

Geometrical basis for symmetry breaking and multi-functionality (invited presentation)

Stoyan K. Smoukov, sks46@cam.ac.uk
Head, Active and Intelligent Materials Lab, University of Cambridge

Symmetry breaking in living systems is often achieved by coupling of chemical reactions and selective growth to achieve shape change. In many systems, however, it is becoming more recognized that the underlying materials themselves can cause the symmetry breaking. It is important to understand such mechanisms as they could help us direct growth, shape change, and be a source of morphogenesis and adaptability in artificial systems.

Materials exhibiting dynamic shape-change behaviour, have shown much promise for engineering multi-functionality. They are useful for developing novel artificial muscles, adaptable structures, and for bringing insights into the processes or morphogenesis.

We show examples of engineering the symmetry breaking and dynamics for multiple structures and processes, on multiple length scales – from nanometers to centimeters. We demonstrate the formation of Janus and other asymmetric particles, which form as a result of coupling of chemical reactions to non-linear mechanical properties of materials[1,2]. We also demonstrate the opposite effects – how mechanical deformations and molecular interactions can help one simplify chemical syntheses[3]. Further, we also demonstrate that even without reactions, the material properties and geometry alone could cause symmetry breaking. By bending a spherical cap and a cone shell, we characterize the instabilities and show novel behaviors, both static and dynamic.

Upon inversion of the magnetic spherical cap, for example, using high speed video, we have captured an intermediate asymmetric quasi-stable state. The results are reproduced faithfully by a finite element model analysis where we only put in the material properties and the remote forces exerted on the cap by a magnetic field[4]. Equilibrium deformations also show symmetry breaking. We have focused on another simple shape – a conical shell. Upon deformation one can achieve in a controlled way symmetry breaking with 2-, 3-, 4- and 5- sided polygonal shapes. We explore the energetics of these transitions, the underlying materials properties which control them, and the dimensionless scaling that could help us predict them for various cones.

References

- [1] Ding T, Baumberg J, Smoukov SK, Harnessing Nonlinear Rubber Swelling for Bulk Synthesis of Anisotropic Hybrid Nanoparticles with Tunable Metal-Polymer Ratios, *J. Mater. Chem. C*, **2**, 8745-8749 (2014) DOI: 10.1039/c4tc01660b
- [2] Wang Y, Ding T, Baumberg J, Smoukov SK, Symmetry Breaking Polymerization: One-Pot Synthesis of Plasmonic Hybrid Janus Nanoparticles, *Nanoscale* (2015) DOI: 10.1039/c5nr01999k
- [3] Marshall, JE, Gallagher S, Terentjev EM, Smoukov SK, Anisotropic Colloidal Micromuscles from Liquid Crystal Elastomers, *J. Am. Chem. Soc.*, **136** (1), 474-479 (2014), DOI: 10.1021/ja410930g
- [4] Loukaides E, Seffen KA, Smoukov SK, Magnetic Actuation and Transition Shapes of a Bistable Spherical Cap, *Intl. J. Smart & Nano Mater.* (2015) DOI: 10.1080/19475411.2014.997322