Compressive Behavior and Crushing of Foams: Experiments and Modeling

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Lightweight cellular materials such as foams exhibit excellent energy absorption characteristics and are widely used for impact mitigation in a variety of applications. This lecture presents results from combined experimental and analytical efforts that investigate the crushing behavior of Al-alloy open-cell foams under quasi-static uniaxial and triaxial loadings and under impact. The foam microstructure is established using X-ray tomography including the cell and ligament morphology. The compressive force-displacement response exhibits an initial stiff branch, followed by an extended load plateau during which localized cell crushing progressively spreads throughout the specimen. When most of the cells are crushed the densified material stiffens again. Foam crushing is simulated using micromechanically accurate models. Skeletal random models generated from soap froth using the *Surface Evolver* software are dressed with solid to match the material distribution and relative density of actual foams. The ligaments are modeled as shear-deformable beams with variable cross sections discretized with beam elements in LS-DYNA, while the Al-alloy is modeled as elastic-plastic. Such models are shown to reproduce all aspects of quasi-static crushing faithfully, including the initiation of instability, its localization, the subsequent propagation and the densification stage. This modeling framework is used to crush model foams in a true triaxial loading apparatus. The recorded responses are shown to exhibit the same three-deformation regimes characterized by stress plateaus and localized crushing. The results of such discrete models are subsequently used to calibrate a pressure sensitive constitutive model with a partially softening material response. It is demonstrated that such a homogenized solid, introduced in finite element analyses of triaxial crushing, can reproduce the responses and localized crushing observed in the discrete models.

Under impact at velocities higher than 50 m/s, the foams develop nearly planar shocks that propagate at well-defined velocities, crushing the specimen. The shock-impact speed and the densification strain-impact speed representations of the Hugoniot were both extracted directly from high-speed images recorded during the impact. The compaction energy dissipation across the shock was found to increase with impact speed and to be significantly greater than the corresponding quasi-static one. Similar discrete foam models used in impact simulations are found to capture accurately the dynamic crushing behavior observed experimentally. That is, limited inertial effects are present below a critical speed, and shock formation above it. In the shock regime, the models reproduce the force acting at the two ends, the shock front velocity and energy absorbed.