Multiscale topology optimization of cellular sandwich and laminated structures

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Keywords: Topology, Optimization, Multiscale, Laminates, Sandwich

Two-scale structural design optimization for the simultaneous design of material and structure, has been a topic of research interest during the last decade. This paper is based on the approach presented in [1] and considers two scales, macro and micro, identified with the design domains of the structure and its material (cellular or composite material), respectively. Structure and material evolve for their optimal layouts as a result of updating the density based design variables such that the global compliance is minimized and a global resource volume constraint is satisfied. Here the class of cellular or composite materials, is restricted to single scale periodic materials, with the unit cell topology locally optimized for the given objective function and constraints. Asymptotic homogenization theory is used to compute equivalent elastic properties at the macroscopic level. The design model may include local constraints for the material microstructure depending on the applications. For instance, some constraints may be related with material manufacture requirements as minimum thicknesses as well as mass transport properties and so forth [2].

The structure design domain is usually discretized using a conforming finite element mesh and then each finite element is associated with a cellular material design region matching a proper global volume fraction or density assumed constant in the element. This type of design model leads in general to a very high number of local problems identified with the material microstructure characterization across the whole structure domain. Eventually, the number of local problems is equal to the number of finite elements discretizing the structure domain. Fortunately, parallel processing techniques may be easily applied to this approach ensuring solutions within reasonable computational times [3].

Although the resulting designs obtained with the described methodology are mechanically very efficient, they are hard to manufacture because the changes in material microstructure occur almost from "point-to-point" over the structural domain. Alternatively, the model described so far may be reformulated assuming that the material microstructure remains equal in a structural region (design element) defined not based on each finite element but from larger sub-regions consistent with manufacture constraints or structural uniformity. Thus, the present work reformulates the multiscale topology optimization presented in [1] to be applied to the design of structures comprised of several sub-regions where each one is identified with an uniform material microstructure. In fact, Industrial applications make effectively use of this type of structures mainly sandwich panels or beams and laminated plates.

Solid and plane finite elements are investigated to model these type of structures post-processing strains and stresses and the quality of the results is evaluated specially in connection with the optimal lay-outs of the material microstructures obtained. Density and fiber angle orientation based design variables are used. Several benchmark case studies are pursued for comparison purposes with classical solutions or other alternative methods. The results will allow one to conclude about the optimality of current designs and new ones suggested by multiscale topology optimization.

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