Data-driven mean-field homogenization for the analysis of composites with a wide range of microstructural features

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Discontinuously reinforced composites, comprising particles or short fibres, represent an important class of engineering materials. Their effective properties are governed by both the intrinsic properties of the constituent phases and key microstructural characteristics, including reinforcement shape, spatial orientation, and distribution. Numerical homogenization methods (full-field approaches) enable the prediction of these effective properties by analysing representative volume elements (RVEs) that capture the composite's heterogeneous microstructure. Among full-field approaches, the most widely used methods rely on the finite element method (FEM) or the fast Fourier transform (FFT) to resolve stress and strain fields. In general, full-field models provide high accuracy and broad modelling capabilities. Nonetheless, in practical applications, numerical homogenization can be highly time-consuming, which limits its applicability. A computationally efficient alternative is offered by mean-field models, such as the Mori–Tanaka method, which generally provide good predictive capability but have certain limitations. In its basic form, the modelling capabilities are limited, among other factors, to the ellipsoidal shape of inclusions, and the accuracy of the results decreases with increasing volume fraction of the reinforcing phase.

To overcome these limitations, a data-driven mean-field homogenization framework is developed by combining the physics-based foundations of the Mori–Tanaka method with data obtained from the full-field simulations [1, 2]. Following the concept presented in [2], the original strain concentration tensor is modified by fitting it to RVE-based data as a function of the volume fraction of inhomogeneities. Results reported in [2], associated with the case of composites reinforced with spherical particles, demonstrate very good agreement with full-field predictions across a wide range of stiffness contrasts and volume fractions. This study aims to extend the model to account for different shapes of the reinforcing phase, including those not captured by analytical solutions. In this case, both the strain concentration tensor and Eshelby's tensor are modified using data-driven corrections. The coefficients associated with the modified tensors are computed using a genetic algorithm. The proposed approach is expected to provide predictions comparable to those of full-field homogenization, while retaining the computational efficiency of mean-field models. During the conference, details of the database generation, the proposed numerical procedures, the obtained results, and future research directions will be presented.

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[1] W. Ogierman, A data-driven model based on the numerical solution of the equivalent inclusion problem for the analysis of nonlinear short-fibre composites, *Compos. Sci. Technol.* 250, 110516, 2024. https://doi.org/10.1016/j.compscitech.2024.110516

[2] W. Ogierman, Data-Driven Mean-Field Homogenization : Enhancing the accuracy of the Mori-Tanaka method, *Compos. Struct*. 358, 118985, 2025. https://doi.org/10.1016/j.compstruct.2025.118985