

Statistical characterization of granular material applied as crash absorber in ship building

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This contribution deals with the determination of material parameters of lightweight granules, which will be used to increase the crashworthiness in ship construction. Using expanded glass or clay granules as a crash absorber requires a detailed knowledge about the single grain properties, such as Young’s modulus or crushing strength. Therefore, a uniaxial compression test was performed and the results are covered with a statistical model consisting of nine parameters.

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1 Introduction

To increase the crashworthiness of modern double hull ships, the filling of the void structures between the outer and inner hull can be considered [1]. This allows a stiffening of existing double hull structures due to two aspects in case of a collision. On the one hand, the load is transferred to the inner hull; on the other hand, energy is dissipated due to the crushing of granules. To simulate these aspects with the Discrete Element Method (DEM), the properties of the grains have to be determined. To account for the large deviation obtained from single particle tests, the granules are divided into several fractions and a statistical evaluation is performed. Furthermore, a sample number generator is used to derive input parameters for DEM simulation.

2 Experimental setup and experimental results

The lightweight granules, here exemplarily shown for expanded glass, are compressed between two plates, as shown in Fig. 1. The upper plate is driven into the grain with a velocity of 50 μm/s. The movement is stopped, when the particle breakage occurs or a maximum strain of 25% is reached. The result of one experiment can be seen in Fig. 2. The first quantity of

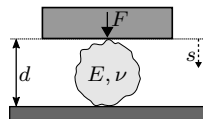


Fig. 1: Experimental setup



Fig. 2: Particle before (left) and after the experiment

interest – the diameter d – is obtained when the punch touches the grain. As second aspect, the crushing strength σ_c is derived from the breakage force divided by its initial cross section area, as can be seen in Fig. 3 (left) and the results for all grains in Fig. 3 (right). Using a Hertzian contact model [2], the following relation between the contact force and the elastic deformation

$$F = \frac{1}{3} \left(\frac{E}{1 - \nu^2} \right) \sqrt{ds^3} \tag{1}$$

is used to derive the Young’s modulus E . To do so, we assume a constant Poisson’s ratio of 0.3 and fit Eq. (1) within the range of up to 2% strain, as can be seen in Fig. 4 (left). In the scatter plot of the results over all fractions – Fig. 4 (right) – we observe a diameter dependency, which will be considered in the next section.

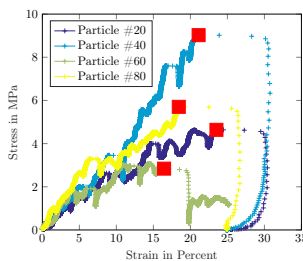


Fig. 3: Determination of the crushing strength

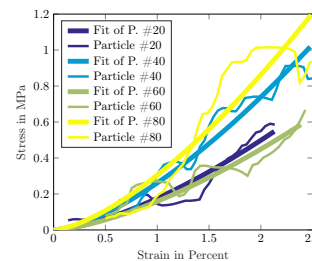
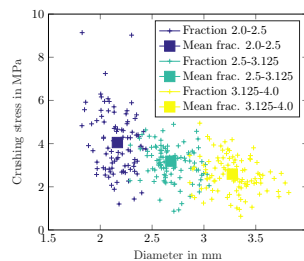
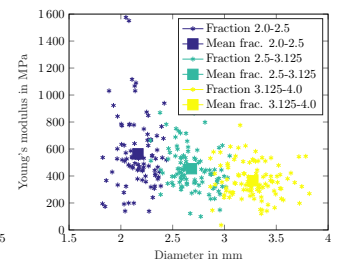


Fig. 4: Determination of the Young’s modulus



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3 Modelling

To model the observed diameter dependency, we introduce a statistical model. For the diameter, we choose a normal distribution and for the crushing strength and Young's modulus a logistic distribution [3] is used. The cumulative logistic distribution function is given by

$$F_X(x) = 1 - \left[1 + \left(\frac{x}{X_{50}} \right)^S \right]^{-1}, \quad (2)$$

where X_{50} is the mean value and S represents a shape factor, which describes the distribution wideness. For each fraction, we fit this formula to the empirical cumulative distribution, as depicted – for the crushing strength – in Fig. 5 step 1. This results in a parameter pair $\{\sigma_{50}, S\}$ for each fraction. It is found, that the shape parameter S is nearly independent of the different fractions. Thus, it is chosen as a constant value for a type of granules and a refit is performed in step 2, see Fig. 5. As last aspect, we consider the observed diameter dependency in step 3. Therefore, we introduce the relation $\sigma_{50} = (A + Bd^2) / (\pi (d/2)^2)$, where the two additional parameters A and B are computed with the least-squares method. If we insert the diameter dependency in Eq. (2) with the obtained parameters A , B , and S , we obtain the breakage probability depending on the diameter and the stress as depicted in Fig. 5 (right). The same approach can be used for the Young's modulus as shown in [3]. The resulting parameter tuples $\{d, \sigma_c, E\}$ for different grains can be seen in Fig. 6 (left).

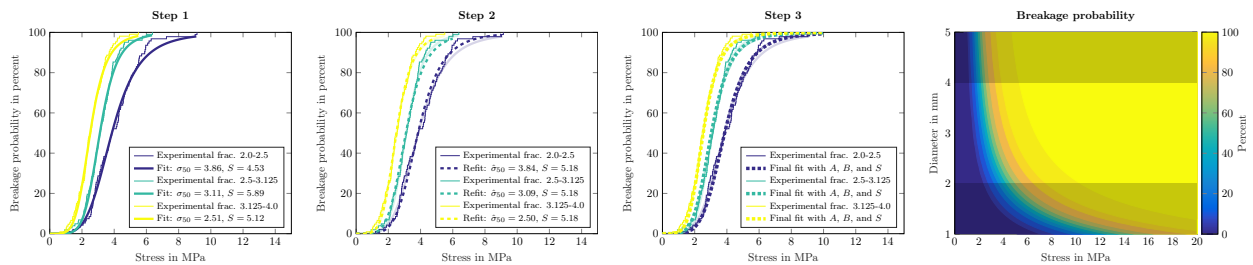


Fig. 5: Steps during the parameter fit for the statistical model and the resulting two-dimensional representation (right)

These two models for the crushing strength and Young's modulus are then combined – also taking into account the diameter distribution – to a three-dimensional model. Neglecting the correlation between the crushing strength and Young's modulus, this corresponds to a simple multiplication of the related probability density functions [4]. The resulting model can be seen in Fig. 6 (right). The experimental results are in a good agreement with the model.

The obtained model, consisting in total of nine parameters, can then be used to generate sample numbers corresponding to a given type of granules. Therefore, a sample number generator is used, which is described in detail in [4], resulting in the parameter tuples shown in Fig. 7.

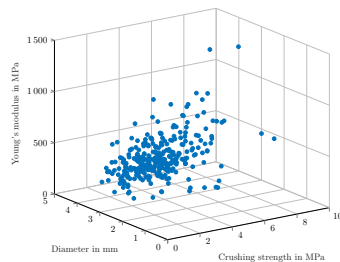


Fig. 6: Parameter tuples in 3d-space (left) and derived model (right)

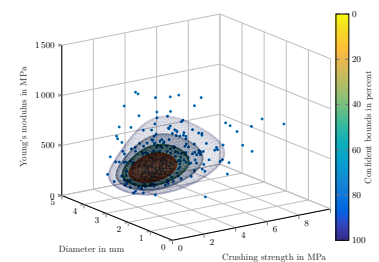
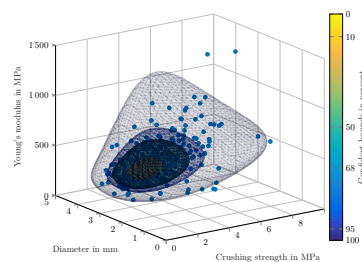


Fig. 7: Pseudo random numbers

As a conclusion, the presented model can be used to generate input parameters for DEM simulation, corresponding to a given type of granules. Thus, the parameters to model the crushing strength and Young's modulus can be estimated separately. Combining these models to a three-dimensional model results in a good approximation with only nine parameters.

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