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Shape and Topology Optimization of Architectured Materials: From the Design to Real Structures

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Shape and topology optimization of architectured materials: from the design to real structures

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Shape optimization methods are promising methods and are gradually becoming industrialized. They provide the ability to automatically design structures with optimal behavior. They are outstanding tools for exploration and design of new materials and in particular architectured materials which are expected to “fill the holes” in the materials space [1]. We first present example of design of microstructures that target extreme thermos-mechanical properties with account of graded interfaces within an optimization framework with a level sets description on the constitutive phases and their interfaces [2, 3]. We use these methods to generate architectured multi-phased materials with prescribed thermoelastic properties. We first propose several solutions and we classify them by the mechanisms they rely on in order to control the effective properties (see Fig. 1). We also propose to evaluate the influence of an interface with a gradient of properties on the obtained architectures. The predicted designs are not aimed to be fabricated in a straightforward from optimization results to STL file and operating Fabrication. Instead, these optimization predictions are used to understand the governing mechanisms underlying the extreme properties to gain insight on these basics for a simplified construction. Thus, a level-set based shape and topology optimization framework is used to investigate the influence of graded interfaces in the optimization of micro-architectured multimaterials. In contrast to other studies usually found in the literature, interfaces are considered as smooth and graded transitions between constitutive phases instead of sharp delimitations. Case studies for extreme thermoelastic properties of 2D isotropic composites are analyzed and optimal designs are presented. It is shown that by explicitly accounting for interfaces can influence the design of heterogeneous materials in composite microstructures.

In a second part, we focus on the plausible manufacturing solution to process the architectured materials. In this context, additive manufacturing methods (often considered as the support of an incoming industrial revolution) is a relevant option. We introduce several strategies to circumvent some limitations and side effects of these manufacturing methods during optimization process. We particularly focus on Fiber Deposition Molding [4], which induce an important mechanical anisotropy in processed parts. Then we consider the problem of overhangings features in design and propose a way to handle them prior to additive manufacturing using a mechanical criterion [5]. In aprticular, we present a contribution to the modelling of the effective properties of the constituent material of structures fabricated by additive manufacturing technologies, and of how they influence the design optimization process (see Fig. 2). On the one hand, emphasizing on the case where the particular material extrusion techniques are used, we propose a model for the anisotropic material properties of shapes depending on the (user-defined) trajectory followed by the machine tool during the assembly of each of their 2d layers. On the other hand, we take advantage of the potential of additive manufacturing technologies for constructing very small features, and we consider the optimization of the infill region of shapes with the goal to improve at the same time their lightness and robustness. The optimized and constraint functionals of the domain involved in the shape optimization problems in these two contexts are rigorously analyzed, notably by relying on the notion of signed distance function. Eventually, several numerical experiments are conducted in two dimensions to illustrate the main points of the study

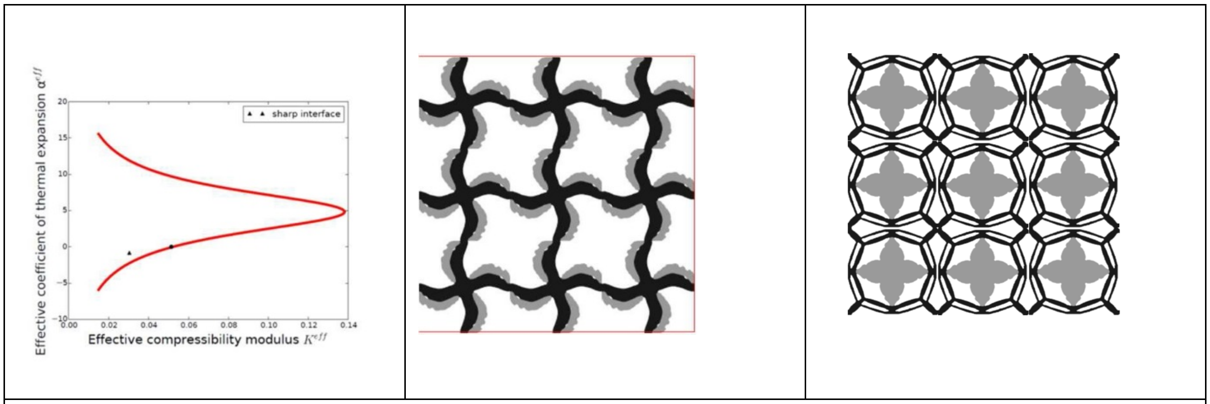

Figure 1: on the left, optimum bound established by [6] the an effective isotropic material made of two constitutive phases and void, two predicted microstructure able to have a zero c.t.e with a threshold Young modules with two different operating mechanisms, a double strip one (centre) and a local

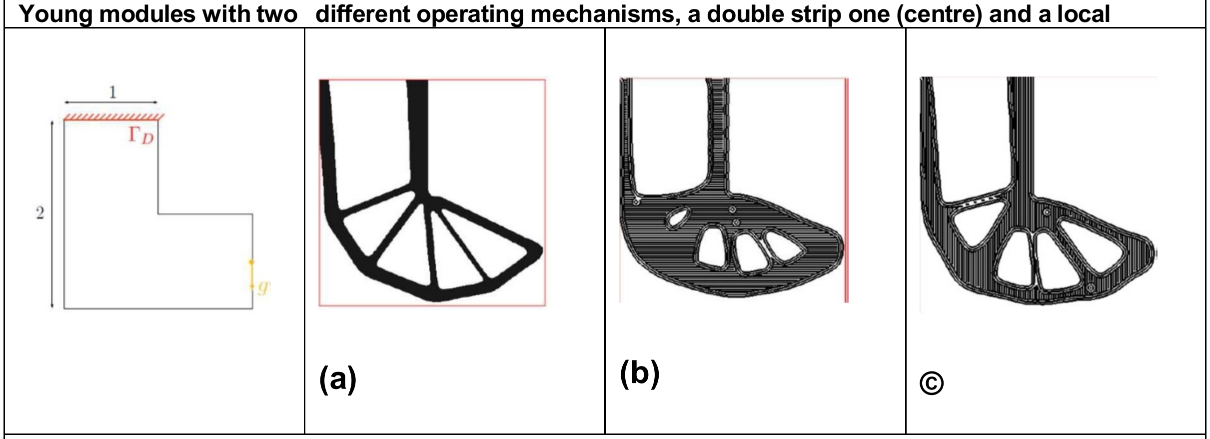

Figure 2: case study og the L-beam and (a) optimal design in the case of a homogeneous bulk, (b) fabrication with crust of horizontal fiber infill, (c) crust and vertically oriented fiber infill

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