ON THE CRUSHING RESPONSE OF OPEN CELL FOAMS

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Summary The paper deals with the compressive response of polymeric, open cell solid foams which exhibit excellent energy absorption. Through a combination of experiment and analysis it has been confirmed that elastic buckling involving interaction of global modes and modes at the cell level are responsible for the stress plateau governing the foam's energy absorption capacity.

Solid foams is a class of light-weight cellular materials with exceptional energy absorption characteristics. They are widely used in shock mitigation, in packaging and in cushioning but also as cores in sandwich structures. Common to most foams is a compressive stress-displacement response with the characteristic three regime shape shown in Fig. 1. Initially the response is stiff and essentially linearly elastic (E). This terminates into a limit load (σ_I) followed by an extensive load plateau (mean stress level $\bar{\sigma}_P$ and extent $\Delta\bar{\varepsilon}_P$) responsible for their excellent energy absorption characteristics. The plateau usually ends into a second branch of stiff response. Design of foams requires that the deformation history of the microstructure be related to the main variables of this response $\{E,\ \sigma_I,\ \bar{\sigma}_P,\ \Delta\bar{\varepsilon}_P\}$.

Experiments on polyester urethane open cell foams have confirmed that the limit load corresponds to the onset of unstable behavior. During the stress plateau, localized deformation bands involving buckled cells initiate and spread throughout the material. The stress plateau terminates when most of the microstructure has collapsed. This paper will present the results of a study combining experiments coupled with several levels of modeling aimed to understand and model the underlying mechanisms of this type of response. The experiments involved characterization of the cell and ligament morphology; measurement of the mechanical properties of the polymer using ligaments extracted from the foam; and crushing of blocks of foams between rigid parallel plates at various constant displacement rates. The major findings are summarized below.

The microstructure consists of interconnected polyhedra each with an average of 13.7 faces, each face having an average of nearly 5 sides. To first order, the microstructure scales with the cell size. In these foams the size of the cells does not vary significantly but the cells are elongated in the rise direction ($\lambda \equiv$ ratio of diameters in rise-to-lateral directions). The ligaments have a three-cusp *Plateau borders* cross section and the cross sectional area varies along their length. The base material is an elastomer and, as a result, it is viscoelastic. In a first modeling attempt the material is assumed to be rate independent and linearly elastic.

Because of the anisotropy of the microstructure, the compressive responses in the rise and transverse directions of the foams are different (see Fig. 1). The rise direction response exhibits the characteristic three regime behavior described above. It was observed that the blocks tested buckled in an overall manner irrespective of the specimen size. As the stress plateau was traversed, localized bands of deformation developed. Their numbers gradually multiplied, while others broadened and coalesced. The response in the transverse direction has a smaller elastic modulus and is essentially a monotone. Overall buckling of the test specimen was not observed in this direction.

A sequence of models for predicting all mechanical foam properties of interest has been developed. The foam is idealized to be periodic using the space filling Kelvin cell assigned several of the geometric characteristics of the actual foams. The cells are elongated in the rise direction (Fig. 2); the ligaments are assumed to be straight, to have Plateau border cross sections and nonuniform cross sectional area distribution. Using this microstructure, closed form expressions have been developed for the elastic constants of the anisotropic foam. The initial response, the onset of instability and the initial post buckling response have been established through characteristic cell type-models discretized with FEs. Figure 3 shows that in the rise direction the prevalent instability exhibits a long wavelength mode while in the transverse direction involves buckling at the cell level. In the rise direction the long wavelength mode leads to a limit load indicating a tendency of localization. By contrast, in the transverse direction, the response of the local cell buckling is monotonic (Fig. 4). The localization of deformation, its spreading and the associated stress plateau are reproduced using large scale finite size type models involving a large number of cells.

References

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[2] Gong, L. and Kyriakides, S. (2003). Compressive response of open-cell foams. Part II: Initiation and spreading of crushing. *J. Mech. Phys. Solids* (submitted) 2003

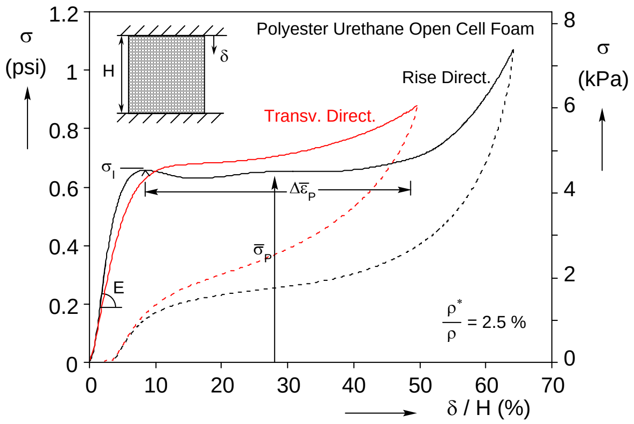


Fig. 1 Compressive stress-displacement responses in rise and transverse directions of polymeric open cell foam.

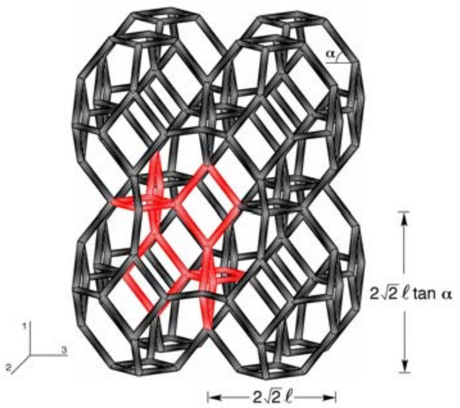
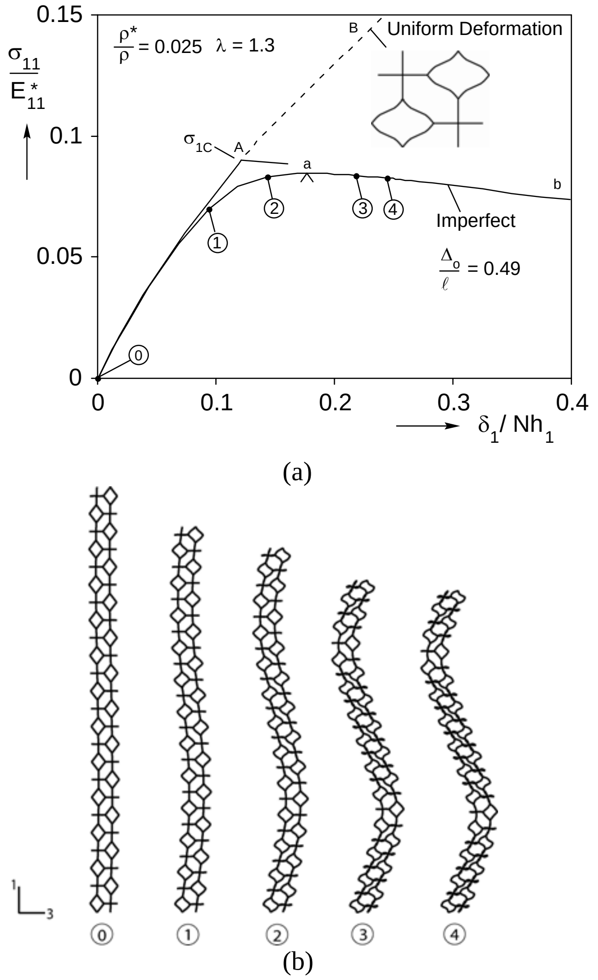
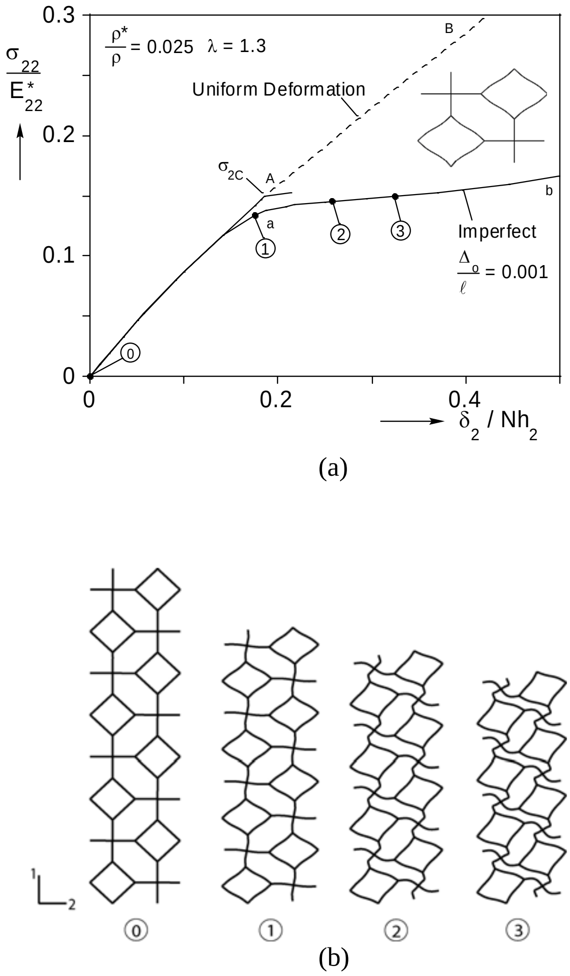


Fig. 2 Anisotropic Kelvin cell. Characteristic cell drawn in red.



(a)

(b)



(a)

(b)

Fig. 3 (a) Calculated prebuckling and postbuckling responses corresponding to long wavelength mode of rise direction. (b) Deformed configurations of a characteristic column of cells

Fig. 4 (a) Calculated prebuckling and postbuckling responses corresponding to local mode of transverse direction shown in (b).

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