Design of homogenized microstructures using stress–based topology optimization

Maxime Collet *[1], Matteo Bruggi[2], Lise Noël[3], Simon Bauduin[4], and Pierre Duysinx[5]
[1,3,4,5]*Aerospace and Mechanical Engineering Department, University of Liège, Liège, Belgium*
[2]*Department of Civil and Environmental Engineering, Politecnico di Milano, Milan, Italy*

Summary This paper aims at designing microstructures using stress-based topology optimization. Most of the developments so far have been made for compliance design in various field of applications as reflected in the literature. The emergence of the new additive manufacturing techniques allows to consider porous material, such as lattice structures for instance, which ca be used for the design of structural components subject to various solicitations. Those components must account for the stress level to prevent failure everywhere in the microstructures and by extension the whole structure itself. This work proposes to design such microstructures using topology optimization with limitation on the stress level within the microstructures before printing the result. The homogenization technique is used to determine the equivalent material properties. The issues and perspectives are also discussed.

ABSTRACT

Topology optimization aims at giving the optimal distribution of the material within a design domain, enabling to place the material where it is the most efficient while staying with void in less effective regions. Problems based on the discrete valued approach (0-1) of the optimal distribution of material are difficult to solve numerically but they are also ill-posed exhibiting convergence issues. To overcome this difficulty, Bendsøe and Kikuchi [2] proposed to relax the problem by introducing porous material, made of an infinite number of holes, whose effective properties can be computed thanks to the homogenization techniques, see e.g. Hassani and Hinton [4, 5, 6]. Even if the numerical solution of the problems is tractable, the manufacturability of the optimized design based on classic machine tooling techniques is not straightforward. Thus clear designs, i.e. nearly black-and-white designs, can be enforced by introducing a penalization of intermediate densities. To this end, a successful approach is the famous SIMP approach as proposed in Bendsøe. [3]. However nowadays, thanks to the emergence and the effectiveness of the novel additive manufacturing techniques, structures including regions made of porous microstructures are now becoming possible to fabricate and topology optimization using homogenization methods receive a revived interest as attested by recent works of Andreassen et al [1] and Xia [8]. The practical applications of these designs including microstructures is motivated by the great performances that can be achieved compared to classical solutions of topology optimization.

In this work, a stress based–topology optimization procedure is considered along with the homogenization technique for the computation of the equivalent material properties of the porous material. Most of the contributions dealing with the design of porous material are indeed focused on compliance minimization in a wide variety of applications. The design using stress–based topology optimization is however gaining in interest, as pointed out by Le et al [7], and it has become critically important to account for the strength of the microstrucutres and not only their stiffness. To this end, we investigate here the problem of bounding the stress level within microstructures, problem that has not been much considered so far, to the author knowledge. The design problem is to find the optimal material distribution within the periodic base cell subject to prescribed macro strains and bounded stress criterion everywhere in the microstructure and *de facto* ensure the structural intregrity of the whole component.

The adopted approach continues along the work developed by the authors. The SIMP approach is adopted while a sequential convex programming approach using MMA is used to solve the optimization problems. The paper discusses the design problem formulation as well as the choice of the considered failure criterion (von Mises, principal stresses, etc) while solving numerical applications. The numerical procedure is at first validated against some analytical results proposed by Vigdergauz [9, 10] for a single inclusion before investigating more complex loading conditions. Design obtained with pure stress–based topology optimization is compared to a formulation embedding both stress constraints and a global compliance constraint. The former method has proven to exhibit better numerical performances, i.e. reduced CPU time . The work focuses also on an efficient and accurate way to measure the stress field coming from the solution of the adopted finite element procedure. Numerical issues and perspectives for further works are also discussed.

Finally the optimized designs are fabricated using a multimaterial inkjet polymer printer (Connex by Stratasys) to assess the actual performance of the optimized designs compared to more conventional results such as compliance–based designs.

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*Corresponding author. Email: maxime.collet@ulg.ac.be

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