s.

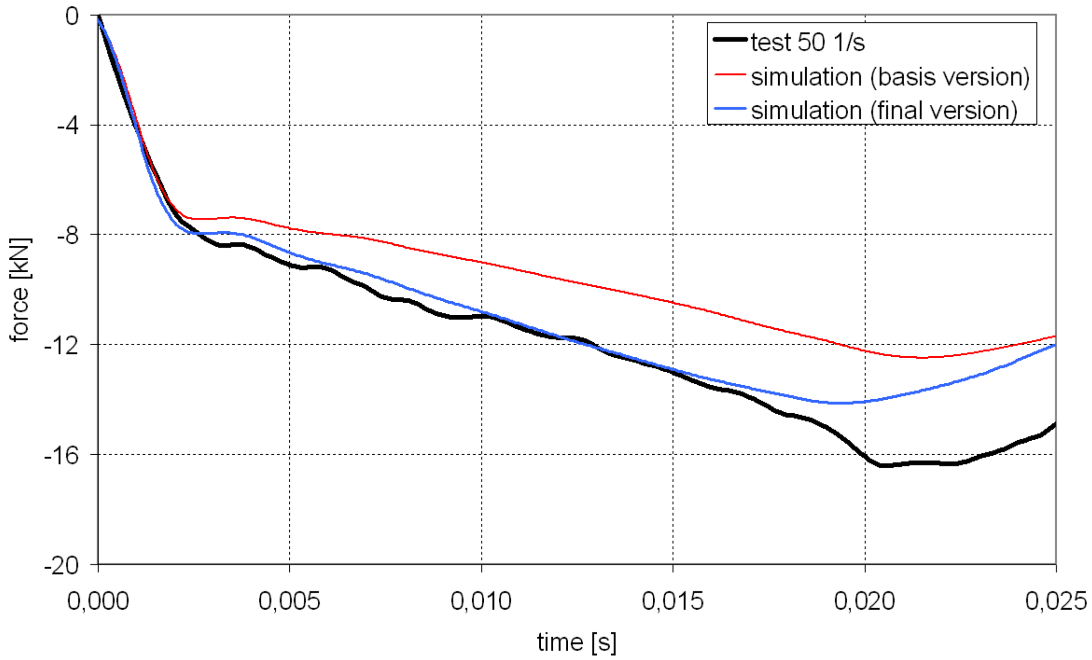


Figure 2. Delay EPP-foam strain rate 50 1/s

The element size is a parameter, which is not only influencing the stability of the calculation, but is also having an impact on the results of the simulation. It turned out that the configura-tion of the fully integrated volume elements for the load cases, produced a further approach to the test curves. Additionally, the occurrence of Hourglass-energy was avoided.

Besides the used element type, the contact definition had a major impact on the stability and the results of the simulation. Contact damping reduced the high frequented oscillations of the contact forces. Such contact oscillations cause instabilities, which especially often occur by contacts with foam. These can be reduced, due to the use of the viscous damping coefficient (VDC). A value between 40 and 60 is recommended for foams. Furthermore, the scale factor for the time step has to be decreased to 0,66 [DYN06].

The acceleration tests represented in Figure 3, demonstrate the result of the validation for the dynamic and quasi-static tests with respective simulations. On the whole, there are good congruities between tests and calculations after the simulation.

The validation of the foam model was used only for the compression phase, because the LS-Dyna version used at the beginning of the project was, in contrast to the current version 971, not able to define the decompression phase in the model *MAT_FU_CHANG_FOAM iso-lated. The relief phase in the material model is thus deter-mined by the lowest strain rate curve. Therefore, there is a stiffer behaviour in the simulation than in reality. Relevant for the determination of in-jury criteria in simulations, exemplary the impact for the foam of a leg impact, is merely the strain phase, not the relief phase. However, this form of validation does not represent a constraint to the generated model.

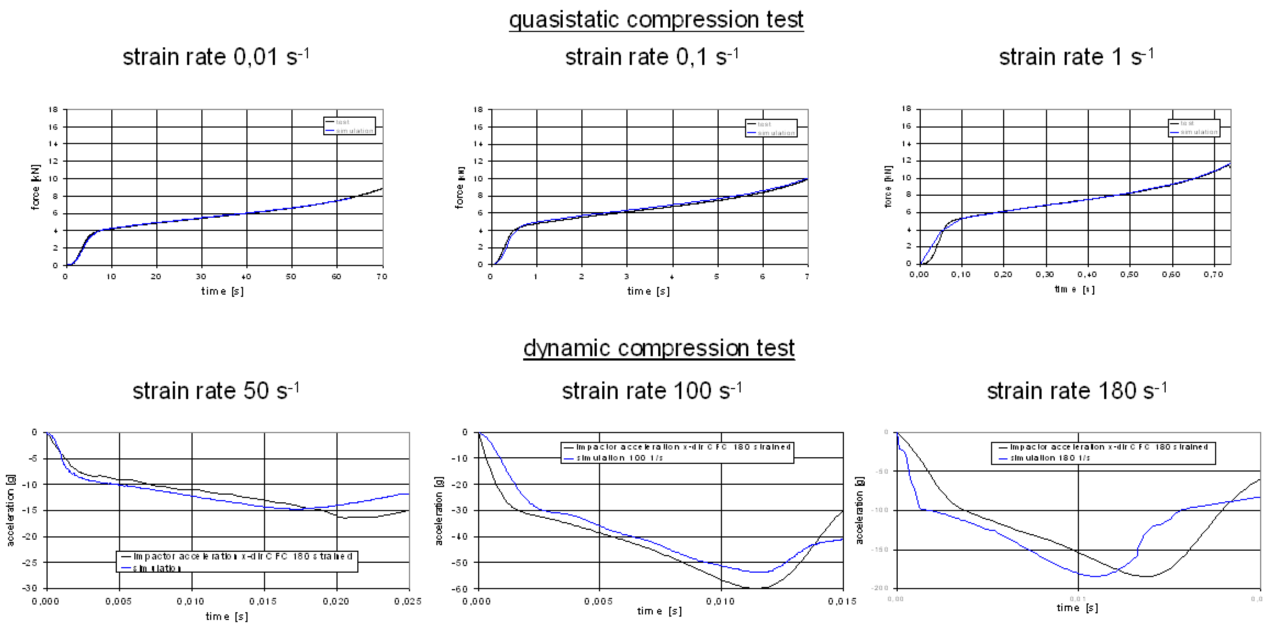


Figure 3. Overview of the compression tests

Determination of the adhesion and sliding friction coefficients

In order to describe the contacts and the already described interactions exactly, the occurring slid-ing friction coefficients between the different ma-terial couples will be determined using various velocities. The surfaces of the metallic materials will be prepared in the following three ways, in order to obtain the different reference values:

- Unmachined: The surface of the steel and aluminium sheets will be used as supplied.
- Coarse-sanded: The surface of the metallic components will be sanded with a disc-type sander using a sanding paper with a grain of 40.
- Polished: The surface of the sheets will be polished.

The surface of the thermoplastic absorber will be used in the delivered condition, because a surface treatment of the eggbox structure is very elaborate. The surface of the EPP-foam which emerged during the production process will be treated as well. The testing geometry will be generated via milling of the delivered foam blocks. In order to obtain measurements of the adhesion and sliding friction coefficients the In-stitute for composite materials in Kaiser-slautern owns a special testing machine. The determined parameters will be used as starting values for the contact definition and the validation.

Simulation and validation of the interaction chains

To be able to reproduce the interaction of com-plex systems in the simulation, it is necessary to gradually build up a system with increasing complexity. Using the simplest system no con-siderable interactions should occur, thus a reli-able experimental and arithmetical repro-duction can be guaranteed. Subsequently the complex-ity of the system has to be enhanced as far as the occurring interactions appear in detectable quantity, however the individual effects should still be recognized solely. The interaction chains will be built accordingly to Figure 4.

First of all, four 2-component-interaction-chains will be examined. Followed by two 4-component-interaction-chains which are composed of the just examined composites.

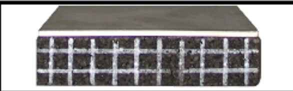
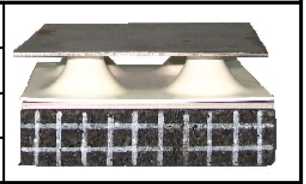
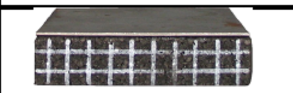
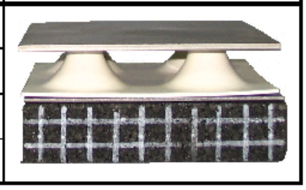
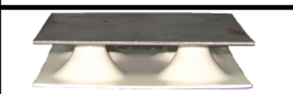
Interaction chains with two components		Interaction chains with four components	
Aluminium		Steel	
EPP		Eggbox	
Aluminium		Aluminium	
Eggbox		EPP	
Steel		Aluminium	
EPP		Eggbox	
Steel		Steel	
Eggbox		EPP	

Figure 4. Testing matrix

The dynamic strain of the interaction chains takes place by using impacter with plane, semi-cylinder-shaped and hemispherical impact surface, in order to reflect different impact scenarios. The chosen strain rate of 180 1/s covers up conditions which can occur with collusions with pedestrians on a vehicle front end.

The single testing configurations will be reproduced in the FEM, and the available variation parameters will be amended in a way that the forces and deformations from the simulation correlate to the tests as most as possible. The validation aims to optimally reproduce all tests on the corresponding material with a material model. For example, the aluminium sheet should not only correctly be reproduced in the quasi-static tensile test, but also with all looked at testing velocities and load situations.

In regard to the modelling of the individual components, based on the finite elements, several objectives are aimed at:

- The verification of the assumption that the mechanical behaviour of the individual components are reproduced correctly in all load situations.
- The preparation of the simulation of the whole interaction chain.

The parameters of the material models will be adopted from the single material validation. The geometric information will be maintained as well as the figures of the element thickness. Static and dynamic contact-friction-coefficients will be deduced from the results of the friction test, but continue to be variation parameters.

The validation process of the 2-component-interaction-chains contains the variation of LS-Dyna-control-cards, -contact cards and the modelling technique. In this case modelling tech-nique stands for the modelling of the impactor and the floor. Both can be compiled from surface elements, solid elements or rigidwalls. Due to the good simulation stability, the im-pactor will be modelled using surface elements, and the floor using rigidwalls. During the validation of the interaction chains several contact- and element-types will be compared with each other as well.

In the second phase, the 4-component-interaction-chains were build. With the aid of the insights of the 2-component-interaction-chain, the same parameters as beforehand will be varied.

Thereby, the strain rate of the eggbox material has a great influence on the behaviour of the 2-component-functial-chains. The interaction chain eggbox-structure-steel is better reproduced without strain rate dependencies. On the opposite, the results of the 4-component-interaction-chains are better obtained with the latter.

RESULTS

The comparison of the carried out tests and simulations of the 2-component-interaction-chains suggest the following results. The interaction chains EPP-foam-aluminium, respec-tively EPP-foam-steel, reveal a good consilience between the simulation and real-life tests. The force level coincides very well, as can be seen in Figure 5. The force peak at 1 ms in the calculation results from the contact calculation. This peak can be reduced through a stronger damping. However, this does not have an impact on the acceleration process. As described in chapter 4.3, the deviation in the relief phase originates from the foam-material-model. This phase is not illustrated for the simulation curve in Figure 5.

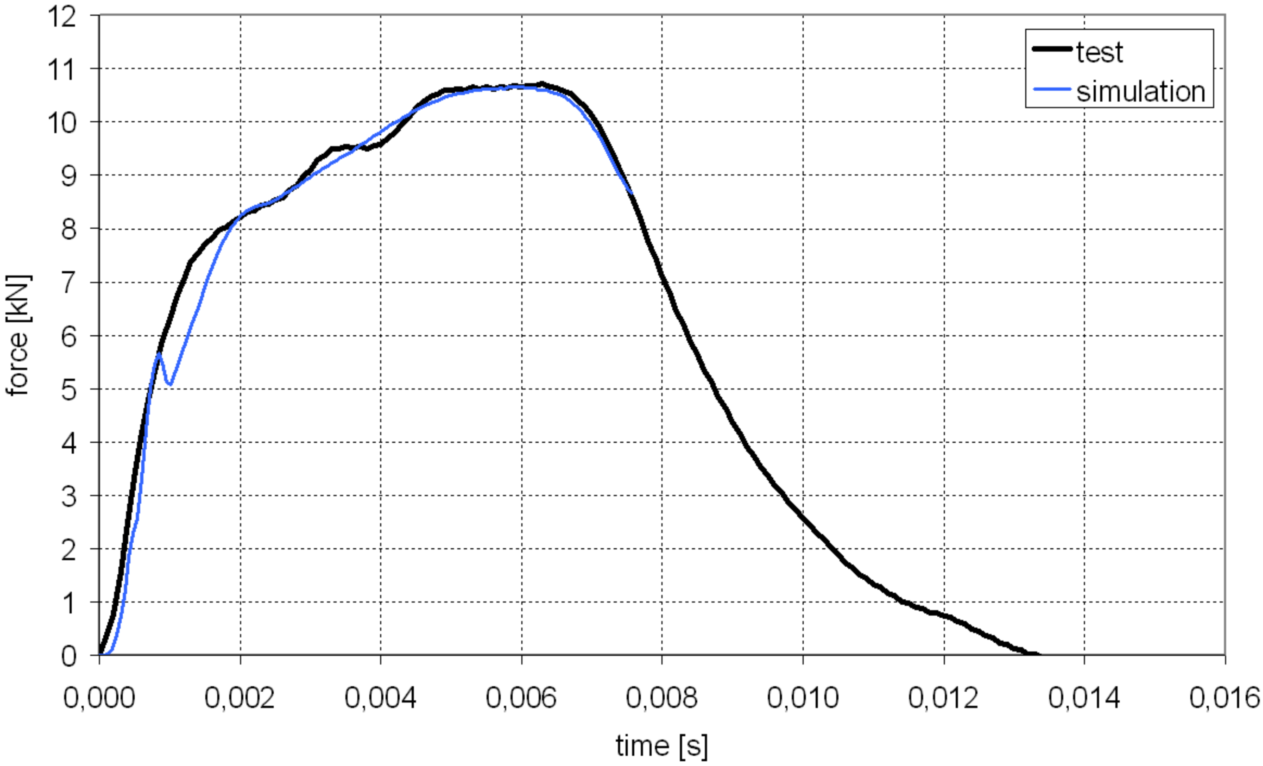


Figure 5. Comparison of simulation and test for the interaction chain EPP-steel with a hemi-spherical impactor

The comparison shows the best consilience for the hemispherical impactor. Greater deviations occur for the plane and semi-cylinder-shaped impactor.

The deviations of the interaction chains eggbox-structure-aluminium und eggbox-structure-steel in simulation and test vary with the impactor geometrics. The plane impactor shows the best consilience. Nevertheless, the outcomes for the hemispherical and semi-cylinder shaped impactors, obtained from the FE-Simulation differ from the data obtained from ex-periments. The interaction chain is stiffer, thus the deformation process is a bit shorter on the whole.

This difference in the results can be moderated when modelling the eggbox structure without strain rate dependency. However, the analysis of other boundary conditions and systems indicate that the strain rate dependency of the eggbox materials should not principally be disregarded, as well as indicating that the deviation of the results come from the interactions of the complex system which were not looked at in detail within this study.

In Figure 6 and Figure 7 a video sequence from the test series with a 4-component-interaction-chain under the load of the hemispherical impactor is contrasted with the simula-tion results. The EPP-foam-aluminium-eggboxstructure-steel-interaction-chain can be repro-duced very well in the simulation. Little differences in the compression phase originate from the facilitation of the eggbox structure. In particular, the material thickness differences, result-ing from the manufacturing process, and the internal strain of the material are not considered in the simulation. Furthermore, the comparison, of the deformation behaviour from the visual information of a high-speed-video-measuring with the information from the calculations, is difficult.

In the process of the validation, the following attributes, respectively parameter, appeared to be especially important:

- Strain rate dependency of eggbox material, EPP-foam and steel
- Impactor geometrics
- Contact definition (especially friction parameters)

Furthermore, it was clearly shown that the order of the interaction chain components, had a major impact on the results.

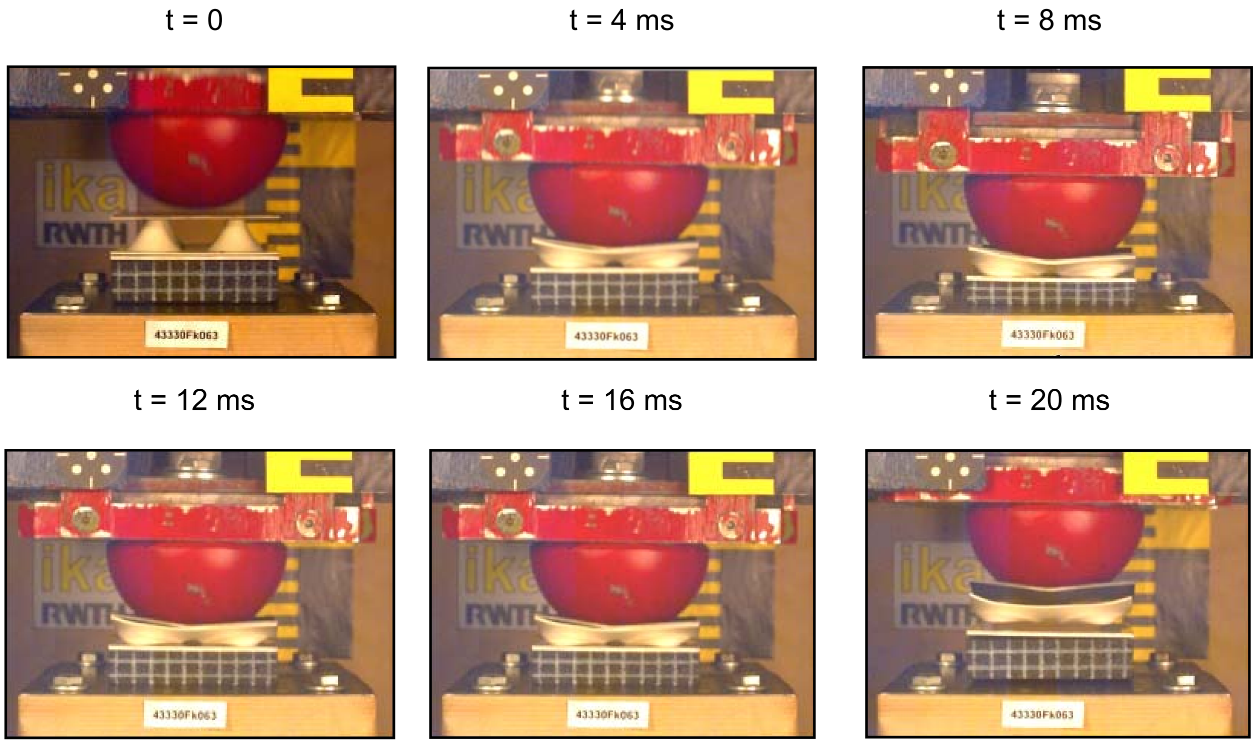


Figure 6. Test interaction chain EPP-foam aluminium eggbox structure steel

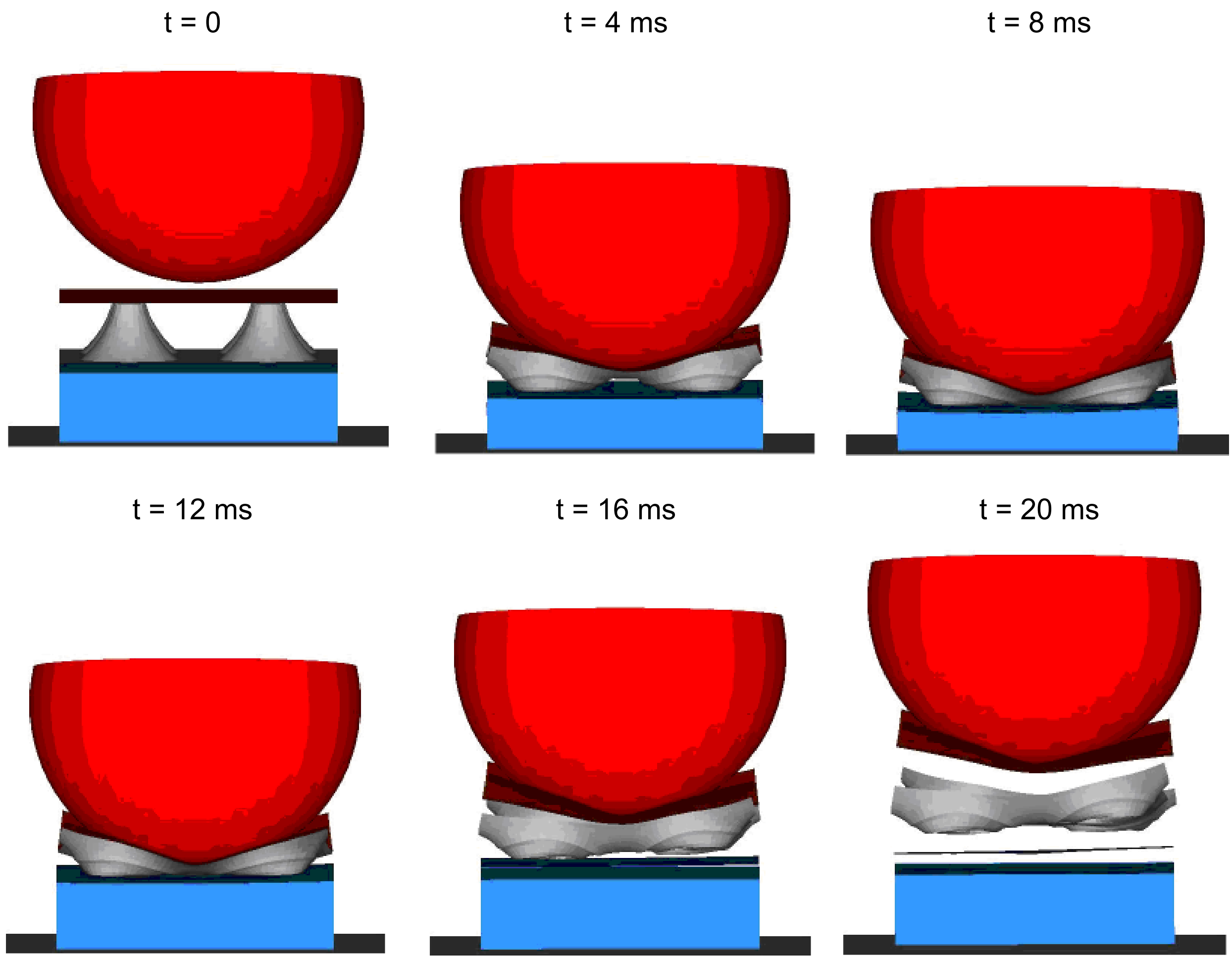


Figure 7. Simulation interaction chain EPP-foam aluminium eggbox structure steel

CONCLUSION

Within the framework of this study, materials for energy absorption were looked at which interact due to an impact with low energy, for example a vehicle-pedestrian collusion. In order to examine the possibility of being able to predict the interactions of different deforma-tion elements, beforehand conducted real-life tests were simulated using LS-Dyna.

Thereby, three different impacters as well as varied dispositions of the materials (aluminium, steel, EPP-foam, and Acrylnitril-Styrol-Acrylester (ASA)) used for the interaction chain were looked at.

The simulation process initially contained the modelling of individual components and the interaction chains, as well as the conduction of parameters obtained in simple tension-, force- and bending tests into appropriate material models for each of the four materials. The validation of the composites was gradually accomplished, in respective to the previously done experiments, first on the 2-component-interaction-chains and thereafter on the 4-component-interaction chains.

During the validation, the contact and friction parameters, the strain rate dependent material curves and the influence of the impector shapes were identified as most important figures. Furthermore, the facilitated depicted eggbox structure in the simulation, proved to be one of the main reasons for the deviations between the simulations and the tests. The thickness differences and internal strains, resulting from the manufacturing process, were not looked at in the simulation. Moreover, the failure behaviour of the eggbox structure turned out to be significantly, but could not sufficiently be covered by the simulation. Therefore, a detailed examination of these effects has to be ensued, in order to achieve an even better consilience between the results of testing and simulation.

It was principally shown that even if the individual modules of the materials with different stiffnesses were very good to simulate, a fine tuning of chosen material parameters as well as an adjustment of the parameters for the contact calculation, already proved to be neces-sary for interaction chains with two or four components, in order to generate an adequate consilience between simulation and test. The approach of the just described examinations indicates respective boundaries for the simulation capabilities which implies vital importance for the interpretation of calculation results. Despite nowadays opportunities to more detailed modelling of components, as well as new or enlarged material models, fundamental tests to verify simulation results will still be necessary in order to achieve increased prediction accu-racy for complex, interacting systems.

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