Length Scale Control and Building Orientation in Topology Optimization for Additive Manufacturing

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ABSTRACT

Additive manufacturing (AM) and topology optimization have allowed a significant progress in the development of highly efficient and lightweight components. However, there are still some technological limitations to account for which prevent the direct link between topology optimization and AM. The goal of this research conducted during the research project AERO+ sponsored by Walloon Region, is to consider manufacturing constraints as soon as the early stage of the design, i.e. during topology optimization, to propose optimized designs that are close to be ready for additive manufacturing, or at least involve a minimum amount of modification.

In this context, length scale control has been an active topic of research as it encompasses a wide variety of manufacturing constraints. In the first part of this work, we focus on the maximum size constraint, which introduces void regions into massive zones to prevent the formation of structural features that are thicker than a prescribed size. The formulation does not control the geometry of the introduced cavities which could bring difficulties to manufacturing. For instance, the constraint tends to place structural members with a small separation distance between them, and to significantly increase the amount of closed cavities in the optimized design (Fig. 1). In this work we present two strategies to control the geometry of the cavities in a maximum-size-constrained problem. The first one is based on the robust design approach based on eroded, intermediate and dilated projections. It is shown that restricting the maximum size on all three projections effectively enforces the minimum length scale of the void phase on the blueprint design (Fig. 2). The second strategy is based on the maximum size formulation. It is a constraint that introduces large void regions into massive zones to increase the separation distance between solid members generated by the maximum size constraint. Examples, including both 2D and 3D design domains, indicate that the proposed approaches significantly reduce the quantity of closed cavities and increases the minimum size of those remaining (Fig. 3). By reducing the complexity of the design, those contributions may facilitate manufacturability of maximum-size constrained components.

The overhang limitation of AM has been another topic of interest in topology optimization. Several authors have recently proposed methods to avoid the overhanging features in the optimized design. Most of them operate with a user-defined building direction, thus, if the selected orientation is not appropriate, structural performance could be drastically compromised. In the second part of this work we present a gradient-based overhang constraint that intends to follow the best printing direction during the optimization process. The main idea is to evaluate printability for different user-defined building orientations. The least penalizing overhang-constraint is added in the topology optimization problem using aggregation functions. Due to the local nature of the formulation, the method is easily parallelizable and of low computational cost. The method is evaluated on 2D and 3D test cases.

Fig. 1: Maximum-size-constrained design.

Fig. 2: Maximum and two-phase minimum size control.

Fig. 3: Maximum / minimum size control and separation distance.