An Introduction into the Physics of Self-folding Thin Structures

Abstract

Spontaneous folding of matter has long been the subject of disparate branches of research, from the earlier vitalistic view of Leibniz to the mathematical description of morphogenetic processes of D'Arcy Thompson. Today, scientific advancements have shown how folding is a common strategy adopted in biological systems to build up more and more complex structures – in proteins, from a peptide chain to a functional enzyme; in plants, from bud petals to a developed flower; in organisms, from layers of cells to diversified embryos. One might think that such folding processes require exceptionally complex biological machineries to orchestrate them. On the contrary, with this contribution, we will show that folding can result from remarkably simple processes – and equally applies to both natural and artificial systems. In the following we will introduce the reader to the necessary theoretical concepts that are needed to understand these phenomena, providing examples from the common experience enabling a more systematic understanding.

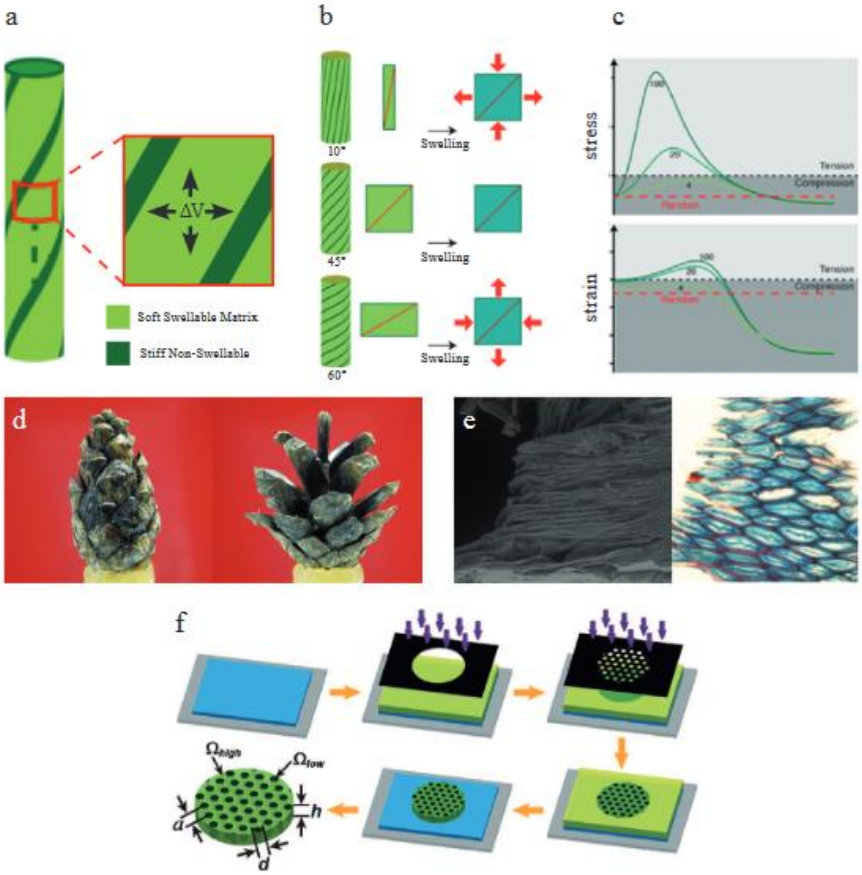

Fig. 4: Strategies to control eigenstrains in biological and artificial systems. (a–c) The cellulose microfibril angle (MFA) controls the mechanics and swelling of the plant cell wall. Dunlop 2016. (a) Schematic of a simplified cell wall, consisting of a soft swellable matrix reinforced by stiff fibres wrapped at an angle μ around the cell. (b) Schematic of how cells with different MFAs will respond to swelling of the soft matrix. (c) Tensional and compressive strains and stresses can be generated depending on the MFA. (d) A pine cone, an example of actuating biological structures responding to change in environmental humidity based on the plant cell wall model. (e) Larger directed expansions are achieved in the active tissue of the iceplant seed capsule through a different spatial arrangement of the swelling (pale blue) and non-swelling (red) materials. (f) Schematic of halftone lithography: by changing the dimension of the low swelling black dots with respect to the high swelling green material fine spatial control of swelling properties in a hydrogel sheet is possible. Kim et al. 2012.