Computational design of engineering materials: an integrated approach for multi-scale topological structural optimization

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ABSTRACT

Multiscale topological material design, aiming at obtaining optimal distribution of the material at several scales in structural materials is still a challenge. In this case, the cost function to be minimized is placed at the macro-scale (compliance function) [1], but the design variables (material distribution) lie at both the macro-scale and the micro-scale [2]. The large number of involved design variables and the multi-scale character of the analysis, resulting into a multiplicative cost of the optimization process, often make such approaches prohibitive, even if in 2D cases.

In this work, an integrated approach for multi-scale topological design of structural linear materials is proposed. The approach features the following properties:

- The “topological derivative” is considered the basic mathematical tool to be used for the purposes of determining the sensitivity of the cost function to material removal [3]. In conjunction with a level-set-based “algorithm” [4] it provides a robust and well-founded setting for material distribution optimization [5].
- The computational cost associated to the multiscale optimization problem is dramatically reduced by resorting to the concept of the online/offline decomposition of the computations. A “*Computational Vademecum*” containing the micro-scale solution for the topological optimization problem in a RVE for a large number of discrete macroscopic stress-states, is used for solving that problem by simple consultation.
- Coupling of the optimization problem at both scales is solved by a simple iterative “fixed-point” scheme, which is found to be robust and convergent.
- The proposed technique is enriched by the concept of “manufacturability”, i.e.: obtaining sub-optimal solutions of the original problems displaying homogeneous material over finite sizes domains at the macrostructure: the “structural components”.

The approach is tested by application to some engineering examples, involving minimum compliance design of material and structure topologies, which show the capabilities of the proposed framework.

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