

Plenary Presentation

MECHANICS AND MATERIALS FOR SOFT MACHINES

Zhigang Suo
Harvard University
Cambridge, Massachusetts, USA

ABSTRACT

The convergence of parts of biology and engineering has created exciting opportunities for discoveries, inventions, and commercialization. The overarching themes include using engineering tools to study biology, combining biology and engineering to invent medical procedures, and mimicking biology to create engineering devices.

An essential feature of life is to receive and process information from the environment, and then move. The movements are responsible for diverse functions, far beyond the familiar function of going from place to place. For example, an octopus can change its color at an astonishing speed, for camouflage and signaling, despite its own apparent color blindness. This rapid change in color is mediated by thousands of chromatophores, pigment-containing sacs lying beneath the skin. Attach to the periphery of each sac are dozens of radial muscles, innervated directly by the brain. By contracting or relaxing the muscles, the pigmented sac increases or decreases in area in less than a second. An expanded sac may be up to about 1 mm in diameter, showing the color. A retracted sac may be down to about 0.1 mm in diameter, barely visible to the naked eye.¹

As another example, in response to changes in pH and concentration of salt, a plant can increase or decrease the flow rate of water through the xylem. This regulation of flow is mediated by pectins, polysaccharides that are used to make jellies and jams. Pectins are long and flexible polymers, crosslinked into a network. The network can imbibe a large amount of water and swell many times its own volume, resulting in a hydrogel. The amount of swelling changes in response to changes in pH and concentration of salt. The change in the volume of the hydrogel alters the size of the microchannels, increasing or decreasing the rate of flow.²

A common lesson in the above examples is that a stimulus causes a large deformation of a material, and the large deformation does something useful, i.e., providing a function. Connecting the stimulus and the function is the material capable of large deformation in response to a non-mechanical stimulus. We call such a material a soft active material (SAM).

Soft active materials are indeed apt in mimicking the salient feature of life: movements in response to stimuli. For example, an electric field can cause an elastomer to stretch several times its length. As another example, a change in pH can cause a gel to swell many times its volume. These soft active materials are being developed for diverse applications, including soft robots, adaptive optics, self-regulated fluidics, and programmable haptic surfaces.³⁻⁶

In this talk, I will describe recent work in my group on the mechanics of soft active materials. We formulate theories to answer commonly asked questions. How do mechanics, chemistry, and electricity work together to generate large deformation? What is the maximal energy that can be converted by a soft material? How do molecular processes affect material response? How can the theories be implemented in commercial software and make the theories useful to other researchers? The theories are illustrated with phenomena arising in applications, drawing on recently reported experimental observations, and focusing on large deformation and instability.⁷⁻⁹

REFERENCES

1. L.M. Mathger, E.J. Denton, N.J. Marshall, and R.T. Hanlon. Mechanisms and behavioral functions of structural coloration in cephalopods. *J. R. Soc. Interface* 6, S149-S163 (2008).
2. M.A. Zwieniecki, P.J. Melcher, and N.M. Holbrook. Hydrogel control of xylem hydraulic resistance in plants.
3. R. Pelrine, R. Kornbluh, Q.B. Pei, and J. Joseph, High-speed electrically actuated elastomers with strain greater than 100%. *Science* 287, 836 (2000).
4. D.J. Beebe, J.S. Moore, J.M., Bauer, Q., Yu, R.H. Liu, C. Devadoss, and B.H. Jo, Functional hydrogel structures for autonomous flow control inside microfluidic channels. *Nature* 404, 588 (2000).
5. L. Dong, A.K. Agarwal, D.J Beebe, and H.R., Jiang, Adaptive liquid microlenses activated by stimuli-responsive hydrogels. *Nature* 442, 551-554 (2006).
6. P. Calvert, Hydrogels for soft machines. *Adv. Mater.* 21, 743-756 (2009).

7. Z.G. Suo, X.H. Zhao and W.H. Greene, A nonlinear field theory of deformable dielectrics . *J. Mech. Phys. Solids* 56, 467-286 (2008).
8. W. Hong, Z.S. Liu, and Z.G. Suo, Inhomogeneous swelling of a gel in equilibrium with a solvent and mechanical load. *Int. J. Solids Struct.* 46, 3282-3289 (2009).
Put text of Annex here
9. S.J.A. Koh, X.H. Zhao, and Z.G. Suo, Maximal energy that can be converted by a dielectric elastomer generator. *Appl. Phys. Lett.* 94, 262902 (2009).