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Modeling high velocity fractures in cellular materials

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The packaging market is growing and is an opportunity for redirecting sustainable forest resources to new products. We believe that it is possible to find new bio-packaging materials, based on sandwich principles, which could be competitive and eventually replace traditional packaging materials such as corrugated boards. Particularly interesting in this context is renewable solid foam materials derived from wood, which are biodegradable and recyclable. Using such foams as core (and papers as facings) in sandwich structures would result in sustainable structures with ideal properties, e.g. insulating, cushioning/shock absorbing, high bending stiffness, high dimensional stability and higher moisture resistance than conventional materials. However, during service of such structures, loads may quickly enter the core and lead to immediate fracture of this weak constituent. Like other cellular materials, wood fiber-based foams are made up of cells, which are likely to contain defects that may grow.

To model the mechanics of cellular materials different models has been used, an example from as early as 1984 is the model by Maiti et al. [1], concerning the quasi-static growth of cracks in cellular materials. For this work a dynamic fracture models based on a discrete particle element method is applied to get insight into this complex phenomenon. The method is based on classical mechanical theories and is a combination of traditional particle dynamics and nonlinear engineering beam theory. Damage is dealt with by fracture of cell walls when the potential energy of a wall exceeds the critical fracture energy [2]. The models identify important microstructural features of the foam -such as cell size, wall thickness, spatial variances, etc.- and link them to the structure's macroscopic fracture behavior, a coupling that is unknown. To demonstrate the model's capability to capture complex fracture behavior in 3D network-like walls in foams, cellular structures of regular and irregular open-cells of different densities are shown in Fig. 1. The elastic structures had single-edge notches and were immediately loaded on their boundaries by impulse loads so that the cracks were loaded in mode I via fast moving deformation waves traveling through the bodies and the cell walls may fracture whenever and wherever the local strain density instantly become sufficiently high.

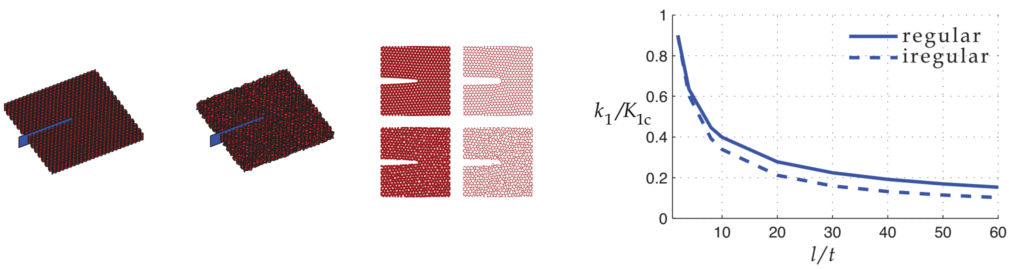

Fig. 1. Left: Regular and irregular 3D discrete meshes having single edge notches. Middle: close-up of deformations in a plane in the middle of the structure. Right: Normalized stress intensity at the tip vs. cell length/edge thickness ratio.

In Fig. 1 the central figures are deformations shown in planes located in the center of the 3D structures at the moment when the waves have their maximum amplitudes at the tips while the right figure in

Fig. 1 display stress intensities at the tips, estimated from an energy method, vs. the ratio between cell length and edge thickness. Several interesting things may be observed. Firstly, the regular and irregular structures deforms completely different. The low-density regular structure attains shear-bands, which are not present in the irregular ones. Secondly, the irregular structures crack paths deviates from the original crack planes, while the ordered structures crack paths are inclined to their initial planes due to symmetry. Thirdly, the structures exhibits severe elastic blunting at low densities, a mechanical behavior typical for gradient-sensitive materials, cf. [3-5]. Interesting is that the irregular structures distribute deformations around the macroscopic tip in an even more complex manner so that the local stress fields are smoothened and stress intensity substantially lowered compared to the regular structures and illustrates that the random spatial distribution have to be accounted for.

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