Physically recurrent neural networks for homogenization of path-dependent heterogeneous materials

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Owing to their high flexibility and potential to reduce computational costs, machine learning techniques are increasingly popular in solid mechanics. These tools are particularly appealing in multiscale methods, such as FE^2, where the computational effort can quickly become prohibitive in practical applications. While several works in the literature showcase speed gains and accurate predictions for bulk homogenization in a wide range of behaviors, the use of surrogate models to predict damage constitutive behavior is a far less explored topic. For such applications, some of the critical limitations in conventional surrogate models have only recently started to be unveiled and addressed.

In [1], we incorporate knowledge of classical constitutive modeling into a neural network for the bulk homogenization of path-dependent heterogeneous materials. The idea is to embed the physics-based material models used in the full-order micromodel inside the data-driven model. For that, the macroscopic strain is encoded into a set of strain vectors for fictitious material points that are evaluated by the material models. The resulting stresses are then decoded in a homogenization-like step to obtain the macroscopic stresses. By keeping track of the internal variables of each material point in the layer in which the material models are introduced, the network can capture path-dependency naturally.

In this work, we present our recent efforts in extending that strategy to also account for microscale damage. Here, a modified architecture is required to incorporate the representation of the cohesive-zone model, which is employed to describe the constitutive behavior in the interface elements. In the new setting, in addition to the bulk material points, we include cohesive zone points mapping displacement jumps to tractions.

Finally, we particularize the proposed approach to model the constitutive behavior of a composite representative volume element with an elastoplastic matrix, elastic fibers, and microcracking modeled by interface elements. The performance of the network is assessed in a set of loading cases with both monotonic and non-monotonic loading.

References

[1] M. A. Maia, I. B. C. M. Rocha, P. Kerfriden and F. P. van der Meer, Physically recurrent neural networks for path-dependent heterogeneous materials: Embedding constitutive models in a data-driven surrogate, arXiv:2209.07320 (2022)