

Advances in the Fracture of Soft Matter: Multiphysics, Sideways Cracks, and Configurational Mechanics

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Our investigations into soft fracture aim to modulate and enhance the fracture behavior of soft materials through innovative strategies and to provide mechanical understanding via advanced computational models. We compile a four-part study including multiphysics fracture of soft hard-magnetic magnetorheological elastomers (hMREs) and dielectric electro-active elastomers (DEAPs), sideways cracking, and the Configurational Force Method. We explore multiphysics fracture in soft hMREs (~ 1 kPa stiffness) with remanent magnetization [1] (Fig.1a). Tensile experiments are performed on non-magnetized and pre-magnetized samples and a bespoke multiphysics phase-field framework for fracture of hMREs is introduced. The results demonstrate that remanent magnetic fields induce beneficial compressive stresses in the medium, decreasing stress concentration at the crack tip and delaying crack propagation. Subsequently, we investigate the fracture behavior of an ultra-soft DEAP [2] (Fig.1b). The use of compliant electrodes on the sides of the elastomeric samples enables the application of a high voltage during tensile deformation. The results reveal that lateral Coulomb forces generate an intricate stress triaxiality state that induces beneficial crack tip blunting and reduces stress concentration. The work of fracture increases and crack propagation is delayed. Another relevant aspect is the emergence of new fracture modes in soft materials due to large deformations and constitutive and geometrical nonlinearities. In sideways cracking, the crack deviates to propagate in the loading direction rather than perpendicular to it. Through a combination of experiments and computations, we demonstrate that the tendency for anisotropic sideways crack propagation in an isotropic elastomer increases with the degree of crosslinking [3] (Fig.1c). We develop a phenomenological phase-field model for sideways fracture where the critical energy release rate is tied to the degree of crosslinking. To wrap up our investigations, we apply the Configurational Force Method to soft materials [4] (Fig.1d). When applied to fracture mechanics, configurational forces can be used to quantify the propensity of cracks to propagate. We approximate the well-known J -integral via configurational forces at large strains.

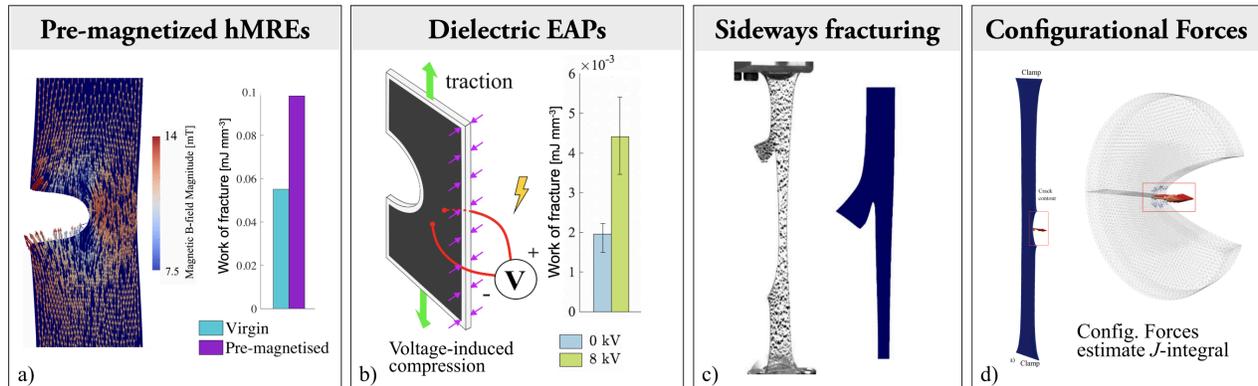


Figure 1. Fracture of (a) hard-magnetic MREs and (b) dielectric EAPs, (c) Sideways fracturing, (d) Configurational Force Method.

- [1] M.A. Moreno-Mateos, *et al.* “Hard magnetics in ultrasoft magnetorheological elastomers enhance fracture toughness and delay crack propagation”. *Journal of the Mechanics and Physics of Solids*, 173 (2023) 105232.
- [2] M.A. Moreno-Mateos, M. Mehnert, and P. Steinmann. “Electro-mechanical actuation modulates fracture performance of soft dielectric elastomers”. *International Journal of Engineering Science*, 195 (2024) 104008.
- [3] M.A. Moreno-Mateos and P. Steinmann. “Crosslinking degree variations enable programming and controlling soft fracture via sideways cracking”. *NPJ Computational Materials*, vol. 10, 282.
- [4] M.A. Moreno-Mateos and P. Steinmann. “Configurational forces meet J-integral on soft materials: a numerical and experimental study”. *Journal of the Mechanics and Physics of Solids*, 186 (2024) 105602.