Multi-scale homogenization of patterning mechanical metamaterials

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ABSTRACT

Mechanical metamaterials are generally multi-scale ‘designed’ materials, whereby the microstructure entails emergent unconventional effective engineering properties. Nowadays, remarkably complex mechanistic responses can be achieved, e.g. converting compression to twist, or converting progressive instabilities into motion. Mechanical metamaterials do not trivially satisfy the classical scale separation principle that underlies conventional homogenization strategies. Upon loading, these microstructures develop fine scale fluctuation patterns that directly influence the coarse scale behaviour. These emerging patterns reveal long range order in the microstructure. This behaviour has a pronounced twofold influence on the macro-scale mechanical response: (i) the coarse scale behaviour no longer depends on the average deformation and stress state only; (ii) strong size effects emerge, since boundary conditions may significantly constrain the developing patterns.

This contribution presents a micromorphic homogenization framework for mechanical materials exhibiting such multiple geometric pattern transformations [1]. Cellular elastomeric materials typically reveal these mechanisms as the result of local microstructural instabilities. Multiple pattern transformations may emerge as the result of the applied load (e.g. compression in two orthogonal directions). A micromorphic computational homogenization framework [2] is here presented, which is extended in order to capture multiple pattern transformations, either in space or in time. The proposed solution ansatz consists of a smooth part, an uncorrelated micro-fluctuation field and multiple spatially correlated fluctuating fields. These correlated fields are determined from the computed bifurcation models, whereby their amplitudes constitute a (phase) field variable in the micromorphic continuum at the coarse scale. An example will be presented, revealing three distinct geometric patterns, including the experimentally observed flower-like pattern observed for these microstructures. It will be shown that the homogenization approach adequately captures the full-scale solution. Moreover, size effects due to constrained boundary layers and loading cases resulting in mixed modes in space and time are also studied, again compared with full-scale reference numerical simulations.

Acknowledgement: The research leading to these results has received funding from the European Research Council under the European Union’s Seventh Framework Programme (FP7/2007-2013) / ERC grant agreement no [339392].

REFERENCES