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Absorbing materials properties in experiment and simulation

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Introduction

A blast loading applied to different kinds of materials and structures is becoming more important task every year because of actual terrorist threats. An absorption capacity of soft, viscoelastic materials at high strain rates is included in wide range of practical applications. One of the critical questions in any similar analysis is setup of material properties including all physical constants. There are many kinds of tests analysing dynamic properties of absorbing elements. In many cases testing and also numerical simulations are influenced by many types of measurement and simulation conditions. This investigation was focused on relations between particular testing results in their complexity and related numerical simulations as well.

The goal of this investigation is to find a numerical material model of absorbing material suitable for explicit numerical simulation especially focused on blast load. Number of variations in real testing is usually strictly limited because of experiment costs. On the contrary numerical simulations have no limits in number of analysed variants but they have handicap in correlation with reality. This should be solved by combined development of requested products. This analysis used four kinds of real tests with different strain rates as consistent and verified points that numerical models should confirm and fill in unknown gaps between them.

Those testing techniques were applied to materials composed of porous glass (Liaver) or ceramic (Liapor) filler and polymeric binder, with density of 125 - 300 kg/m3 and particle size in range of 0,25 – 2 mm.

Material filler	Particle size	Material Density [kg/m3]
Liaver	0,25 – 0,5	381
	0,5 – 1	343
	1 – 2	334
Liapor	0,25 – 0,5	785
	0,5 – 1	752
	1 – 2	644

Table 1: Analyzed materials

Set of Experiments

Quasistatic compression in closed space is the simplest test of analyzed materials. In this test absorbing materials exhibit typical behavior consisting of three phases. In the first phase the material exhibits quite high values of stiffness at the beginning of deformation. This phase is followed by a process of permanent destruction of bonds between individual elements. In the last phase the material is maximally compressed and the value of force necessary even for small increment of compression rises significantly.

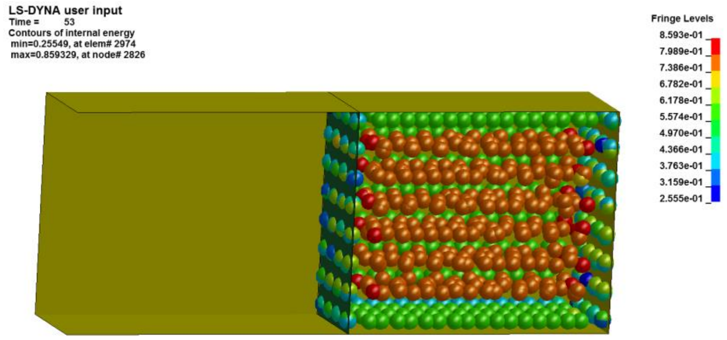

Figure 1: LS-DYNA simulation of quasistatic compression

This test was performed with 40x40x80 mm specimens. The measured data were used to create numerical material models of both types of absorbing materials. Material model from LS-Dyna database which is dedicated to modeling crushable foam with optional damping and tension cutoff was used. Unloading is fully elastic. Tension is treated as elastic-perfectly-plastic at the tension cut-off value.

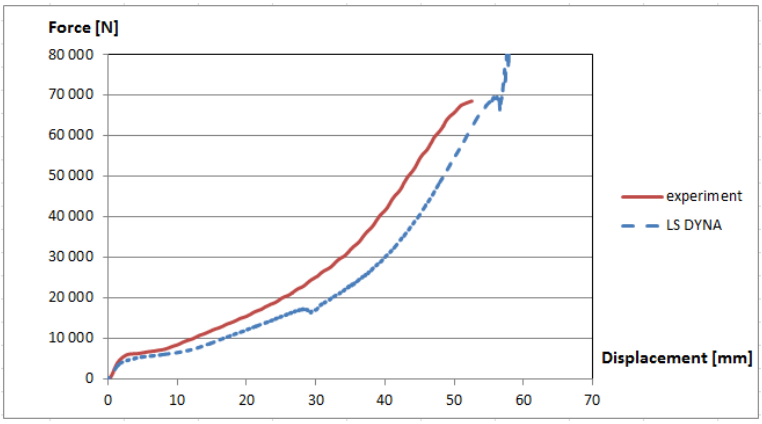

Figure 2: Comparison between numerically and experimentally found material behaviors (quasistatic compression)

The Newton cradle principle was used for dynamic test. The impact test of absorbing material with sample size of 50 mm was performed. The impact velocity 3.5 m/s is relatively low but obtained testing results present significantly different process of deformation regarding to static pressure test. The energy absorbed in sample can be simply evaluated by residual potential energy of a punch body.

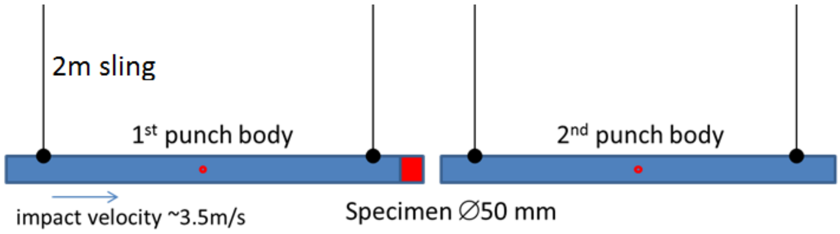

Figure 3: Scheme of “Newton Cradle“ experimental setup

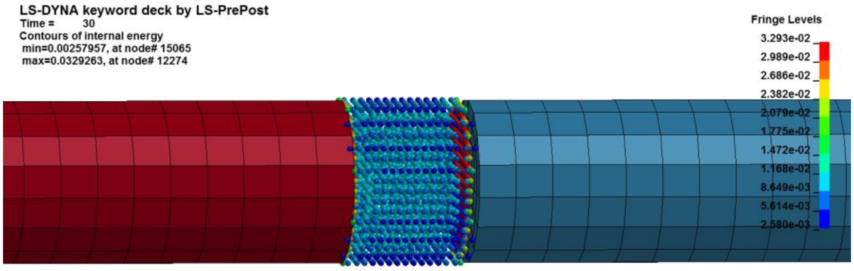

Figure 4: “Newton Cradle“ numerical model

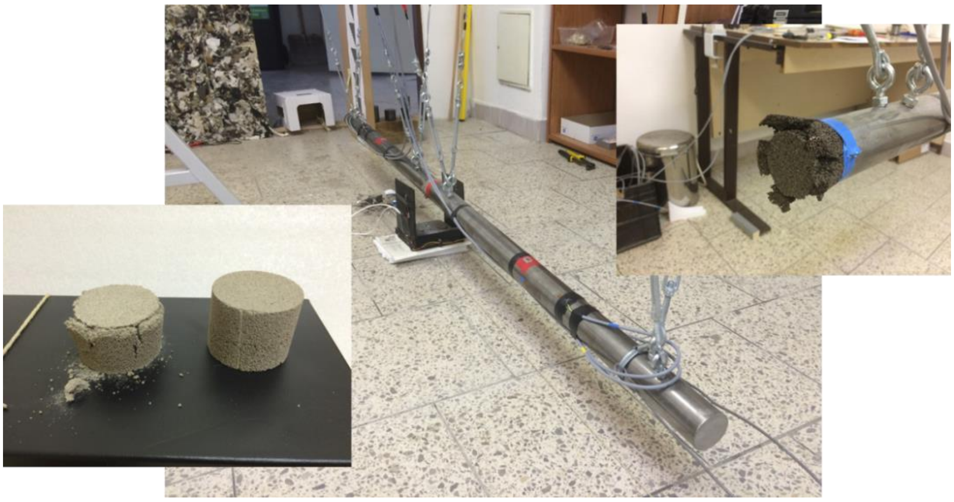
Figure 5: “Newton Cradle“ experimental setup

The residual velocity of both hitting rods from an experiment and simulation were used for a verification of the numerical model. A maximum difference under 5% in velocity values was observed. This satisfies model from an energy point of view. However a process of sample destruction should be analysed in next step with regards to simulation boundary conditions.

The Split Hopkinson Pressure Bar (SHPB) test was performed with goal to evaluate stress-strain in higher strain rate values (about 2000 s^{-1}). Of course higher strain rate in SHPB experiment caused higher deviation on stress-strain results than impact test presents. However an evaluated absorption of analysed materials was found in sufficient precision.

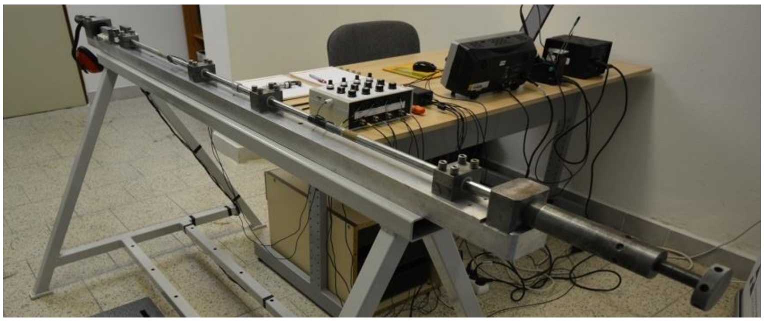

Figure 6: Split Hopkinson Pressure Bar device

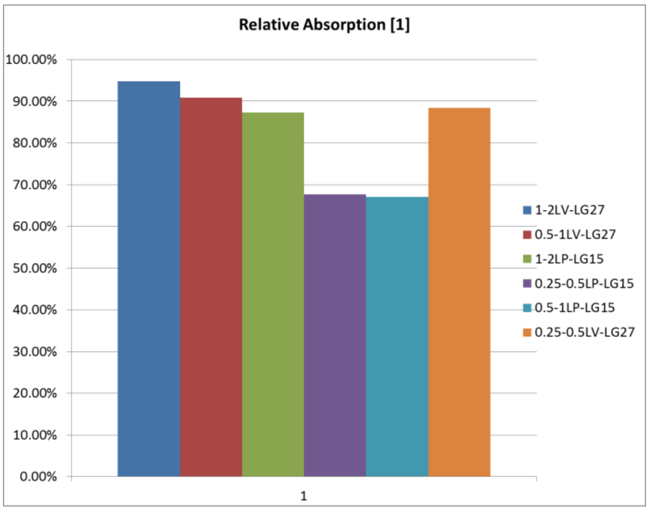

Figure 7: Relative absorption of sample in SHPB test

Blast load. All previously described tests enables testing of relatively big number of samples (more than 200). A real blast load limits strongly number of successful tests. A blast load was analysed in two kinds of experiments. The first one investigated relative absorption of analysed materials in simplified one dimension experimental setup. The absorption was evaluated from an elastic wave measured in steel rod, which had a sample attached to its front face, during an explosion (see figure below).

For the explosive load test there was a steel rod with diameter of 50 mm and length of 2000 mm freely hanged on the construction (see Fig. 9). The hanging enabled the rod to move freely in axial direction. There was a specimen fastened to the front face of the rod. The specimen had the same diameter as the rod (50 mm) and it was 40 mm long. Right on the other face of the specimen there was a cylinder shaped, 40 mm long explosive attached to it. The axial deformation caused by the shock wave from the explosion was measured in the middle of the rod's length with resistance strain gauges.
The comparison on fig. 10 shows good correlation between experimentally measured data and numerical simulations based on material curve acquired from SHPB test.

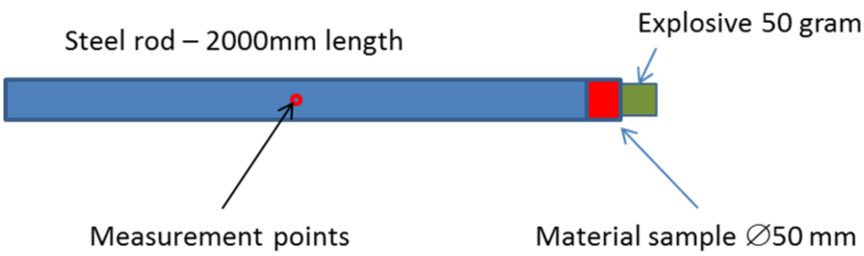

Figure 8: Scheme of explosive load experimental setup

Figure 9: Explosive load experimental setup

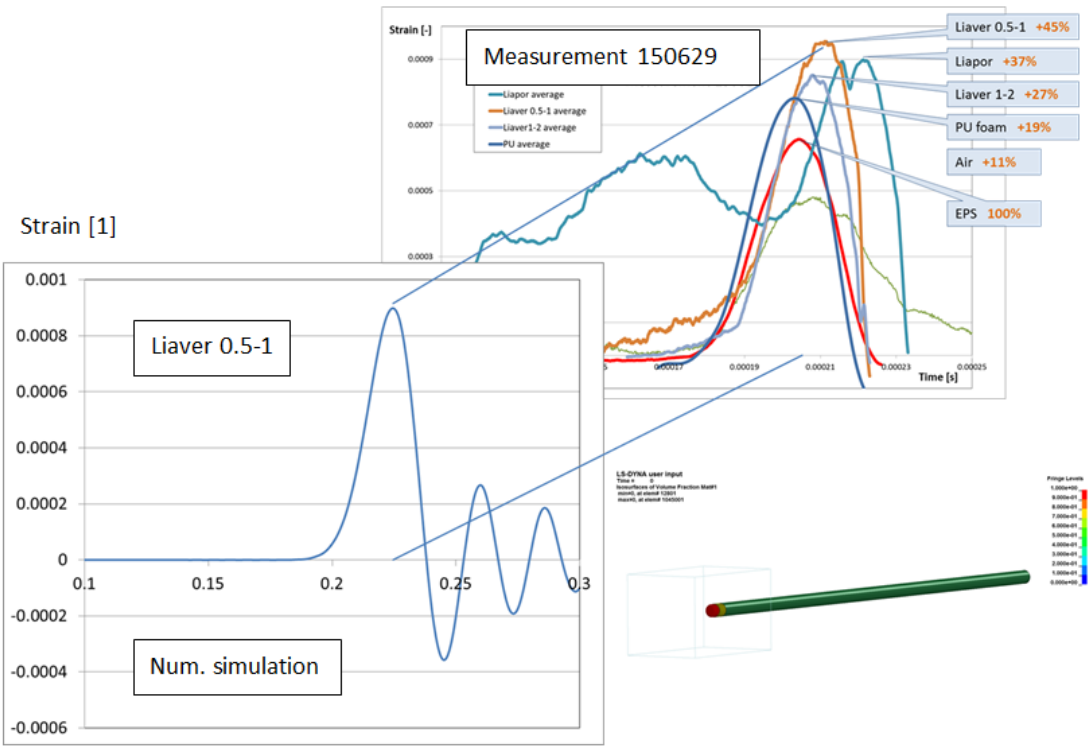

Figure 10: Comparison of numerically and experimentally found results of explosive load testing

The second experiment with blast load was prepared as explosion of 100 g of TNT placed in limited distance above a square sample with size of 500x500 mm^2 supported around in fixed frame.

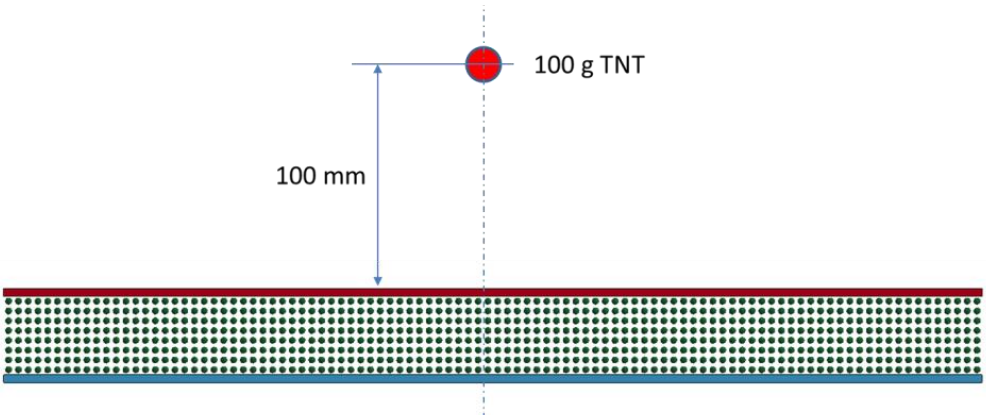

Figure 11: Blast load experiment setup

The response of the absorbing material was evaluated by a residual deformation of the sample, especially deformation of a back sheet.

Optimization

In order to create universal material model, that would be able to describe behaviour of analysed materials when variously loaded, the process of optimization was utilized. For this purpose optimization software optiSLang was used. The project, that was created to optimize material model to behave like the real material, consisted of one input file and several solvers. Each solver represented one type of testing that was performed on the material before. The input file was a file which contained material model. Therefore the optimization was able to design a material model and then use this model in several numerical simulations representing various material tests. Then in these simulations the same kind of data as in the real tests were collected and compared with experimentally measured data. The differences between numerically obtained data and experimentally measured data were responses of the process. The aim of the optimization was to alter the input in such way that it would minimize these differences.

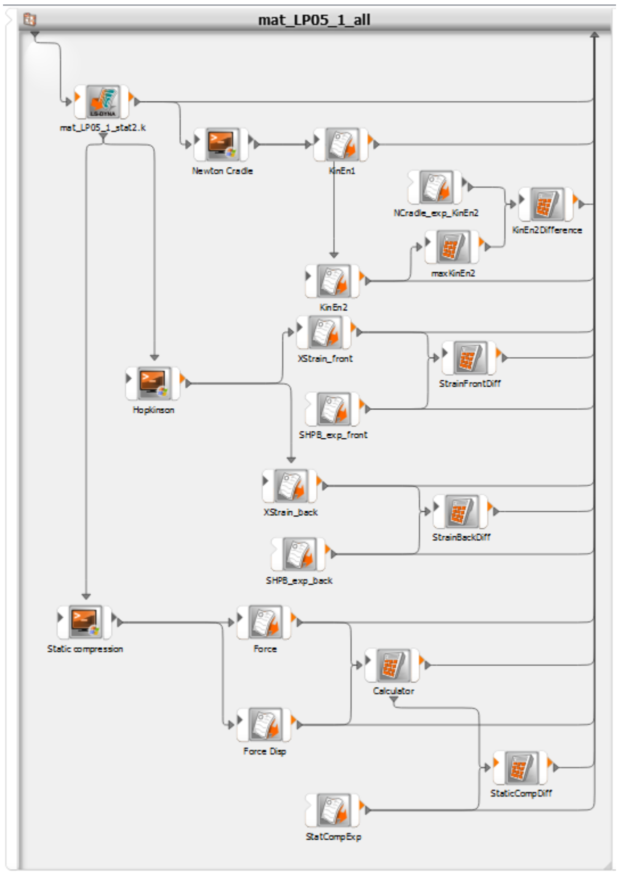

Figure 12: Optimization project

Conclusion

The aim of this project is to find universal material model of absorbing materials composed of porous glass/ceramic filler and polymeric binder.
The wide range of experiments on selected absorbing materials brings a general numerical models matching expected behavior of this material in real applications. The numerical model was based on stress-strain dependency analyzed in quasistatic commpression test and then altered according to stress-strain dependency found in SHPB testing. This relation was implemented in crushable foam material model. Together the absorption capacity of this numerical material model was compared with results from the blast test and “Newton Cradle,, experiment. Performed real experiments represent very wide spectrum of material behavior relating to strain rate. At the point of designing a real application this model is sufficient for the first response assessment of analyzed absorbing system. It is obviously necessary to experimentally verify the final design of the application.
The final numerical material model is actually used in design of blast resistant litter bin and other application as anti-blast wall and so on.

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