ON THE CRITICAL ROLES OF CELLULAR STRUCTURE AND FLUID TRANSPORT IN THE MECHANICS OF CELLULAR MATERIALS

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A multi-field approach is developed for simulating the continuum-scale dynamic response of cellular materials [1]. This approach departs from traditional methods developed for modeling such materials, which focus almost exclusively on the mechanical response of the cellular solids, while essentially ignoring the fluids permeating the corresponding intricate networks of cells. In the present work, conservation equations are derived in multi-field form, producing a coupled set of governing equations with source terms depending on gradients in the cellular solid stress, but also on gradients in the permeating fluid pressure and momentum exchange resulting from relative motion between the cellular solid and permeating fluid fields. Constitutive relations for each of these terms are required. For the cellular solid stress, an advanced stochastic constitutive model is developed for describing the related continuum-scale mechanical response [2].

The multi-field equations of motion are implemented in a standard finite-volume computational test bed and used to study the mechanical response of cellular material systems. Physical limits on the stochastic variables provide upper and lower bounds on the constitutive response of these materials, while suitable choices for the stochastic material representation are shown to accurately reproduce experimental stress-strain data through the large deformations associated with densification. For quasi-static loading, results show that dispersity in geometric structure has little to no effect on the initial elastic properties of cellular materials. For finite deformations of materials with low degrees of dispersity; however, increasing dispersity is accompanied by decreasing stiffness, an increase in critical strain, and a decrease in the extent of localized deformation. Most notably, materials with the highest degrees of dispersity in their cellular structures exhibit mechanical response that remains stable for the entire range of compressive deformations, demonstrating a general stabilizing and stiffening effect of dispersity in geometric structure on the associated continuum-scale mechanical response [3].

For dynamic loading, the influence of various permeating fluids is examined. Changes in aperture size, loading rate, and boundary conditions, also are examined. Results demonstrate that the permeating fluid can play a major role in the response of cellular materials, contributing to the load-carrying capacity; affecting rate dependence, signal propagation speeds, and fluid transport; and influencing susceptibility to failure. Furthermore, the results point to the usefulness of the multi-field formulation and provide evidence to suggest that any modeling approach developed for cellular materials provide a proper accounting of the pressure evolution and flow behavior of the fluids present in these material systems.

References

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