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Modelling and experimental testing of expanded granules as crash-absorber for double hull ships

Christian Woitzik[1,*], **Mohsin Ali Chaudry**[2], **Peter Wriggers**[2], and **Alexander Düster**[1]

[1] Numerical Structural Analysis with Application in Ship Technology (M-10), Hamburg University of Technology
[2] Institute of Continuum Mechanics, Leibniz University Hannover

In this contribution, expanded glass granules are investigated, which will be used to increase the crashworthiness in ship construction. Therefore, an experimental setup is presented. This setup represents a simplified side hull structure of a double hull ship. The empty space between the double hull structure can be filled with the granular material which acts as crash absorber.

The described experiment will be used to validate the finite element simulation of the penetration of the double hull with the bulbous bow. To model the granules the Mohr-Coulomb material model is taken advantage of. Based on the experimental data the suitability of the Mohr-Coulomb model will be discussed.

1 Introduction

Using granular material as crash absorber is a new approach in ship building [2]. The granules are used as filling material for the void space of a double hull ship. This allows a stiffening of existing double hull structures due to two aspects in case of a collision. First, the load is transferred from the outer hull to the inner hull like in a sandwich panel. Second, the granular material dissipates energy due to the crushing of particles. The particles will be modelled using a combined FEM-DEM approach, where the DEM is used in regions with high compression. To fully understand the behaviour of these particles, experimental testing is mandatory. Therefore several tests were already performed to find material parameters for FEM or DEM modelling [3,4]. To combine these two methods, a simplified collision test is used for validation. In a first step, this test is modelled using FEM only to study the limitations of this approach.

2 Experimental setup

The side hull structure is modelled as follows. Between two steel plates, with a distance of $280\ \mathrm{mm}$ and made of Steel 235, a rectangular box is placed, as shown in figure 1. The overall dimensions of this test rig is inspired by [1] to allow for additional comparisons with their results. Thus, the outer and inner hull are $1500\ \mathrm{mm} \times 1090\ \mathrm{mm}$ and the box for the granulate is $750\ \mathrm{mm} \times 700\ \mathrm{mm}$. All the plates have a thickness of $3\ \mathrm{mm}$ and are welded to a rigid, reusable frame, as shown in figure 2. This allows well-controlled boundary conditions for every test. Using displacement sensors it can be confirmed that the frame can be considered rigid. In addition to displacement sensors and strain gauges on the side hull structure, an optical measurement system was used to obtain surface data on the inner side hull structure.

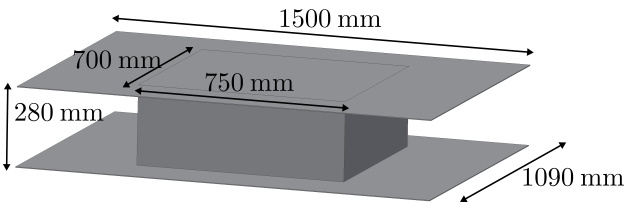

Fig. 1: Sketch of the model

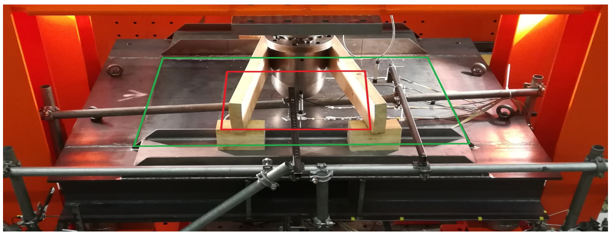

Fig. 2: Outer side hull (green) and area of the filled box (red)

To simulate the collision with a bulbous bow, a half-sphere with a radius of $135\ \mathrm{mm}$ is pushed into the structure with a uniform rate of $0.2\ \mathrm{mm/s}$, as shown in figure 2.

3 Numerical modelling

The finite element analysis of the experiment is carried out using the software Abaqus/Explicit (Dassault Systèmes). For the steel plates shell elements with four nodes are used, reduced integration, and five points through the thickness. The material parameters for the steel plates were determined using an uniaxial tension test ($Re_H = 342\ \mathrm{MPa}$, $Rp_{0,2} = 317\ \mathrm{MPa}$). To simulate the material failure, Abaqus offers different models for damage initiation and evolution. Here, the ductile damage

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[*] Corresponding author: e-mail christian.woitzik@tuhh.de, phone +49 40 42878 6103, fax +49 40 4273 14469

model is chosen with an exponential damage evolution. For the granular material the Mohr-Coulomb model is used together with hexahedral elements for the spatial discretization. The material parameters were determined using a triaxial test and an uniaxial compression test in a cylinder. The mesh used for the simulation is shown in figure 3. The rigid frame was also modelled with finite elements to check its stiffness. The element size in the model was determined by a convergence analysis. For the indenter an analytical formulation is used to describe its geometry. For the frictional contact between the materials the friction coefficients were determined using a linear friction test. We are using for the pair steel-steel $\mu = 0.2$ and steel-granulate $\mu = 0.7$. To save some computational time, the symmetry of the model is taken advantage of, compare figure 3 and figure 4.

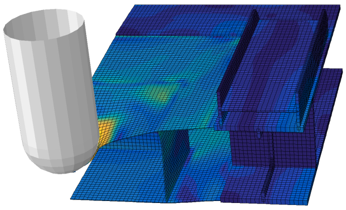

Fig. 3: Finite element model

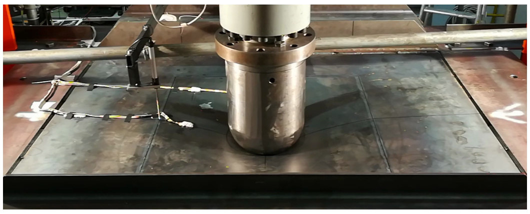

Fig. 4: Side hull structure during the experiment

4 Experimental and numerical results

The results are shown in figure 5 and 6. The applied forces are plotted against the displacement of the indenter. For the empty setup the two side hulls behave similar. There is an increase in force until the rupture of the outer hull occurs at 150 mm with an applied force of 395 kN. Then, the inner hull is touched at 280 mm until it ruptures at 415 mm at 350 kN, as indicated with the vertical lines. Compared to this, the filled hull has a stiffer behaviour in the beginning due to the additional support of the granules. Thus, it can exhibit a slightly higher force. After the rupture of the outer hull, the force remains around 200 kN and starts to increase again until the inner hull ruptures. Compared to the empty structure, this rupture occurs at a smaller indention depth due to to the additional material between the indenter and inner side hull. Despite this fact, looking at the dissipated energy until rupture of the inner hull, see figure 6, we measure an energy increase of approximately 75%.

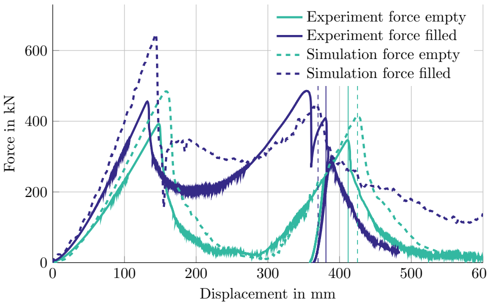

Fig. 5: Force vs. displacement of the indenter

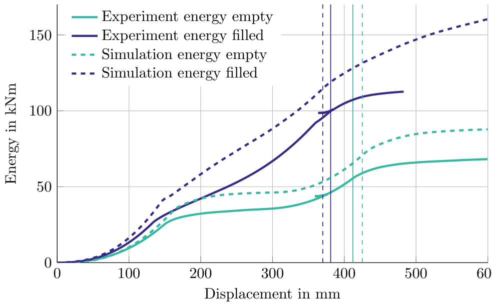

Fig. 6: Dissipated energy during the indention

Looking at the simulation results we observe higher maximum forces for both cases. The displacement, where the rupture occurs, is predicted very well. The force during the transition from the outer hull to the inner hull is overestimated for the filled structure. The simulated energy increase until the rupture of the inner hull is 60%, thus slightly underestimating the measured result.

To conclude, the assumed behaviour due to the granules can be observed. The simulation with the finite element method lacks of a realistic representation of the granular properties. Especially the crushing and deformation of the granules can not be modelled. Nevertheless, it is applicable to make a conservative estimation of the increase in energy dissipation.

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