Multiscale Simulations of Composites with Non-Local Damage-Enhanced Mean-Field Homogenization

Ling Wu[†], **Ludovic Noels**[†], **Laurent Adam**[‡], **Issam Doghri**[‡,*]

[†]University of Liège, CM3, Chemin des Chevreuils 1, B-4000 Liège, Belgium
L.Wu@ulg.ac.be, L.Noels@ulg.ac.be

[‡]e-Xstream Engineering, Rue du Bosquet, 7, 1348 Louvain-la-Neuve, Belgium
laurent.adam@e-xstream.com

[*]Université Catholique de Louvain, iMMC, Bâtiment Euler
Avenue G. Lemaître 4, 1348 Louvain-la-Neuve, Belgium
issam.doghri@uclouvain.be

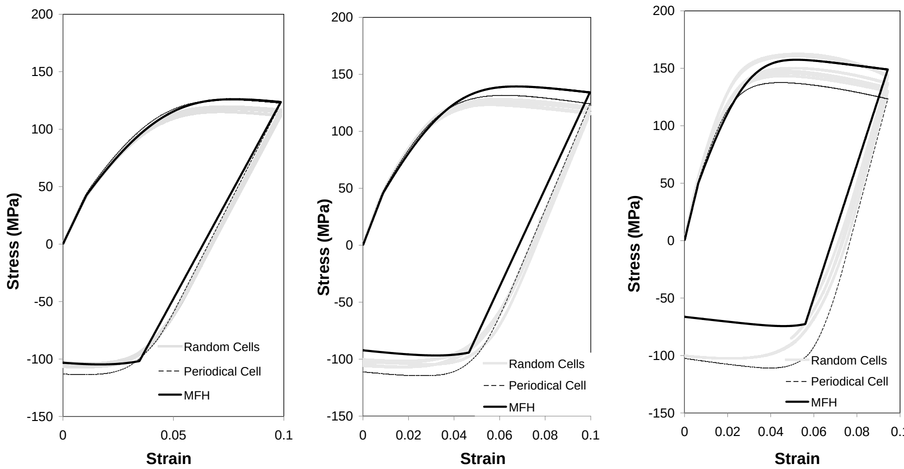
ABSTRACT

The mean-field homogenization (MFH) approach is an attractive framework for multiscale methods, as it provides predictions of the macroscopic behavior of particle or fiber reinforced composites at a reasonable computational cost. Efficient MFH methods have been available for a long time for linear elastic problems, using for example the Mori-Tanaka scheme [2], but they can also be extended in the non-linear regime after linearization of the constitutive behavior at the current strain state, as for the incremental approach, e.g. [1].

In this work, the application of ductile-damage theories to a multiscale analysis of continuous fiber reinforced composites is considered. Toward this end, the incremental MFH approach is extended to account for the damage behavior happening in the matrix material at the micro-scale and to derive the effective properties of particle or fiber reinforced composites.

However, capturing the degradation, damage or failure of material happening at the micro-scopic scale could lead to loss of uniqueness in the solution as the governing partial differential equations may lose ellipticity at a given level of loading corresponding to the strain-softening onset. Thus, in order to avoid the strain/damage localization caused by matrix material softening, the gradient-enhanced formulation [3] is adopted to describe the material behavior of the matrix during the homogenization process, as we have recently proposed [4].

As illustration, the behavior of a fiber re-enforced elasto-plastic matrix is considered. The properties of the matrix correspond to an elasto-plastic material experiencing damage, with a non-local form of Lemaitre Chaboche model. The fibers are assumed linear elastic, see [4] for details. A loading-unloading cycle is applied in the direction transverse to the fibers. A maximal deformation of 10 % is reached before the unloading proceeds to zero-transverse deformation. The effective behavior predicted by the MFH models is compared to the solutions obtained by finite element computations performed on a unit periodic cell and on RVE where the micro-structure is fully meshed. The results for three fiber volume ratios are presented in Fig. 1. For the three fiber volume ratios, the homogenized property is dominated by the properties of the matrix, with an obvious elasto-plastic behavior exhibiting softening. For $v_{\mathrm{I}} = 15\%$ and 30%, rather good predictions are given by the MFH model, with, as



(a) $v_{\mathrm{I}} = 0.15$ (b) $v_{\mathrm{I}} = 0.30$ (c) $v_{\mathrm{I}} = 0.50$

Figure 1: Stress-strain behavior of the epoxy fiber reinforced composite, for different fiber volume ratios v_{I}, under transverse loading.

expected, higher macroscopic stress and damage predicted by the MFH due to the incremental formulation. However for $v_{\mathrm{I}} = 50\%$, the MFH model overestimates the macroscopic stress considerably. This error comes from the assumption of Mori - Tanaka based MFH.

As it is shown to be an efficient multi-scale approach, the developed gradient enhanced MFH formulation presented can now be used to model the behavior of composite laminates experiencing damage.

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