SUBPROJECT 6: Constitutive modeling and multi-scale and multi-physical simulation of I-FRC

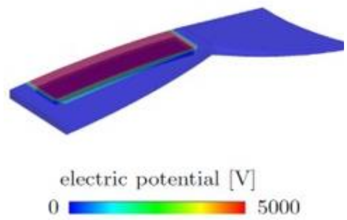
M. KALISKE in cooperation with M. ZIMMERMANN;
external advisor: L. DORFMANN (Tufts University, USA)

Motivation

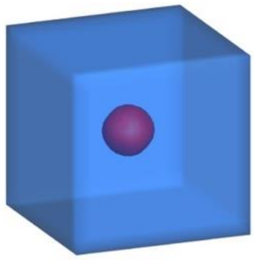
I-FRC typically consist of an elastomer matrix, an integrated active material (e.g., a dielectric elastomer actuator), and embedded fiber reinforcement structures. The functionality of I-FRC mainly depends on the interaction between matrix, external stimulation and the mechanical response of the integrated active material. According to the specific active material selected for a composite structure, stimulation is based on the induced thermal, electrical and magnetic field. In order to predict the response behavior of this highly heterogeneous material taking into consideration the interaction of different fields, suitable mathematical solutions for the constitutive behavior and efficient computational simulation approaches must be developed.

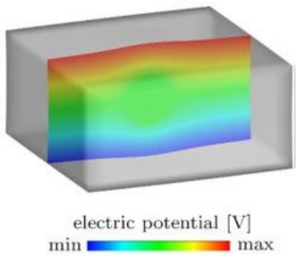
State of the art and previous research

Electro-active and magneto-active polymers are novel composite materials that function through multiphysical phenomena. Numerical modeling of these materials is based on two- or three-field multiphysical constitutive models and implementations into a finite element analysis software. The 1st and 2nd cohorts have developed and demonstrated various such models (see Figure). The thermo-electro-mechanical fields, analyzed in the 1st cohort, were treated at both the meso- and macro-scale via a homogenization procedure [1, 2]. The meso-scale models are based on fundamental physical relations, and the macro-scale models are conceived with a phenomenological approach. The thermo-magneto-mechanical fields have been examined in the 2nd cohort, as well as interface mechanics [3, 4]. This examination has not yet been brought to the macro-scale with a three-field homogenization scheme [5].

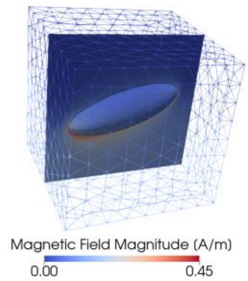


fish-fin-like structure


heterogeneous electroactive material



electrified sample



magnetized elliptical inclusion

Scientific questions and project objectives

The objective of SP 6 is to model and simulate the multi-physical, multi-scale phenomena of electro-active and magneto-active polymers. In particular, homogenization procedures for thermo-magneto-mechanics and matrix-inclusion interactions must be investigated. The exact nature of the interface mechanisms is also not fully explored and further testing is necessary. These models will ultimately be able to predict the behavior of full-scale MAE structures. Collaboration for homogenized models will take place with SP 4, which deals with analytical modeling approaches. Experimental characterization and validation of interface phenomena will follow from collaboration with SP 3 and SP 8, which deal with manufacture and characterization of I-FRC.

References

[1] Kanan, A.; Kaliske, M.: Finite Element Modeling of Electro-viscoelasticity in Fiber Reinforced Electro-active Polymers. International Journal for Numerical Methods in Engineering, 2021, 122(8): 2005–2037, https://doi.org/10.1002/nme.6610.

[2] Kanan, A.; Kaliske, M.: On the Computational Modelling of Nonlinear Electro-Elasticity in Heterogeneous Bodies at Finite Deformations. Mechanics of Soft Materials, 2021, 3(1): 4, https://doi.org/10.1007/s42558-020-00031-6.

[3] Fleischhauer, R.; Behnke, R.; Kaliske, M.: A Thermomechanical Interface Element Formulation for Finite Deformations. Computational Mechanics, 2013, 52(5), 1039–1058, https://doi.org/10.1007/s00466-013-0862-7.

[4] Klausler, W.; Kaliske, M.: Meso-scale Thermo-magneto-mechanical Constitutive Model for Magneto-active Elastomers. Proceedings in Applied Mathematics and Mechanics, 2023, e202300291, https://doi.org/10.1002/pamm.202300291.

[5] Fleischhauer, R.; Thomas, T.; Kato, J.; Terada, K.; Kaliske, M.: Finite Thermo-elastic Decoupled Two-scale Analysis. International Journal for Numerical Methods in Engineering, 2020, 121(3): 355–392, https://doi.org/10.1002/nme.6212.