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On the development of a multiscale topology optimisation tool

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Abstract. *Composite materials are among the most prominent materials today, both in terms of applications and development. Nevertheless, their complex structure and heterogeneous nature lead to difficulties, both in the prediction of its properties and on the achievement of the ideal constituent distributions. The main focus of this work is to show the importance of computational procedures in this sense, namely in terms of the different applications of Asymptotic Expansion Homogenisation (AEH) and its integration in multiscale topology optimisation procedures.*

Keywords: First keyword; second keyword; last keyword.

1 INTRODUCTION

Topology optimisation in structural mechanics consists of searching for the optimal material distribution within a certain admissible domain. This distribution, dependent on density variables, fluctuates between high and low density regions. As a matter of fact, the initial definition of the problem is discrete, in which the variable can only take the values 1 (dense material) or 0 (void or soft phase). Among several others, one of the strategies for relaxing this problem is allowing for the existence of intermediate densities and giving it physical meaning by association with coherent microstructures of cellular or composite material. This approach leads to multiscale procedures and is usually classified as homogenisation method, leading to several different implementations and using a number of alternative methods to deal with the local problem. In this sense, the authors show a multilevel or hierarchical methodology, for both thermoelasticity and heat conduction. The Asymptotic Expansion Homogenisation method is used in the local problem of this application, both in terms of constitutive analysis and sensitivity evaluation. This methodology, due to the clear separation of the problem in two distinct scales, provides a further utility. It is possible to use the inner problem to perform local optimisation. Thus, ideal cellular or composite microstructures can be obtained as an optimal answer to a localised far-field state. This is commonly called the local anisotropic problem or inverse homogenisation method [1].

2 NUMERICAL REMARKS

One of the main aspects of this work is related to several applications of the finite element method (FEM) and specific periodicity boundary conditions. Moreover, the developed computational tool works seamlessly within several alternative modes: (i) macroscale optimisation; (ii) macroscale optimisation with local homogenisation; (iii) local optimisation with macroscale far-field states; (iv) local optimisation with macroscale evaluation; (v) coupled multiscale optimisation; (vi) uncoupled multiscale optimisation.

The most wide-ranging case of the optimisation problems shown here appears in the form of the hierarchical multiscale problem [2]. This has a very high computational cost. Note that it requires two finite element models, each one discretising each scale. Moreover, the computational requirements are worsened from the fact that most of the time consumed in topology optimisation problem solving is spent on the finite element method equation solving. The hierarchical structure needs, for each iteration, several FEM solutions. On the one hand, the macroscale equilibrium problem. On the other hand, for each point on the macroscale (often an average for each finite element), an

asymptotic expansion homogenisation problem is solved over the microscale discretisation. This, in itself, consists of several systems of equations to solve. Note that, for a two-dimensional problem, the elasticity problem requires three systems of equations, the thermal expansion one more and the thermal problem a further two. For the three-dimensional case, these values become six, one and three, respectively. Another aspect of these local problems, including the local approach, is related to conditioning problems, since the penalty method used here to enforce periodicity boundary conditions tends to unbalance the equations and to slow the convergence of the solver. All of this led to the building and configuration of a parallel processing platform, a Beowulf cluster [3].

3 RESULTS

In the scope of this work, the authors show some representative examples. First of all, a macroscale optimisation benchmark is presented. In this case, a mechanical (compliance) objective and a thermal (conductivity) objective are pondered on a multiobjective problem. Different applications and levels of multiscale optimisation follow. The next example features inverse homogenisation, showing the optimal microstructures for several mechanical and thermal problems, with macroscopic far-field strains and heat fluxes. The next examples use a hierarchical structure. In this case, for each iteration, a multiscale problem is solved. The global problem is solved on the macroscale, using constitutive information taken from the microscale. This problem leads to a strain field that can be used in different forms to control the microscale problem. In this first case, the strain field is averaged and pondered using the equivalent strain over the macroscale in a simplified hierarchical structure. All the macroscale is made of the same material, which constituent distribution is updated with the evolution of both the optimisation procedure and the macroscopic strain field, resulting from a simultaneous bending and torsion test. A second problem shows a general case of the hierarchical procedure, with concurrent optimisation of the material distribution over the two scales. Figure 1 shows one of the solutions, where a typical 2-D bicycle wheel mechanical optimisation problem is solved along with a thermal problem, for a multiobjective strategy. In this case, the weight of the thermal problem is $w_t = 0.5$. Some of the local problem solutions are also presented, giving the notion of effective material distribution, as well as the shear dimension of the problem, even for a 2-D case. Furthermore, some 3-D multiscale cases are also presented.

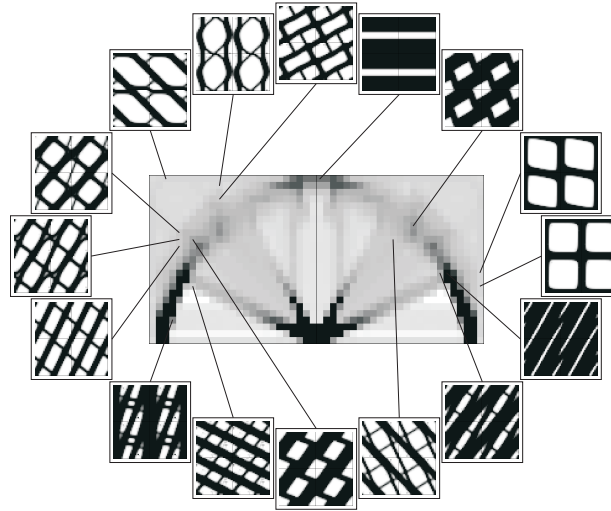


Figure 1: Hierarchical multiobjective (mechanical and thermal) 2-D example ($w_t = 0.5$), showing the macroscale density distribution and some local material distributions.

4 FINAL REMARKS

The usage of homogenisation procedures in topology optimisation problems is shown to be varied, ranging from local to hierarchical optimisation. The capability to solve a large variety of problem configurations makes the presented software a useful tool for structural engineering applications.

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