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# Modeling of large deformation of the foam part using LS-DYNA

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Our article deals with modeling large deformations during the drop test of the part made from expanded polypropylene (EPP). This work is related to simulations considered only static material tests [2] and measurements focused on a real drop test [3]. EPP foam is used for the damping part of the protective helmet. These helmets are usually tested to meet technical standards when the helmet is subjected to impact by a rigid punch (drop test). The numerical analysis was done using explicit FE method (solver LS-DYNA) so the full dynamic behavior of the tested structure is considered. Because the used foam material has a strongly nonlinear behavior and the dynamic loading does not have a constant speed, it was necessary to measure the stress-strain characteristics at different values of the strain rate. These curves were obtained by the dynamic tests using the Split-Hopkinson pressure bar method [1].

For accurate and repeatable results of dynamic material tests it is necessary to produce material specimens with high shape accuracy. The most important is the parallelism of the opposite surfaces of the cube that are subject to the load. At first, we tried to use cutting with a knife with cutting tool (guide for knife sliding) but the resulting surfaces of the cube were not exactly perpendicular/parallel to the others. Even with the guide, the cut was not straight. Grinding and/or sanding down was not effective too because there was no material removal. As our experience suggests, the only way how to get final 13 mm cube as a specimen is to use milling. The first step to the final specimen is prism creation by handsaw from the top longitudinal part of the helmet. This prism is machined to the final width of 13 mm. The last phase is cutting of the prism and the final milling to reach the third dimension of 13 mm (Fig. 1). The specimen is made so that its orientation during material testing corresponds to its original orientation on the entire foam part during the real drop test.

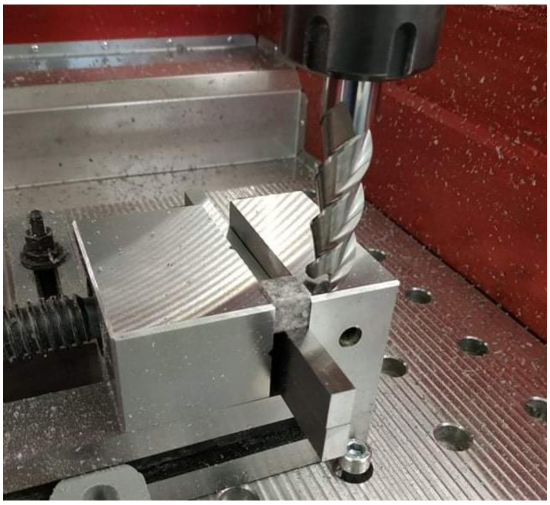

Fig. 1. Machining a foam specimen

To check and select the most accurately produced specimens, a 3D shape analysis was performed using laser scanning. Due to the structure of the foam material, which is not smooth, evaporating titanium powder was used to better scan the rough surfaces of the specimens. There is the selection of 10 specimens with a maximum parallelism deviation of 0.22 degrees as the result of the 3D analysis.

The foam specimens thus produced were loaded by impact Open Hopkinson Pressure Bar method (OHPB). Main parts of testing machine are two measurement bars (diameter 20 mm), each equipped with a foil strain-gauge (Fig. 2). First of these, the 1600 mm long incident bar works as an impactor. It is accelerated by an air cannon to the required impact velocity, its linear guidance ensures that a collision with the specimen occurs in a precisely defined position. A specimen is attached to the front of the second, transmission bar (1600 mm long). This procedure produces stress-strain characteristics under dynamic loading, in our case for two different strain rate values.

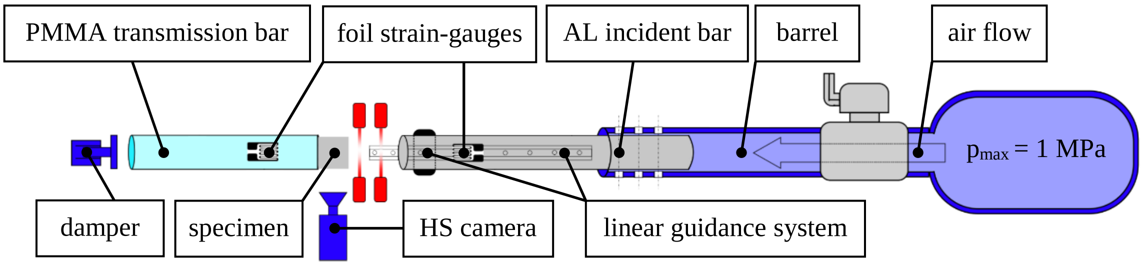


Fig. 2. Basic scheme of the OHPB testing machine

Standard configuration of the test machine consists of these two bars made from the same material – aluminum alloy (EN-AW-7075). In the case of tested EPP foam, too low force values measured during tests (F < 100 N) can be expected. Such low forces are difficult to measure with standard foil strain gauges. Therefore, it was necessary to use poly-methyl-methacrylate (PMMA) as the material for the transmission bar. This makes it possible to accurately measure forces, but signal evaluation requires the use of more complex techniques for decomposing deformation waves [1].

For the purposes of explicit numerical simulations, an FE mesh was created entirely of hexahedron elements. The original external and internal surfaces of the foam part were simplified by removing negligible details to obtain smoother surfaces. Such a geometry was divided into several volumes, each of which can be fully meshed with hexahedrons.

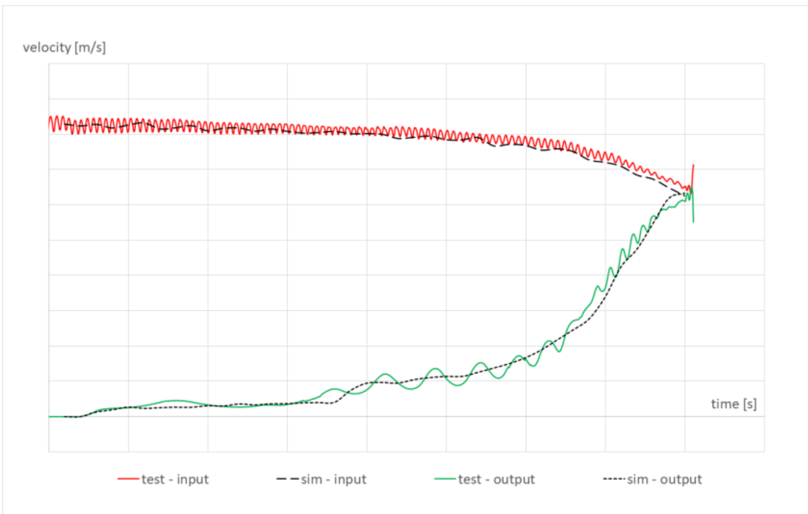


Fig. 3. Velocity of incident bar face (input) and transmission bar face (output) during the OHPB test – comparison between real test and its simulation

Numerical simulations of the drop test were performed using the LS-DYNA solver and the LS-PrePost software. For the EPP foam, the material model *MAT_FU_CHANG_FOAM (*MAT_83) was used. This model was defined using these material properties: material density, tensile modulus of elasticity, tensile stress cutoff, Poisson's ratio, stress-strain curves from uniaxial compression OHPB tests and static test. For good numerical stability and result accuracy it was necessary to prepare measured raw data before using them as input stress-strain curves in the simulation [4]. Before simulating the entire drop test, the foam material model was first validated using OHPB test simulation (Fig. 3).

The ERODING_NODES_TO_SURFACE type of contact has the possibility to keep contact even if some elements are eroded from the surface of the foam part due to high compression. Therefore, it is necessary to select nodes in the entire volume compressed by the punch, not just surface nodes.

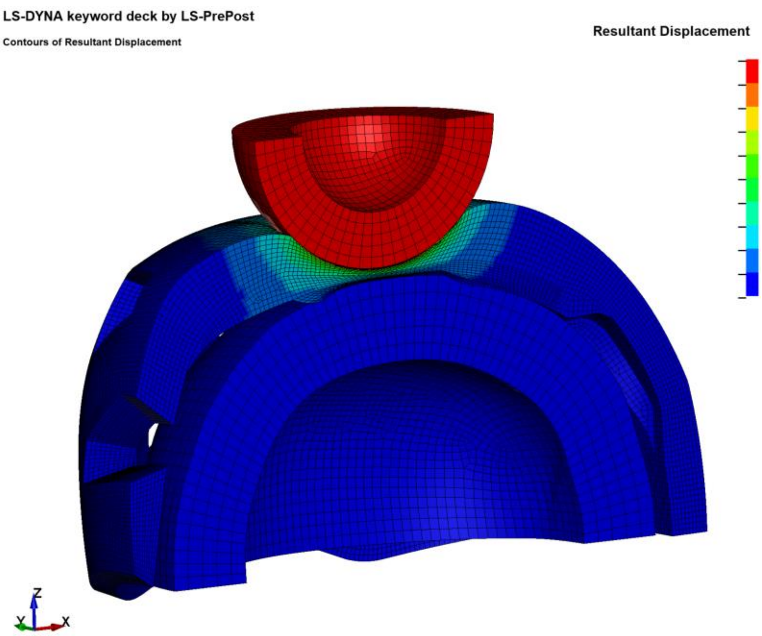


Fig. 4. Drop test simulation – displacement of the foam part

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