COMPARING ACCELERATION TECHNIQUES FOR FE^2: CLASSIC MESOSCALE MODELING, BLACK-BOX DATA-DRIVEN MODELING AND PHYSICS-INFORMED HYPER-REDUCTION

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Fiber-reinforced composites are intrinsically multiscale material systems. In their characterization, most of the experimental effort is concentrated at the mesoscale. Modeling the material at ply level is therefore a popular approach. State-of-the-art mesoscale models take into account plastic strains that give rise to the nonlinear shear behavior observed experimentally. However, mesomodels often struggle to represent stress combinations not covered during calibration and cannot incorporate new information without being reformulated from scratch. Alternatively, material behavior can be upscaled by embedding a micromodel in each mesoscopic integration point (FE^2 approach). However, the computational cost of FE^2 quickly becomes prohibitive: at each iteration of each analysis step, a nonlinear micromodel must be solved at each mesoscopic integration point, making the technique unsuitable for practical use.

A number of strategies can be used to improve the computational efficiency of FE^2 without giving up on the constitutive generality provided by the method. One popular approach consists in reducing the complexity of micromodel computations through structure-preserving Model Order Reduction (MOR): a series of full-order solution snapshots is used to find reduced-order solution manifolds for both displacements and internal forces, with *online* predictions being obtained by projecting the original problem on these manifolds. Another popular strategy consists in abandoning physics-based models in favor of purely data-driven alternatives, for instance by training an Artificial Neural Network (ANN) to provide a surrogate mapping between strains and stresses at the mesoscale.

In this work ([1]), these three alternatives to FE^2 — artificial neural networks, hyper-reduced micromodels and a state-of-the-art mesomodel ([2]) — are compared in terms of accuracy, efficiency and calibration effort. The models are trained on data obtained from a micromodel with linear-elastic glass fibers and an epoxy resin with pressure-dependent plasticity. After training, the surrogates are assessed on their ability to represent stress states not covered during training and on how well new constitutive information can be incorporated through retraining.

References

[1] Rocha, I.B.C.M.; Kerfriden, P. and van der Meer, F. P. (2020). Micromechanics-based surrogate models for the response of composites: A critical comparison between a classical mesoscale constitutive model, hyper-reduction and neural networks, *Eur J Mech A Solids* **82**:103995.

[2] Vogler, M.; Rolfer, R. and Camanho, P. P. (2013). Modeling the inelastic deformation and fracture of polymer composites - Part I: plasticity model. *Mech Mater* **59**:50-64.