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XFEM MODELING OF MAGNETOACTIVE MATERIALS

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Magnetorheological elastomers (MRE) feature mechanical moduli that become strongly enhanced by an applied external magnetic field as well as the ability to generate magnetically induced deformations and mechanical actuation stresses. Typically, MRE represent a two-component system, in which micron-sized magnetizable particles are embedded in a cross-linked polymer network. The spatial distribution of the magnetic particles in MRE can be either isotropic or anisotropic depending on whether the particles have been aligned by an applied magnetic field before the cross-linking of the polymer. Because the effective coupled magneto-mechanical behavior is of special interest in technical applications, an in-depth understanding of the structure-property relations in MRE as well as suitable theories for computing the effective macroscopic material response are required. To this end, this contribution presents a homogenization approach for coupled magneto-mechanical problems. In order to simulate magneto-mechanical interactions in a microscopic representative volume element (RVE), a weakly coupled modeling approach based on a continuum formulation of the magneto-mechanical problem which utilizes a split of the total stress tensor into magnetic and mechanical parts has been derived.
This formulation was discretized using the extended Finite Element Method (XFEM) [1, 2]. The application of XFEM allows for the use of non-conforming, structured meshes which do not have to be adapted to the particle-matrix interfaces. This is advantageous if random particle arrangements are to be discretized. In addition, the implicit interface representation by level sets facilitates the automatic conversion of micrographs or computed tomography (CT) scans into a numerical model of the local material structure, which is one of the essential requirements for a multi-scale analysis. Based on the simulation of the magneto-mechanical interactions in the microscopic RVE, the effective coupled material behavior has been predicted using periodic boundary conditions for both the magnetic potential and the displacements. Results obtained from computations are comparable to the analytic findings of Ponte Castañeda et al. [3] and outlined in more detail in [2].
The following example which considers a two-dimensional arrangement of three circular inclusions (Fig. 1 (a)) representing an idealized chain-like microstructure. The non-linear magnetization behavior of the inclusions is modeled by a Langevin function. While the

magnetic induction is gradually increased, the macroscopic deformation was fixed, nevertheless allowing for periodic fluctuations. The effective response is computed in terms of macroscopic mechanical actuation stresses $\bar{\mathbf{t}}$, which result from the magneto-mechanical interactions in the case of fixed marcoscopic deformations. The results shown in Fig. 1 correspond to a load case where the macroscopic induction is applied at an angle of 45°. In Fig. 1 (b) the contour plots of the local magnetic induction with a sigmoidal deformed RVE are displayed. An essential aspect of the results is, that the macroscopic mechanical stress tensor in Fig. 1 (c) is non-symmetric with $\bar{t}_{12} < 0$ and $\bar{t}_{21} > 0$.

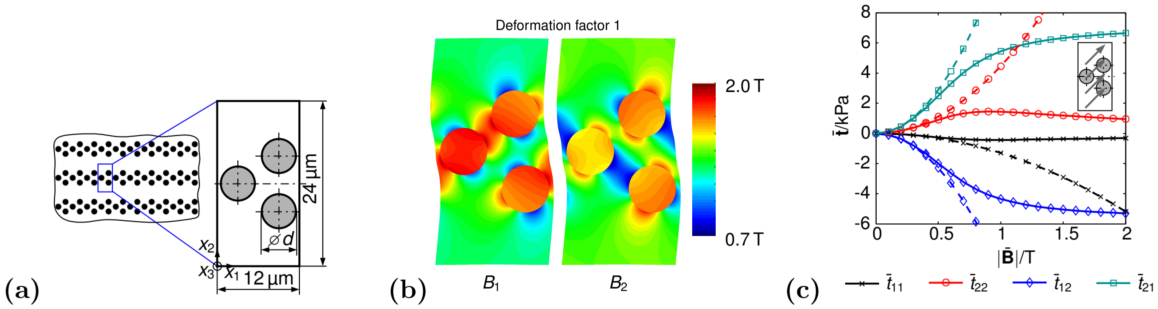

Figure 1: **(a)** Idealized RVE including three circular inclusions, **(b)** local magnetic induction and periodic displacement field and **(c)** macroscopic acutation stresses $\bar{\mathbf{t}}$ obtained from homogenization process [2].

In addition to the small strain results mentioned above, the present contribution will discuss the extension of the approach to account for large deformations and more complex random isotropic and anisotropic particle distributions. This includes the generalization of the continuum model, the implementation of an update-Lagrange XFEM for magneto-mechanical problems, the conversion of CT scans into XFEM models and the formulation of suitable material models as outlined in [4].

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