Abstract

In the automotive industry, the market share of innovative and individual product variants has increased dramatically in recent years. The vehicle-independent requirements relating to quality and equipment are growing. Summarizing, the expenditure on product development is rising, forcing car producers to reduce development times and costs. The need for reengineering of the product development process is increasingly being met by virtual product development. A key factor is the reduction of time- and cost-consuming prototype tests by pre-designing automotive components virtually. The prerequisite for this are numerical methods which meet a high quality standard and allow predictive statements to realize concept decisions on the basis of calculation results. Questions of product liability are becoming increasingly important and may also concern test results based on numerical results in future.

An example of these methods of calculation is the crash calculation using the finite elements method, which is being used increasingly to improve passive safety within the general context of reengineering. In view of the growing requirements relating to occupant safety, this method of calculation, which is established highly efficient in the design of the body-in-white, will have to be improved in a way, that realizes a virtual design of interior safety components in the future. This will include especially simulating the complex material behaviour of the materials used in the vehicle interior. Describing these materials with sufficient material models affords a high quality of reproduction, which often can only be achieved at considerable cost and effort. This paper introduces a general process for the methodical integration of these new materials in the crash calculation. The objectives of the integration process are to improve and assure detail reproduction quality, as well as to increase efficiency using standardizable material modelling procedures.

The integration process will be developed on the basis of the so-called Quality Improvement Paradigm and subdivided into four phases: the **planning** phase, the **performance** phase, the **evaluation** phase and the **know-how acquisition** phase. During the **planning** phase, the necessary fundamental data on the material, the areas of application of the material within the vehicle and the associated application boundary conditions will be formulated. Targets will be defined for the integration process on the basis of these fundamentals. They will include a clear definition of assumptions regarding material behaviour and requirements relating to the planned material model. Under consideration of the validity of these assumptions and requirements, further action will be described in a project plan and assessed on the basis of a risk appraisal. Material characterization, as well as material modelling and validation will take place in the **performance** phase of the integration process. Material characterization involves formulating all the fundamental data required for development of the model so that material behaviour can be described. The first step - material modelling - involves examining the models existing in commercial calculation programs and literature, and validating their suitability for detail reproduction of material behaviour. The objective is to select a model that can be used for crash calculation in the productive development process, or for the necessary further developments. Further development of the model will be subdivided into formulation of the materials equation, implementation of the materials equation in the finite element tool and verification of development steps. The implemented material model has to be validated. During the **evaluation** phase of the process, the process steps will be analyzed in detail and validated. The quality of the developed material model will be proved. This will include a definition of quality specifications for the model and for components to be designed by numerical simulation. The final step in the integration process is the **know-how acquisition** phase, which serves to improve the quality of material models and leads to a long-term improvement of the process efficiency. In addition to empirical process data acquisition, this phase will include saving all experimental and numeric data. In addition, know-how will be derived by using the material model in the productive development process.

The integration process will be shown for the first time within this paper by using a polymer brittle foam with high energy absorption capacity as an example. The fundamental data required for this purpose will be formulated in the process **planning** phase. The foams are synthetically manufactured materials with a low specific weight and a cellular. The material behaviour of the foams is affected by the properties of the basic materials and the characteristics of the cellular structure. Mechanical behaviour is characterized by the compressive plateau- or crush-stress over a large compression strain and by a low elastic recovery rate after pressure relief. The usual areas of application with regard to occupant protection are the headliner trim, the instrument panel and the side door trim. These foams are also used in bumpers for vehicle protection in lower impact collisions and for pedestrian safety. Regardless of the area of application, polymer brittle foams are primarily subjected to compressive stresses. As a result of the formulated fundamental data, it is necessary to account for the changes in mechanical properties in dependence on varying conditions, such as strain rate, temperature and the application of force - characterized by varying sample and impactor geometries - in order to characterize the material.

Classifying polymer brittle foams, two representative materials are determined which are used for material characterization. The thermoplastic and closed-cell particle foam system Noryl® EF will be considered in addition to the thermoset and nearly open-cell polyurethane-based Bayfill® EA foam system. Based on the procedure defined by the integration process, the material characterization will be realized by material tests such as the uniaxial compression test and the shear test, as well as application-oriented basic tests in accordance with the actual area of application of the foams. These tests will be conducted under varying application boundary conditions. Evaluation and analysis of the test results shows that the material behaviour of the two foam systems can be described by an elastic-plastic approach. The main characteristic of this approach is the dependence of plasticity on the first and second stress invariants which is represented by a closed yield surface the multiaxial stress space. The material behaviour observed, is heavily dependent upon the application boundary conditions strain rate and temperature, as well as the density of the foam system. Failure of the Bayfill® EA also occurred when it was subjected to tensile and shear stresses, which have a strong influence on the behaviour of components under application-oriented loads.

The examination of existing material models which have the potential to reproduce the polymer brittle foam, leads to the selection of a model developed for aluminium foams by Professor N. Fleck at Cambridge University. The material model will be improved based on the results of the material characterization. This further development necessitates adapting the flow rule, introducing a law for the strain rate dependency of the material behaviour and formulating a damage model for modelling the failure mechanism of brittle polymer foams. The modified material model will be implemented as a user material in the ABAQUS/Explicit finite elements program and validated on the basis of the material tests and application-oriented tests.

The potential of the integration process will be established during the **evaluation** phase. Though being of a pilot nature, this process supports the quality-controlled modelling of polymer brittle foams to a high degree. This is clearly reflected in the detailed process descriptions which allow a target-oriented distribution of labour among the development partners involved. Thus, the material characterization will be performed in close cooperation with IVW GmbH and material modelling will be carried out in cooperation with HKS Inc. The transparency and reproducibility of the process are also essential for long-term quality improvement and assurance.

Analysis of the model validation in the **evaluation** phase leads to an acceptance of the developed material model for numerical simulation of the material behaviour of polymer brittle foams. A prerequisite for use is compliance with various quality specifications for the material model and for components to be designed based on numerical simulation. The components are required to exhibit a homogeneous density distribution and little scatter within defined bounds of production. The main requirement for use of the material model is quality-controlled calibration of the material parameters. The necessary material tests must be conducted on the foam system used for the component. The parameters also have to be validated by application-oriented basic tests. Calibration and the validation should be supervised by the component manufacturer and carried out by a test institute with the necessary equipment and experience. Following the implementation of the integration process, two different calculation models which are representative of the area of application of the foams - the bumper test according to NHTSA, Part 581 and the head impact test according to FMVSS 201 – demonstrate the productive use.