

A MULTI-MATERIAL TOPOLOGY OPTIMIZATION FRAMEWORK BASED ON UNCONSTRAINED MATERIAL VOLUME FRACTIONS

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Abstract

The design of lightweight structures is of the utmost importance in aircraft design. Reducing structural mass directly translates into lower fuel consumption, increased range, and improved overall performance. Over the past decades, Topology Optimization (TO) has been employed in such design challenges by solving an optimal material redistribution problem for a given structure. More recently, Multi-Material Topology Optimization (MMTO), an extension of TO to multiple materials, has expanded the design space and enabled the development of novel designs that combine materials with distinct mechanical properties. However, conventional TO and MMTO formulations are based on material redistribution problems in which the allowable volume is prescribed by the user and held constant throughout the optimization, rather than being determined as part of the design process. This study presents a MMTO framework that removes the requirement for user-prescribed per-material volume fractions, thereby allowing the optimizer to determine which material combinations to use and their relative proportions. The framework is built upon the density-based approach, employing a mapping-based multi-material interpolation function and the Method of Moving Asymptotes (MMA) as the optimization algorithm. The objective is to minimize the mass of a cantilevered beam subject to a static load at its free end. To ensure structurally feasible designs, a stress-based constraint is imposed, allowing the optimal layout to depend primarily on the material properties, loading, and boundary conditions. This formulation constitutes a shift from an optimal material redistribution problem to optimal material distribution, in which the structural volume is no longer fixed a priori. Numerical studies on a three-dimensional beam are conducted to evaluate the proposed framework and to show the impact of free material selection by the optimizer. In addition, multi-material layouts are compared to single-material ones. To assess the practical feasibility of the optimized structures, the resulting topologies are converted into a printable format and manufactured using Multi-

Material Additive Manufacturing (MMAM) techniques. Experimental validation of the computational topologies will be addressed in future work. Preliminary results indicate that the proposed methodology produces load-carrying connected domains while achieving mass reductions, highlighting its potential for the design of lightweight aircraft structural components.