NUMERICAL MODELING OF THE CRUSHING RESPONSE OF ALUMINUM OPEN-CELL RANDOM FOAMS

Stavros Gaitanaros[*], Stelios Kyriakides[*a)], Andrew Kraynik[**]
[*] *Research Center for Mechanics of Solids, Structures and Materials*
University of Texas at Austin, Austin, TX 78712, USA
[**] *School of Chemical Engineering and Analytical Science,*
University of Manchester, Manchester,M13 9PL, UK

Summary The paper presents a new modeling framework for calculating the complete crushing response of random foams. The model has a random microstructure of a soap froth that is dressed with beams with representative distribution of elastoplastic solid. Compression leads to localized collapse of cells and contact between ligaments that causes spreading of the collapse at a nearly constant stress level. The crushing stress and the associated deformation patterns reproduce well corresponding ones recorded in physical crushing experiments.

The paper aims to connect the truly random microstructure of foams to their mechanical properties. In particular, the effort is focused on simulating the complete crushing response of Al-alloy open-cell foams. X-ray tomography was used to characterize the microstructure of such foams including the geometry of the irregular polyhedral cells, ligament length and area distribution, cell anisotropy, density, etc. [1,2]. Cubical specimens compressed between rigid platens produced responses such as the one included in Fig. 1a. It starts with a relatively stiff linearly elastic regime that terminates into a load maximum; it is followed by an extended load plateau during which localized cell crushing initiates and gradually spreads throughout the specimen. When most of the cells are crushed, the densified material stiffens once more. Exploiting the nearly monodisperse nature of these foams, [3] showed that such responses could be fully reproduced using a suitably modified Kelvin cell microstructure. Exceptions are that the resulting crushing patterns differ from those observed in the experiments and that such periodic idealizations cannot be used in foams with a wider distribution of cell sizes.

The present modeling framework [4] overcomes the limitations of the Kelvin cell models by considering truly random foam microstructures generated using the Surface Evolver software. Both the experiments and the modeling involve crushing of finite size rectangular blocks with free lateral sides. For the response of such blocks to be representative of bulk material they have to be large enough. The requirement that the models be large in turn dictates that the ligaments be modeled as beams. Thus, such a model starts as a random soap froth with N^3 cells. The ligaments are dressed with straight beams with non-uniform cross sections that mimic measurements made on the actual Al foam. The models are assigned the density and anisotropy of the actual foams and the elasto-plastic properties of the Al-alloy base material. The microstructure is discretized with finite elements using LS-DYNA, which allows for beam-to-beam contact on the outer surface of the ligaments. The latter is an essential feature for locally limiting the extent to which collapsing cells can deform and thus enabling the spreading of crushing to neighboring cells.

Cubical models of several sizes are crushed between rigid surfaces. Because the lateral sides of the models are free, the solution can be influenced by the size of the domain. Parametric studies showed that calculated responses converge at a model size of 10^3 cells. A rise direction stress-displacement response from such a model, included in Fig. 1a, is seen to track a measured response very closely. Following a load maximum, localized cell crushing nucleates at the weakest sites. Slices out of the initial and three deformed configurations from this simulation, included in Fig. 1b, show localization patterns that compare vary favorably with ones reported in [2] using X-ray tomography (e.g., ① and ②). Contact between ligaments of crushed cells arrests local deformation causing crushing to spread to neighboring cells. In this way, crushing propagates throughout the model while the stress remains relatively unchanged. As the crushing fronts approach the top and bottom planes, the stress gradually increases because of the stiffening effect provided by the rigid surfaces (e.g., ③). Hence, the end cells crush last. Continued loading beyond this point requires an increase in stress in order to further compact the already significantly densified microstructure. These events and the associated crushing patterns mimic well corresponding experimental ones. Coulomb friction between contacting ligaments was found to have a stabilizing effect on the numerical solution. Crushing the model in the transverse direction results in a similar behavior but at an overall lower stress level. The simulations are once again in good agreement with experimental results.

References

[1] Jang W.-Y., Kraynik A.M., Kyriakides S.: On the microstructure of open-cell foams and its effect on elastic properties. *Int'l J. Solids & Structures* **45**:1845-1875, 2008.
[2] Jang W.-Y., Kyriakides S.: On the crushing of aluminum open-cell foams: Part I Experiments. *Int'l J. Solids & Structures* **46**:617-634, 2009.
[3] Jang W.-Y., Kyriakides S.: On the crushing of aluminum open-cell foams: Part II Analysis. *Int'l J. Solids & Structures* **46**:635-650, 2009.
[4] Gaitanaros S., Kyriakides S., Kraynik A.M.: On the crushing response of random open-cell foams. *Int'l J. Solids & Structures* (submitted, 2011)

[a)] Corresponding author. Email: skk@mail.utexas.edu.

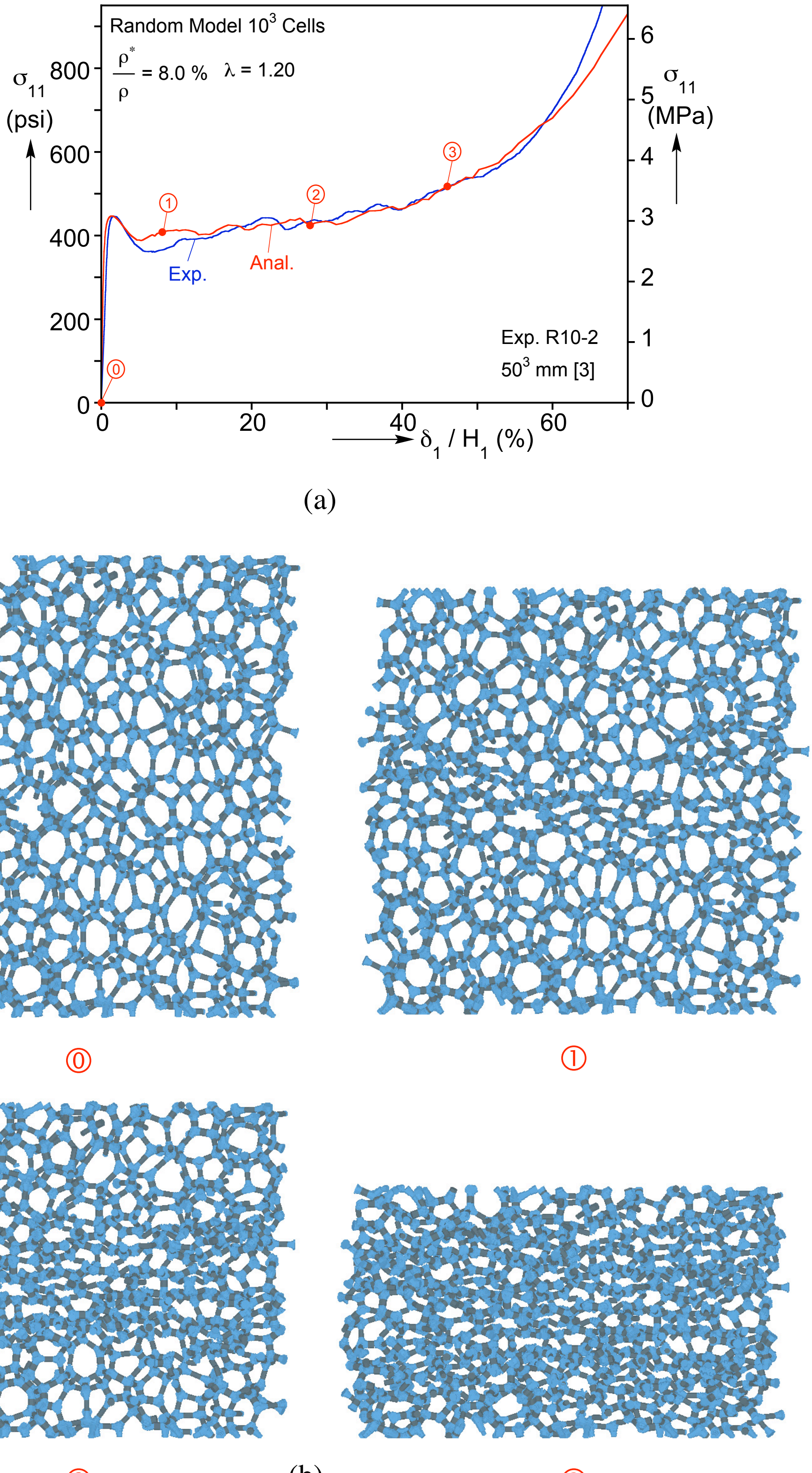

Fig. 1 (a) Measured force-displacement response of an Al-alloy open-cell foam and prediction from a random cell model. (b) Selected corresponding deformed configurations from the model.