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# Stress constrained topology optimization for additive manufacturing: Specific character and solution aspects

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Since the fundamental work by Bendsøe and Kikuchi [3], topology optimization has been based on compliance type formulations [4] while the number of works considering stress constraints are rather limited [6]. More recently the generalized shape optimization approach using level set methods (see for instance [1,2]) has followed the tracks of topology optimization and has mainly been focusing on compliance minimization problems.

The 'compliance type' formulation has produced quite interesting results in many problems because controlling the energy and the displacements under the loads is generally favourable for deflection control and because, for one load case, the compliance minimization leads to a fully stressed design nearly everywhere in the structure. However there are theoretical results that clearly show that the strongest and the stiffest structural layout can be quite different. As demonstrated in Ref. [8] truss topology optimization can lead to different results when there are several load cases, different stress limits in tension and compression, or when there are several materials involved.

Therefore, the first goal of the paper points out the importance of considering stress constraints as soon as the preliminary design phase, that is, to include stress constraints in the topology optimization problem. Revisiting some contributions of the authors, this paper aims at illustrating the key role of stress constraints in the framework of topology optimization of continuum structures. The recent developments are able to treat:

- Integrated stress criteria (i.e. global) relaxed stress constraints that aggregate the stress constraints in each finite element in order to be able to circumvent the large scale character of the local stress constraints.
- Stress criteria that are able to tackle non equal stress limits in tension and compression. The usual von Mises criterion is unable to predict real-life designs when the structure is made of materials with unequal stress limits like concrete or composite materials. These different behaviours in tension and compression result in quite specific designs.

Numerical applications make possible to point out the different nature of structural lay out for maximum strength and maximum stiffness. This one is clearly demonstrated in two kinds of particular situations: once several load cases are considered and when unequal stress limits in tension and compression are involved.

The second contribution of the paper deals with the solution aspects of large scale constrained optimization problems. Because of the huge number of design variables, dual methods combined with local convex approximations such as CONLIN [7] or MMA [10] are well indicated to solve classical topology optimization methods. However stress constrained problems introduce also a so large number of active constraints that one comes to a rather delicate situation. We show that the optimizer effort increases mostly as the cube of the number of constraints. In order to circumvent the problem, the idea developed in the paper is to combine first or second order approximations [5] with zero order approximations of stress constraints, especially for the subset of restrictions that are likely not to be active or not to change too fast. At first the paper presents the way to derive zero-order approximations of ε-relaxed stress constraints (that is necessary to cope with the singularity phenomenon of stress constraints in topology optimization). Then the proposed hybrid approach mixing approximation of different orders is benchmarked on numerical applications illustrating the reduction of computation time for solving optimization problems without sacrifying to the robustness and efficiency.

Numerical applications will investigate topology optimized benchmark examples combined with additive manufacturing fabrication to illustrate the developments.

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