

Proposed Thesis Topic at LMS, Ecole Polytechnique:

Experiments and numerical implementation of magnetorheological elastomers: a study of the micro-deformation mechanisms

Principal Objective: To develop new experimental procedures and high fidelity numerical models for the understanding and constitutive description of microstructured magnetorheological elastomers.

1. Background

A variety of multi-scale and multi-functional composite materials with broad applications in the industry and in new technologies have been developed [1, 2]. By mechanically coupling various active materials together new properties and functions could be achieved which are otherwise not possible. In general, active materials convert electrical, thermal or magnetic energy into mechanical energy and vice versa. By combining various active materials together it is possible to transduce between electrical, thermal and magnetic energies. Although such composites are known since the 1950s, recently new biomedical needs called for the revisit and new applications for such materials are constantly being discovered in the fields of forming processes, actuators and biomedical implants. The length size of these materials ranges from the nanometer or micrometer scale (e.g., polymeric or metallic nanocomposites and thin film coatings) to the meter scale (metallic or polymeric fiber reinforced or porous composites).

Materials whose rheological properties can be varied by the application of magnetic fields are referred to as magnetorheological (MR) materials. They belong to the broadly defined class of active materials because they can respond, via solid-state electronics and modern control algorithms, to changes in their environment. Such materials can be utilized in devices or can be incorporated in composites to form advanced composite structures with an ever-increasing number of applications in modern automotive, aerospace and electronics industries.

MREs (magnetorheological elastomers) consist of ferromagnetic (typically micron-sized) particles embedded in an elastomer matrix. Their short response time (of the order of msec), continuously controllable mechanical properties and ability to sustain large stiffness changes make the MREs attractive in industrial applications. The recently discovered MRE materials have many exciting potential applications in aerospace, automotive, civil and electrical engineering fields, such as actively adaptive lenses, man/machine tactile interfaces, vibration damping devices and variable stiffness mounts.

A schematic explanation for the behavior of an MRE is illustrated in Fig. 1. The elastomeric matrix contains micro sized carbonyl iron particles in a volume fraction of 25%. The application of a 0.8T magnetic field during the curing process leads to formation of particle chains aligned with the curing field direction. The application of a magnetic field \mathbf{h}_0 leads to a stiffening of the shear stress-strain response of the MRE .

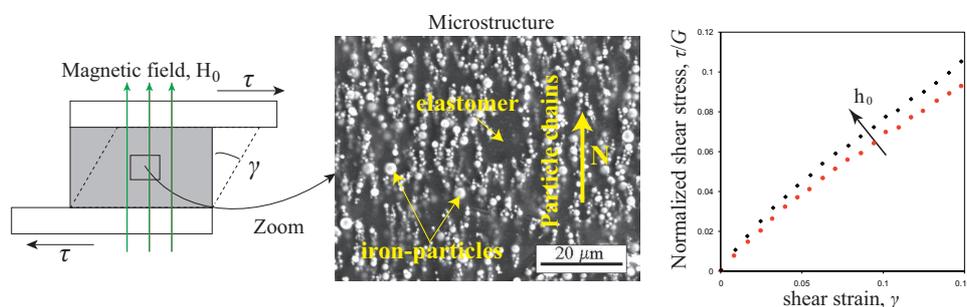


Figure 1: An illustration of the stiffening effect of a magnetic field on the shear stress-strain behavior of a MRE (left) with particle-chain microstructure, initially aligned with the applied magnetic field (center). The stiffening in the mechanical response when a magnetic field \mathbf{h}_0 is applied is due to inter-particle magnetic forces (right).

2. Proposed research and intellectual significance

The proposed project deals with the development of new experimental techniques and high fidelity numerical models for the understanding of the role of microstructure upon the macroscopic response of the composite when subjected to combined magneto-mechanical loading conditions.

Aim I : Experiments

The first part of the project consists of a detailed experimental program to fabricate and subsequently analyze MREs made of different types of elastomers (e.g., silicone, hard gels, etc) as matrix phase and magnetizable particles (e.g., soft or hard iron, spheres or needles) as filling phase in various volume concentrations and different micro-geometrical configurations. Their response under a wide variety of combined magnetic and mechanical loads will be subsequently studied in our laboratory.

The making and testing of MREs present interesting challenges, since we must solve problems pertaining to the appropriate material selection, creation of desired micro- and macro-geometries and so on. The subsequent experimental study of the MREs macroscopic and microscopic responses to magnetic and mechanical loads will require designing appropriate experimental setups that create uniform and controllable mechanical and magnetic fields in the tested sections.

Aim II : Numerical implementation

The second part of the proposed work pertains to the modeling of these materials using both macroscopic (continuum) and full-field (numerical) microscopic approaches. These studies will allow us to understand the impact of the microstructure upon the macroscopic magneto-mechanical coupling. To this end, new numerical techniques will be developed in order to deal with the underlying nonlinear, multiphysics problem. The modeling approach proposed here is original, for it is based on new, coupled variational principles that simultaneously satisfy all relevant governing equations (mechanical as well as magnetic) and take into account the finite size of particles and the variations of the magnetic fields inside them. There are interesting theoretical and numerical challenges associated with the choice of appropriate discretization techniques, given the different compatibility requirements for displacement fields and for magnetic potential fields. These numerical tools are essential for the study of a series of different microstructural configurations, in order to compare with the corresponding experimental studies.

3. Contact Information

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Starting date: October, 2013

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References

- [1] Ginder, J.M., Clark, S.M., Schlotter, W.F., Nichols, M.E., (2002). Magnetostrictive phenomena in magnetorheological elastomers. *Int. J. Mod. Phys. B* 16, 2412-2418.
- [2] Danas K., Kankanala S.V., Triantafyllidis N., (2012). Experiments and modeling of iron-particle-filled magnetorheological elastomers, *J. Mech. Phys. Solids*, 60, 120-138.