Spectral electromagnetic couple-stress modelling of stiff fibre-reinforced composites

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This study presents a nonlinear modelling framework based on spectral invariants to describe the electromagnetic behaviour of fibre-reinforced composites, with explicit consideration of fibre bending stiffness. Using Cosserat continuum theory, we derive general constitutive relations for both stress and couple stress that account for the coupling between mechanical and electromagnetic effects. The formulation also provides a physically meaningful decomposition of the couple stress tensor. For materials where fibre bending is dominant, the model is further refined by limiting its dependence on fibre direction gradients to directional derivatives along the fibre axis. Prototype expressions for the internal energy are introduced for both the general and specialized formulations. The effectiveness of the specialized model is demonstrated through boundary value problems (BVPs) involving the pure bending of a slab and the extension and inflation of a solid cylinder, where they are important for validating our model from the experimental and numerical point of view. The BVP results indicate that the electromagnetic fields significantly affect the stress-strain behavior and our couple-stress formulation helps us to analyze the effect of bending stiffness in these BVPs. Overall, the proposed framework establishes a foundation for the analysis and design of advanced smart materials in which electromagnetic interactions and fibre microstructure are strongly coupled.

[1] MHBM Shariff, On the electromagnetic Cosserat spectral modelling of fibre-reinforced composites with fibre bending stiffness, International Journal of Engineering Science. **217**, 104360, 2025. https://doi.org/10.1016/j.ijengsci.2025.104360