A Numerical Framework to Analyze the Conductivity of 3D Printed Tracks under Mechanical Loading.

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In recent years, the production of lightweight and complex structural parts with embedded electronics and fully encapsulated interconnecting conductive tracks has evolved due to the application of additive manufacturing techniques. Conductive ink formulations with functional nanomaterials are printed using direct writing techniques to create the conductive connections between the electrical components in electronic products [1-2]. The electro-mechanical performance of these printed tracks, typically characterized through their effective resistivity under mechanical loading, strongly depends on the composition of the conductive inks and the microstructure obtained after processing of these inks.

To analyze this functional performance, a framework is presented for the electromechanical analysis of conductive materials that provides insight into the influence of mechanical strains on the formation of cracks and the subsequent increase of resistance in conductive materials. In the proposed multi-physics model, the behavior of the conductive material is described in terms of its mechanical- and electrical response, and an auxiliary crack phase-field variable that accounts for damage development and crack propagation. The phase-field approach to brittle fracture is adopted to model the crack propagation in a diffuse manner as proposed in numerous studies [3-4] before. Existing models are altered and extended for the application to conducting media and the electro-mechanical failure analysis of these materials.

It is assumed that the increase in effective resistivity is a direct consequence of damage, i.e. fracture of the solid microstructure of the conductive medium, which is exclusively caused by the mechanical strains imposed on the body. The accumulated damage then results in direct degradation of the mechanical stiffness and the electric conductivity as a consequence of the increasing mechanical crack openings.

As an input for the model, representative volume elements of the complex microstructure are generated either based on experimental data, from FIB-SEM images & CT scans, or syntactically created based on ink characteristics and process conditions of the printed material.

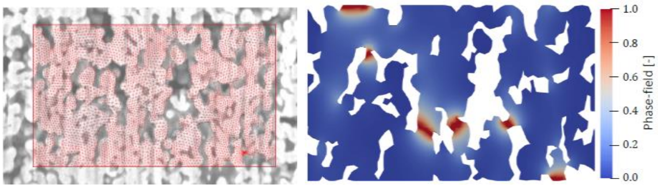

Figure: Left: Geometrical representative example of a porous layer of a 3D printed conductive material. Right: Phase field after loading.

The effective resistivity under mechanical loading is quantified as a representative measure for these conductive tracks. An increase in resistivity is observed, which is caused by crack formation in the track, which is consistent with the trends observed in experiments.

References

[1] Lu, B.-H., Lan, H.-B., & Liu, H.-Z. (2018). Additive manufacturing frontier: 3D printing electronics. Opto-Electronic Advances, 1(1), 17000401–17000410

[2] Maalderink, H.H.H., Bruning, F.B.J., de Schipper, M.M.R., van der Werff, J.J.J., Germs, W.W.C., Remmers, J. J. C., & Meinders, E. R. (2017). 3D Printed structural electronics: embedding and connecting electronic components into freeform electronic devices. Plastics, Rubber and Composites, 47(1), 35–41

[3] De Lorenzis, L., & Gerasimov, T. (2020). Numerical Implementation of Phase-Field Models of Brittle Fracture. Modeling in Engineering Using Innovative Numerical Methods for Solids and Fluids, 75–101.

[4] Miehe, C., Welschinger, F., & Hofacker, M. (2010). A phase field model of electromechanical fracture. Journal of the Mechanics and Physics of Solids, 58(10), 1716–1740.