PhD Thesis Opening – CNRS, Ecole Polytechnique

(Thesis Funded by an ERC Starting Grant)

Harnessing Instabilities in Magnetorheological Elastomers: Experiments and Numerical Investigation

General Context: In recent years, there has been an increased effort by scientists to obtain new composite materials with extreme properties. Inspired by natural and biological processes, scientists have proposed the use of hierarchical architectures (i.e., assembly of structural components) spanning several length scales from nanometer to centimeter sizes. Depending each time on the desired properties of the composite material, optimization with respect to its stiffness, weight, density, toughness and other properties is carried out. In the present subject, the interest is in magneto-mechanical coupling and tailored instabilities. Hierarchical materials, such as magnetorheological elastomers (MREs) which combine magnetic particles (at the scale of nanometers and micrometers) embedded in a soft polymeric non-magnetic matrix, give rise to a coupled magneto-mechanical response at the macroscopic (order of millimeters and centimeters) scale when they are subjected to combined magneto-mechanical external stimuli. These composite materials can deform at very large strains due to the presence of the soft polymeric matrix without fracturing. From an unconventional point of view, a remarkable property of these materials is that while they can become unstable by combined magneto-mechanical loading, their response is well controlled in the post-instability regime. This, in turn, allows us to try to operate these materials in this critically stable region, similar to most biological systems. These instabilities can lead to extreme responses such as wrinkles (for haptic applications), actively controlled stiffness (for cell-growth) and acoustic properties with only marginal changes in the externally applied magnetic fields. Unlike the current modeling of hierarchical composites, MREs require the development of novel experimental techniques and advanced coupled nonlinear magneto-mechanical models in order to tailor the desired macroscopic instability response at finite strains.

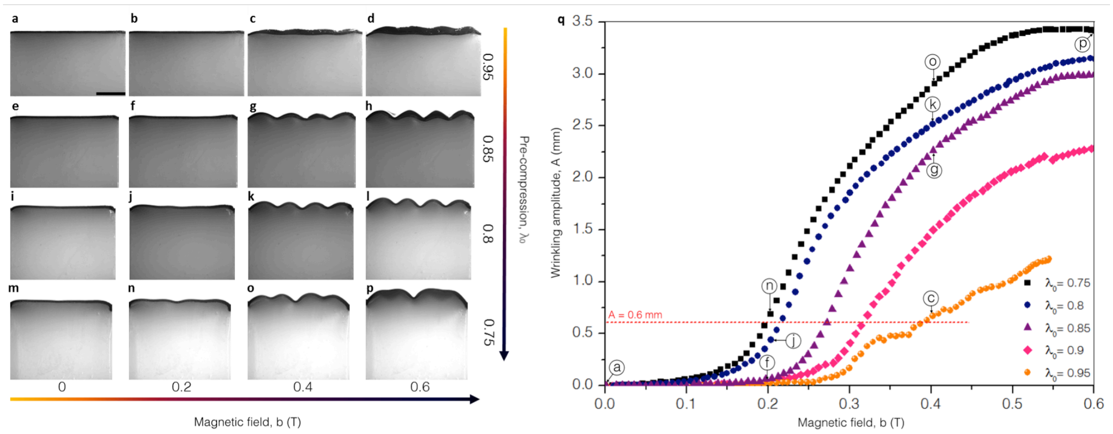

Figure 1: Experimental influence of the magnetomechanical coupling on bifurcation and post-bifurcation. Optical images of the morphological pattern versus the applied magnetic field, under different pre-compressions. Critical modes depend on the geometry as well as on the mechanical and magnetic contrast of the layer and the substrate. (a-p) Post-buckling is defined by the appearance of wrinkles and creases. (q) Measurements of the bifurcation amplitude A as a function the applied magnetic field, for different pre-compressions. A clear decrease the critical magnetic field for bifurcation transition is obtained with applied pre-compression.

The proposed thesis has multiple branches. The project is expected to span specimen fabrication, experiments and numerical investigation of MRE films with particle-chain microstructures. This work will have as a goal to reduce further the magnetic fields needed for triggering instabilities. Subsequently, we will try to construct a device that is able to give different patterns by considering multi-axial in plane mechanical pre-compressions with superimposed fields. The device will be first designed numerically and then realized experimentally. Finally, the last part of the thesis involves the exploration of novel geometries that lead to a metamaterial response such as negative-Poisson-ratio structures and hierarchical instabilities of multi-beam magnetoelastic materials.

Additional comments: The project will offer a number of opportunities to present the thesis work in national and international conferences as well as access to high-end experimental and numerical infrastructure.

Competencies: By pursuing the above-described PhD, the student is expected to acquire a strong combined knowledge of experimental methods (e.g., image correlation techniques, mechanical and magnetomechanical testing, 3D printing) and numerical tools (finite element method including Abaqus and FEAP software, fortran, matlab and python scripting). This knowledge together with the novelty of the project can equally provide industrial and academic opportunities after the end of the thesis.

Thesis co-supervisors: Kostas Danas (LMS, Ecole Polytechnique) and Laurence Bodelot (LMS, Ecole Polytechnique)

Funding: The PhD thesis will be funded by a European Starting Grant (ERC).

Starting date: October 2017

Contacts

Interested applicants should contact Dr. Kostas Danas including a CV and detailed grade transcripts (Relevés des Notes) from all their undergraduate and master studies. It is also preferred to include references with contact information (email and phone number).

Kostas Danas (kdanas@lms.polytechnique.fr)

General info can be found at the following webpages:

Project webpage: http://www.kostasdanas.com/erc-magneto/
PI webpage: http://www.kostasdanas.com/

Ecole Polytechnique webpage: http://www.polytechnique.edu
Laboratory webpage: http://www.lms.polytechnique.fr