Department of Aerospace Engineering SEMINAR

An Analysis of Thermo-Electro-Mechanical Material Response Across Scales

Dilek GÜZEL-MEIER

Institute of Mechanics, TU Dortmund University, Dortmund, Germany
dilek.guezel@tu-dortmund.de

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The macroscopic response of electrically conductive materials is inherently governed by their microstructural characteristics and the interactions between thermal, electrical, and mechanical fields. Interfaces, such as grain and phase boundaries, play a crucial role in this context, acting as preferential sites for degradation and contributing to the overall electrical resistivity of the material. Analytical homogenisation techniques based on asymptotic expansions and two-scale convergence are employed to derive the governing macroscopic equations for coupled thermo-electrical behaviour. The analysis demonstrates that the effective relations, previously established on physical grounds through Hill–Mandel-type arguments, emerge naturally within the rigorous framework of two-scale convergence, thereby providing a sound theoretical foundation for the macroscopic description of conductive materials [1].

Building upon this computational framework, the formulation is further extended to microstructures containing cohesive-type interfaces, allowing for the investigation of interface-induced anisotropy and size effects within a first-order homogenisation setting. Energetic consistency between the micro- and macroscales is preserved, and the formulation is validated through analytical benchmarks and representative numerical examples [2].

Overall, these developments establish a unified and thermodynamically consistent framework for the multiscale analysis of coupled thermo-electro-mechanical processes in heterogeneous materials. The resulting formulation provides a rigorous basis for analysing the influence of microstructural features and interfaces on the effective behaviour of conductive materials, with potential applications in non-destructive diagnostics and the design of advanced functional conductors.

References

[1] D. Güzel, D. Wiedemann, T. Kaiser and A. Menzel, On dissipative effects in thermo–electrically coupled systems: Hill–Mandel-type homogenisation, asymptotic expansions and two-scale convergence. J. Mech. Phys. Solids, (2026) 208:106427

[2] D. Güzel, T. Kaiser and A. Menzel, A computational multiscale approach towards the modelling of microstructures with material interfaces in electrical conductors. Math. Mech. Solids, (2025) 30(2):247–266

Dr.-Ing. Dilek Güzel-Meier is a Senior Researcher at the Institute of Mechanics, TU Dortmund University. She received her doctorate from TU Dortmund in 2025 for her work on multiscale modelling of thermo-electro-mechanically coupled material behaviour in the group of Prof. Andreas Menzel. She joined the Institute of Mechanics in 2021, following her work as a Research and Teaching Assistant at METU. She holds an MSc in Aerospace Engineering from METU, where she also completed her BSc in 2018. Her research interests include computational homogenisation, two-scale convergence, interface formulations and viscoelasticity, with a focus on multiscale modelling of coupled physical phenomena.