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MULTI-SCALE DESIGN OPTIMIZATION

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ABSTRACT

Multi-scale modeling, discretizations and simulation has been an interesting research area for years. It promotes new computational technique development and deeps understanding of material characterization, transport mechanism in porous media and other physical phenomena.

In multi-scale simulation and design optimization, physical laws in different scales can be different for different scales. Numerous research papers on the subject can be seen in literatures. For tutorial on the subject readers are refereed to Park and Liu(2004). In the present work, we limit our study for the problems that continuum mechanics is applied at all scales. Such problems exist widely in sciences and engineering. Typical examples are dam structure made of concrete, ultra-light structure made of truss-like material if behaviors in both structural scale and material scale are interested. Many bio-material and bio-structures are also excellent examples. Study on multi-scale modeling, discretizations and simulation deeps understanding of physical phenomena and provides possibility to study influence of geometric or/and physical parameters at different scale on the structural behaviors. This in turn naturally leads to the desire of multi-scale design optimization.

From its very beginning, structural topology optimization is formulated as material distribution optimization in a given design domain (Bendsoe and Kikuchi, 1988). Material micro-structure parameters are optimized in order to find optimum structural topology. Inverse homogenization generated a number of material micro-structural designs for specific material characteristics (Sigmund, 1994). Multi-scale design optimization and structural topology optimization is closely related. Thus, structural topology optimization approaches will be applied in the present work.

We study optimum design of structures made of material with periodically distributed micro-structure. Both macro homogeneous and inhomogeneous material are considered. Manufacture cost of the macro homogeneous material could be lower. Macro inhomogeneous material needs point-wise varying material composition and very

advanced manufacture techniques, but provides better structural performance. Design variables in different scales which describe topology, shape and size in macro-structure and material micro-structure scales are to be optimized in order to design ultra-light structures. Behavior variables in different scales are governed by different constitutive laws which are obtained by homogenization approach or some averaging process at its lower scale. Objective function and constraint functions depend on design variables in different scales. Design variables in different scales are coupled through sensitivities of behavior variables with respect to design variables in different scales. The mathematical formulation of the optimization problem can be cast into either hierarchical or concurrent formulations. In hierarchical formulation (Rodrigues, 2002; Coelho, 2008), optimization problem is solved scale by scale. It works well on condition that the optimization problems could be decoupled properly. Otherwise the problem has to be solved iteratively. In concurrent formulation(Liu, Cheng, Yan, 2006), design variables in different scales are solved simultaneously. For optimum design of macro homogeneous material, we manage to reduce the number of design variables.

A number of structure design problems with different objectives are presented. They include: minimum compliance design under static mechanical load, maximum natural frequency design subject to a given amount of material constraint, minimum compliance design under static mechanical load and thermal load. Both optimum structural topology and material micro-structural topology are obtained. From the result, several interesting observations are obtained. For example, it is found that Kagome truss-like material often performs the best. Finally, the need for multi-disciplinary optimization methods, which dedicates to multi-scale design optimization is emphasized.

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