The Geometric Design and Fabrication of Actuating Cellular Structures

Abstract

Biological actuators provide a rich source of inspiration for the architectural design of their synthetic analogs. In particular the hygromorphs found in the plant kingdom provide many examples of mechanically actuating systems that do not require a metabolic energy source to function. In these systems, directed, controlled forces/deformations are generated at the material level, through the introduction of appropriate meso-scaled architectures. As a result, both load bearing and morphing functions can be combined into a single integrated actuating material. From a materials perspective, plant tissues can be viewed as porous composites, made up of a honeycomb-like array of cells, whose walls consist of stiff cellulose microfibrils embedded in a softer hygroscopic matrix of lignin, hemi-cellulose, and other polysaccharides. The cellulose microfibril angle (MFA) that these reinforcing structures make relative to the long axis of the plant cell, has a strong influence on both the rigidity and mechanical actuation behavior of plant tissues. Just by controlling the simple architectural parameter of MFA, plants with the same polymeric building blocks can grow tissues that produce tensile or compressive strains along the plant cell longitudinal axis. Such a configuration is optimal to produce large stresses such as those needed to balance increasing gravitational loads on branches as plants grow, but are limited in the magnitude of strains that can be produced. Nevertheless, since the mechanical work, the product of force and displacement, cannot exceed the chemical energy gained upon moisture sorption, it should be possible to conceive a different actuating tissue architecture where displacements are maximized at the expense of force.

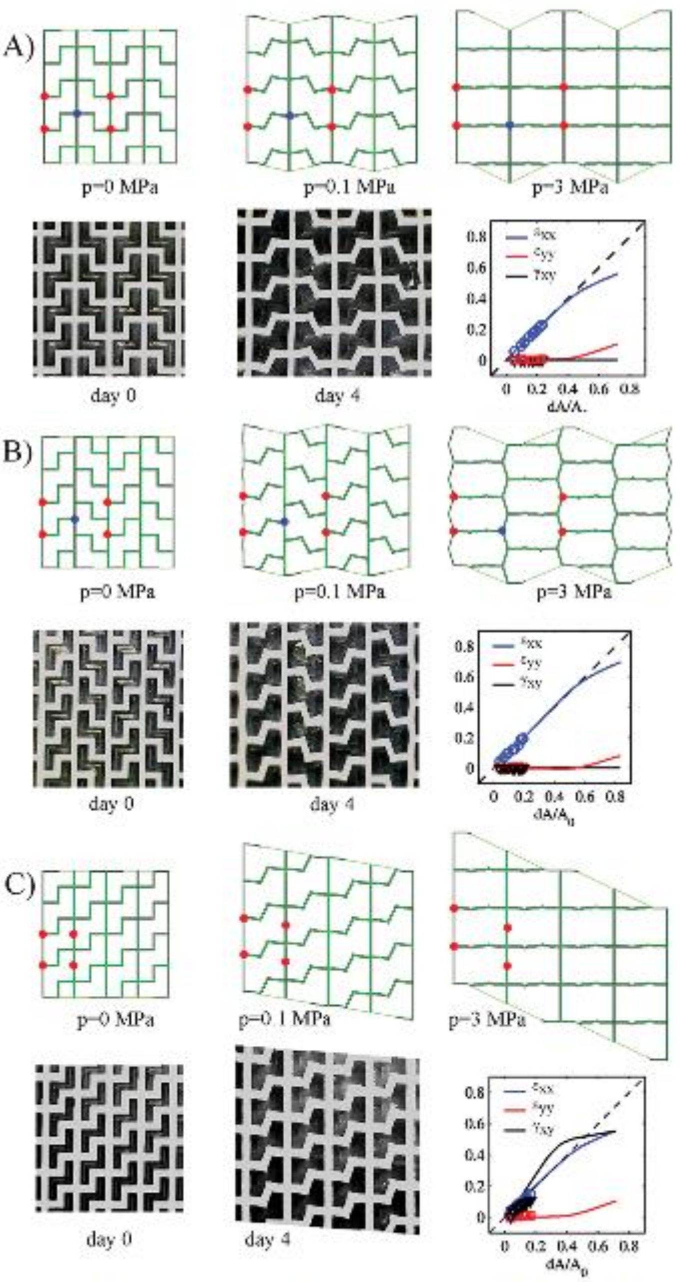

Figure 3. Deformations in inflating (FE) and swelling (rapid prototyped models) T-honeycombs with different architectures providing: A,B) macroscopic biaxial expansion; C) macroscopic biaxial and shearing expansion. Although smaller, the honeycomb strains measured in the swelling experiments (empty markers) are consistent with the FE simulations prediction (solid lines), thus illustrating how the honeycombs' expansion is primarily dictated by their architecture.