Reduced-order modeling and nonlinear homogenization

Pierre M. Suquet*, Jean-Claude. Michel*,

* Aix Marseille Univ, CNRS, Centrale Marseille,
Laboratoire de Mécanique et d'Acoustique
4 impasse Nikola Tesla, CS 40006, F-13453 Marseille Cedex 13 - France
e-mail: [suquet,michel]@lma.cnrs-mrs.fr

ABSTRACT

A common engineering practice in the analysis of composite (or polycrystalline) structures is to use *effective* or *homogenized* material properties instead of taking into account all details of the individual phase properties. Unfortunately when the individual constituents are nonlinear, the exact description of the effective constitutive relations requires the determination of the local fields (at the microscopic scale). For structural computations, the consequence of this theoretical result is that the two levels of computation, the level of the structure and the level of the unit-cell, remain intimately coupled. The nested resolution of these coupled problems (known as FE^2 analysis) is so far limited by their formidable size.

It is therefore quite natural to resort to *model-reduction techniques* achieving a compromise between analytical approaches, which are costless but often very limited by nonlinearity, and full-field simulations which resolve all complex details of the exact solutions, but come at a very high cost.

The reduced-order model considered in the present study is the Nonuniform Transformation Field Analysis ([1][2]). It proceeds in two steps. First a basis of modes for the microscopic plastic strain fields is generated from full-field simulations. In a second step, evolution equations for the amplitudes of the fields on the modes are derived. Without any further simplification these kinetic equations still require computing local fields. They can be efficiently approximated by using a variational formulation ([3]) and techniques imported from nonlinear homogenization ([4][5]), only requiring "off-line" calculations. It will be demonstrated through a few examples that the second step is the one providing, by far, the most dramatic acceleration.

REFERENCES

[1] Michel JC, P. Suquet, 2003, "Nonuniform Transformation Field Analysis" *Int. J. Solids Structures* **40**, 6937-6955.

[2] Michel JC. and Suquet P., 2004, "Computational analysis of nonlinear composite structures using the Nonuniform Transformation Field Analysis", *Comp. Meth. Appl. Mech. Engrg*. **193**, 5477-5502.

[3] Fritzen F., M. Leuschner, 2013, "Reduced basis hybrid computational homogenization based on a mixed incremental formulation " *Comput. Meth. Appl. Mech. Eng.* **260**, 143–154.

[4] Michel JC. and P. Suquet, 2016, "A model-reduction approach in micromechanics of materials preserving the variational structure of constitutive relations". *J. Mech. Phys. Solids* **90** (2016), 254-285.

[5] Michel JC. and P. Suquet, 2016, "A model-reduction approach to the micromechanical analysis of polycrystalline materials". *Computational Mechanics* **57** (3), 483-508.