Pressurized honeycombs as soft-actuators: a theoretical study

Abstract

The seed capsule of Delospermanakurense is a remarkable example of a natural hygromorph, which unfolds its protecting valves upon wetting to expose ist seeds. The beautiful mechanism responsible for this motion is generated by a specialized organ based on an anisotropic cellular tissue filled with a highly swelling material. Inspired by this system, we study the mechanics of a diamond honeycomb internally pressurized by a fluid phase. Numerical homogenization by means of iterative finite-element (FE) simulations is adapted to the case of cellular materials filled with a variable pressure fluid phase. Like its biological counterpart, it is shown that the material architecture controls and guides the otherwise unspecific isotropic expansion of the fluid. Deformations up to twice the original dimensions can be achieved by simply setting the value of input pressure. In turn, these deformations cause a marked change of the honeycomb geometry and hence promote a stiffening of the material along the weak direction. To understand the mechanism further, we also developed a micromechanical model based on the Born model for crystal elasticity to find an explicit relation between honeycomb geometry, swelling eigenstrains and elastic properties. The micromechanical model is in good qualitative agreement with the FE simulations. Moreover, we also provide the force-stroke characteristics of a soft actuator based on the pressurized anisotropic honeycomb and show how the internal pressure has a nonlinear effect which can result in negative values of the in-plane Poisson's ratio. As nature shows in the case of the D.nakurense seed capsule, cellular materials can be used not only as low-weight structural materials, but also as simple but convenient actuating materials.

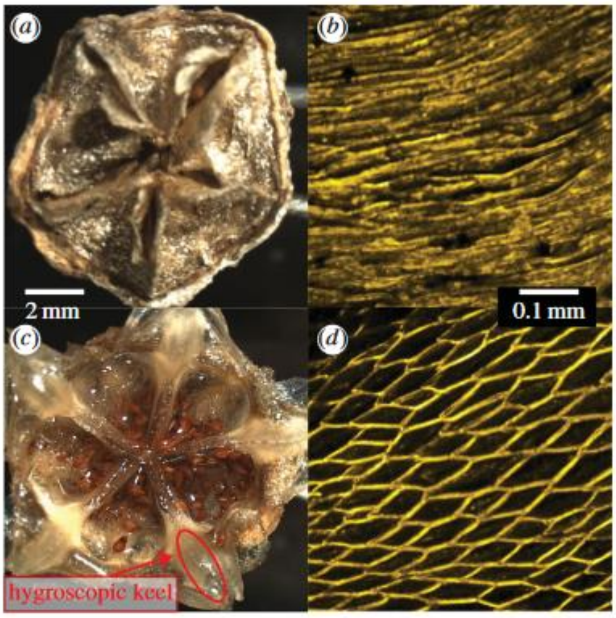

Figure 1. Anatomy and material architecture of the hydro-actuated *D. nakurense* seed capsule. The seed capsule of the *D. nakurense* is a natural example of passive actuation driven by water adsorption. The dry seed capsule (*a*) opens upon water absorption (*c*) due to the expansion of the hydroscopic keel. One of the five keels is highlighted in red in (*c*). The anisotropic architecture and differential composition of the keel tissue (as seen in *b*) in the dry state and (*d*) in the wet state enables a huge localized swelling which translates in the opening of the valves that protect the seeds (images provided courtesy of K. Razghandi, (*b*,*d*) are modified from [18] with permission).