CONTRIBUTION TO FURTHER DEVELOPMENT OF SIMULATION METHODS FOR IMPACT LIMITING MATERIALS AND STRUCTURES - A REPORT ON THE SITUATION FROM THE GERMAN QUEST-PROJECT

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ABSTRACT

The safe transport and storage of radioactive material must be guaranteed by an appropriate package design. The efforts in this project are necessary to achieve modern analysis methods for developers, users and manufacturers of packages, i. e. transport and storage casks.

The main objectives of the presented German QUEST-project, which is carried out in close cooperation with the ENREA-project of BAM (German Federal Institute for Material Research and Testing), are basic investigations in the area of describing the behaviour of material-specimen exposed to high-speed loading.

Material samples from wood, polyurethane-foam and damper concrete are investigated with sophisticated methods. These materials are typical components of the impact limiting concepts of packages or interim storage facilities. The material samples are subject to a variety of possible appearing physical parameters, to achieve information how to describe the mechanical behaviour.

The loads that appear during the drop of a transport and storage cask from a given predefined height onto different targets are the criteria for the experimental and numerical investigations. The necessary development of new material models and the proof of their validity with the experimental collected data has to be done first. With this procedure it is planned to obtain a more precise prediction during future numeric simulations. The reduction of the appearing physical loads during critical drop-scenarios is the final objective.

The presentation will give a brief overview of the aims and the progress within the QUEST-project. The first tasks of supplying the project with suitable specimen and materials and the efforts to ensure quality-control during delivery have been successfully completed. The design and the check of the test facilities are also finished. First simulations of pre-tests were successful and have shown the necessary precision of the test facilities and the possibilities of the numerical analyses. The more sophisticated simulations of the various examined materials have been started.

INTRODUCTION

The safe and economical handling of radioactive waste from operation and dismantling of nuclear facilities represents an important task during realization of current and future disposal strategies. In this case, employed casks must guarantee the secure inclusion of the radioactive contents under assumed accident situations. The mechanical loads are of central importance for the integrity of the cask components and/or the whole waste packages during impact or crash. Furthermore this can be influenced by the mechanical characteristics of involved damping materials and structures of buildings coming in contact with the casks.

The development of new and/or improved analyzing-methods by using Finite-Element-Methods (FEM) to evaluate more precise the appearing loads of the involved structures open up possibilities to optimize the mechanical structure of the impact limiters and also the casks themselves (Figure 1).

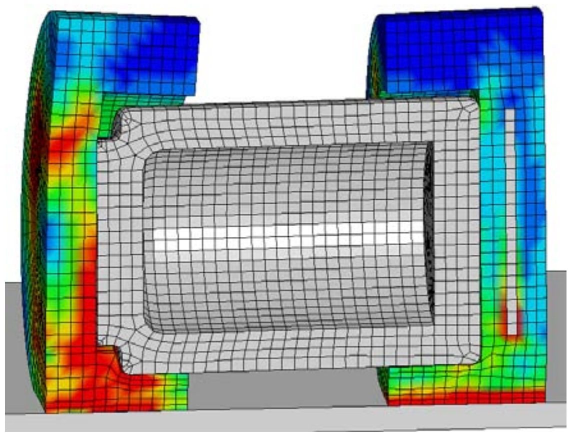

Figure 1. Optimization of impact limiters with FEM-Analysis

With the focus on safety, a better knowledge and higher accuracy during the assessment of the relevant load conditions offer considerable potential. In second order the rising number of waste packages and also the increasing handling frequencies will offer possibilities to the involved parties on cost savings by more efficient use of possible damping structures. Another important efficiency profit results from optimizing the design-security by new improved methods of analysis that can be applied by designers and experts to accelerate design approval and licensing processes.

CHALLENGE OF THE PROJECT

The regulations for the safe transport of radioactive materials of the International Atomic Energy Agency (IAEA) require free drop tests onto targets to demonstrate the robustness of transport and storage casks under accident loads.

Deformation and energy absorption of shock-absorbing structures are difficult to analyze because they are ruled by sophisticated dynamics and the non-linearity of the impact. This is the reason that only few calculation methods and/or approaches combined with many uncertainties currently exist. That is among other things also caused by the fact that sophisticated experimental methods, investigating systematic the appearance of influencing parameters, to which impact limiters and/or their components are exposed, are extremely time- and cost-consuming. The most important parameters that will be investigated are loading velocity and deformation rate, multi-directional load-application by lateral constraint, material temperature and the influence of specimen sizes.

The here described project started from the present state of knowledge about the shock-absorbing materials wood, polyurethane (PU)-foam and damping concrete. For the first time systematical tests for the definition of static and high-impact load-deformation curves of specimen-cubes without and under complete lateral constraint will be carried out for all three materials. The measured data will be implemented into material-models to develop Finite-Element-Formulations that can simulate the experimentally received reference behavior. The comparison of the numerical and experimental results shall by that way verify the modelling. Within this project only small pieces of shock-absorbing plates or small pieces of damping material will be in the focus of interest.

New material characteristics and new calculation tools are the main aim of the investigations. Furthermore the activities shall gain better insight concerning shock-absorbing materials with a focus on their effectiveness and the range of applications. By the chosen approach the technological requirements will be developed to improve future methods of analyzing and evaluating safety optimized casks and waste-packages regarding mechanical accident situations.

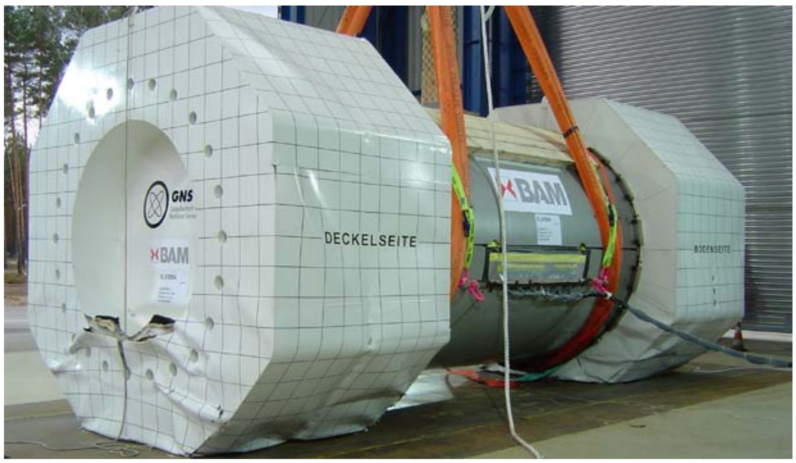

Figure 2. Drop test cask with impact limiters

Wood is widely used as main part of impact limiters attached to transport and storage casks. Large quantities of such shock absorbers (Figure 2) are used with transport casks in Germany. They consist of a steel structure whose cavities are filled with wood as damping material. Under accident conditions, the wood takes up the majority of kinetic energy when the cell cavities are packed by deformation of the internal wood cell structures. Several investigations have been carried out to describe under small deformations the properties of wood and the behavior during fatigue under compression. Considering great deformations, wood can no more be described as continuum because separated fiber bundles appear. Additionally to that, within the project efforts will be made to investigate the influences of the other essential factors temperature and lateral constrain onto the material describing stress-strain-relationships.

Polyurethane and metal foams as cellular solids can bear considerable amounts of energy by plastic dissipation under pressure. They can already be found in shock-absorbing constructions used by the automotive industry. But they are used as shock absorber material for impact limiters together with transport and storage casks in Germany however not yet. The energy consumption occurs through bend, buckling or fatigue of the inner cell walls. This property and their typical homogeneousness and isotropy are good arguments for polyurethane foams.

CONCEPT AND PROJECT MILESTONES

The project QUEST started in December 2008 and is scheduled for a period of at least three years. The whole project is subdivided into three main sections. During the first section several hundred specimen will be investigated by loading them with a servo-hydraulic testing machine from quasi-static up to high-speed velocity of 3000 mm/s. Within the following sections, tests will additionally be carried out as drop tests using a weight-loaded impact on the material specimen. In both cases load-deformation-dependencies and acting forces will be measured and analyzed. The evaluation of the experiments will be the start point to derive new material laws for the Finite-Element-Application that should also include the influence of temperature and the situation of lateral constraint.

In this context the energy dissipation of the involved components and materials are of high importance. The behaviour of these materials within the relevant loading speed and the temperature boundary conditions have significant influence on the numerical simulation. The specification of the boundary conditions and the kind of loads during the entire test-program are of special importance for the experimental and numerical analyses.

By developing new material models and checking their validity with the experimentally collected data it will be possible to obtain a more precise prediction by future numeric simulations. The material samples are subject to a variety of additionally appearing physical parameters, so that the mechanical behaviour can exactly be measured and analysed. The efforts in this project are also necessary to achieve modern analysis methods for developers, users and manufacturers of transport and storage casks.

PROVIDING THE PROJECT WITH TEST MATERIAL

One of the main tasks during the here reported period of the QUEST-project has been the process of providing the experimental activities of BAM within the ENREA-project with suitable specimen. The materials specimens that will be intensively tested are damping concrete, polyurethane foam (Figure 3) and several kind of wood specimen (Figure 4).

Figure 3. Specimen of damping concrete and polyurethane foam

Figure 4. Specimen of several kind of wood

Another challenge in that project is the large number of tests that have to be performed. The reason is, that a combination of several parameters shall be investigated and most tests have to be repeated for statistic reasons with at least 10 specimens. The main parameters that will be under investigation are the kind of material, the direction of fibres or the growth, the velocity of loading, the boundary conditions and the temperature of the material. An overview of the number of tests to be performed in every category is given in Table 1.

Material	Quantity of tests / specimen
Polyurethane foam - PU 3718	224
Polyurethane foam - PU 3750	224
Wood-Specimen Fibres parallel to loading direction	240
Wood-Specimen Fibres perpendicular to loading direction	240
Wood-Specimen Four layers with fibres in two directions	240
Wood-Specimen Variable fibre angles	25
Cubes of damping concrete	96
Plates of damping concrete	15

Table 1. Summary of all scheduled tests

In order to receive information on the behaviour of wood during loading conditions under given angles of variable fibre-directions additional tests have to be carried out. With this investigation, where the loading direction and fibre direction will be varied through seven angles between 0° and 90° reasonable information to develop material models are expected. This information shall finally also be used to verify the accuracy of the developed material models and the derived parameters.

The challenge in that context was to obtain enough suitable specimens – sum app. 1300 – that satisfy the given specifications. This became especially difficult with the great amount of specimen from wood. By several previously made analyses the acceptable range for the damping material wood could be determined. There were some main parameters the specimens have to comply with (Table 2).

Gross density	Range of parameter
planned range	0.41 < … < 0.45 g/cm³
achieved range	0.42 < … < 0.48 g/cm³
Wood moisture	Range of parameter
planned range	12^{+2}_{-3}%
achieved range	min: 10%, max: 14% condition totally kept

Table 2. Parameters of the material specimen

BOUNDARY CONDITIONS OF THE TEST SETUP

In order to achieve new information on material properties of damping materials for impact limiters, the experimental setup used during all the planned test-sections should not be modified. That is the reason why during the first tests the focus was concentrated on the examination of all possible effects influencing deviations during the further investigation.

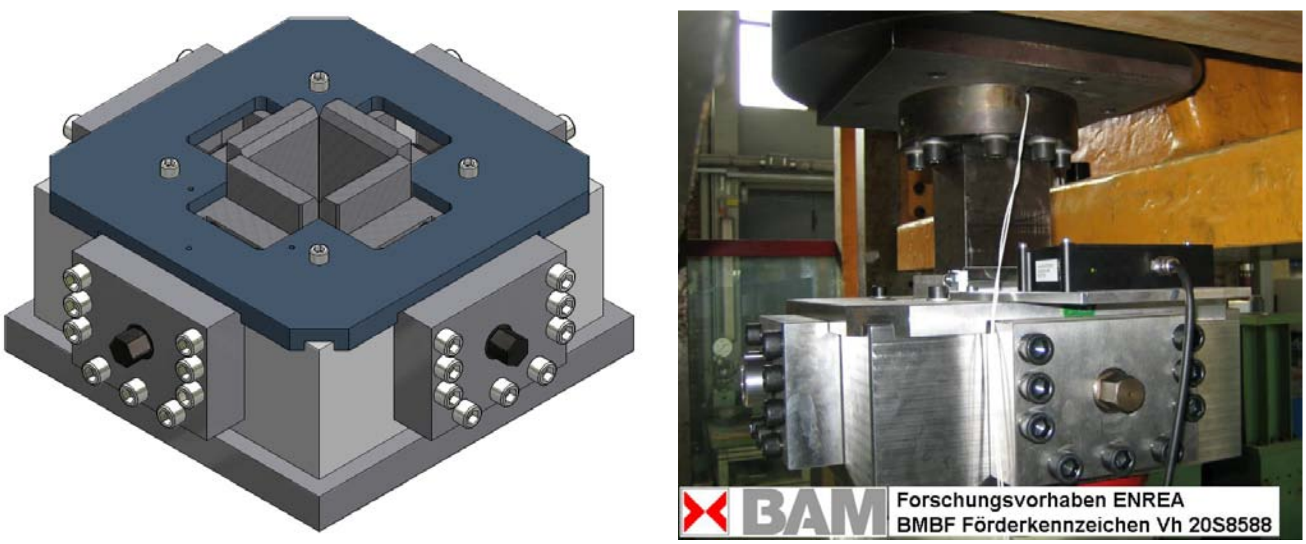

Figure 5. BAM-developed specimen holder and servo hydraulic test setup

The main aim of the test setup final design (Figure 5) is a really rigid construction that can bear the very high forces appearing during the loading with up to 1000 kN. One characteristic result of the applied force versus displacement of three different test specimens can be seen in Figure 6 during the first pretests.

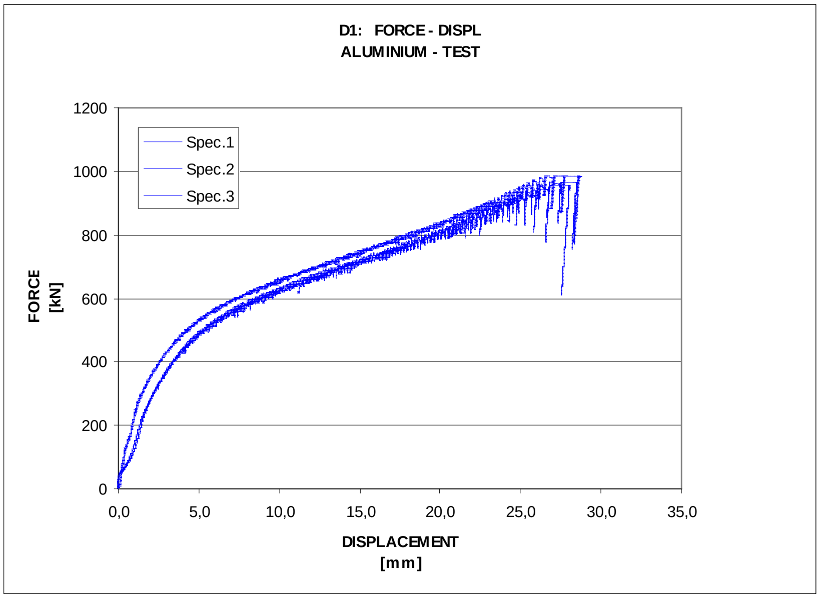

Figure 6. Test result from the loading facility up to 1000 kN

VALIDATION OF THE TEST PROCEDURES AND MODELLING

With several tests, which are presently analyzed the accuracy of the test procedures is verified. With these tests the quality of the data-acquisition and the data processing can be evaluated. By comparing the experimental results with the data from the dynamic simulation of the loading the assumed coefficient of friction during the simulation and the applied stress-strain relationships of the material will be verified. This can be seen as a first test whether the planned procedure of developing new, more precise, parameters and/or stress-strain relationships can be derived from the experimental data that will be collected during the whole research project.

Figure 7. Wood specimen after compression

The stress-strain-relationship needed for the Finite-Element-methods will be derived from the performed compression test with specimens from wood, PU-foam and damping concrete. These tests are carried out with cube sized specimens of the dimension 100mm x 100mm x 100mm. Shape and the most important lateral constraint of the specimen have to be determined according to the compression characteristic of the impact limiter to be modelled by the FE-analyses. The compression characteristic of the damping material has a large influence on the dynamic numerical simulations and should therefore be carefully considered. First test with specimens from wood (Figure 7) have shown that compression rates of 50 to 70% can be achieved with the chosen test setup and the developed handling procedures.

PRELIMINARY CONCLUSIONS AND OUTVIEW

The conclusions obtained by the presented project so far can be summarized as follows. The need for more precise data that can improve modern analysis-methods with Finite-Elements makes it necessary to investigate the mechanical behaviour of damping materials. This will open the opportunity to derive new mechanical material models that take especially into account the lateral constraint conditions and material temperature as well.

During the first part of the project great efforts have been made to deliver material specimen for the experimental investigations with an adequate narrow parameter distribution. After an extensive selection especially of wood all required specimen could be provided successfully.

Furthermore several tests of the experimental setup have been conducted to show the good performance of the involved servo hydraulic test setup. Especially the stiffness of the designed setup and the boundary conditions during testing are fully satisfying.

The data, which could be obtained from the ongoing compression tests, show very positive results. After performing more sophisticated analysis methods on that data, this approach opens the opportunity of deriving new and more precise material models for wood, polyurethane-foam and damping concrete.

ACKNOWLEDGEMENT

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