Macroscopic optimization of porosity distribution using Thermodynamic Topology Optimization

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Abstract

Functionally graded materials may vary in their local physical properties (structural, mechanical, thermal, electrical...) and thus open up new challenges for the optimization of technical components.

This gradation is usually achieved by manipulating the microstructure to achieve the desired properties. One of the possible ways is by varying the porosity distribution in the material. Thus, we can achieve similar structure as in bones, with a solid hard outer surface and a spongiform structure inside. Porous materials can be very light with relatively low moment of inertia and exhibit good resistance to dynamic stresses and advantageous damping properties.

Determining the optimal porosity distribution is often not trivial, meaning a dedicated optimization method needs to be developed. It seems sensible to extend the existing topology optimization algorithms and optimize both the geometry and the porosity simultaneously.

As a basis we are using the Thermodynamic Topology Optimization (TTO), derived from the Hamilton principle, which in its most basic form maximizes the stiffness under a maximal volume constraint, evolving the density variable towards a (local) optimum.

Introducing a new design variable and extending the TTO, we're able to optimize the porosity distribution within a given range in non-void regions of the topology optimization depending on local strains. Modifying the material model, based on the standard SIMP (Solid Isotropic Material with Penalization) approach, we define a metamaterial, whose stiffness changes depending on the local porosity. The density and porosity variables are coupled through the maximal volume or cost constraint, and new evolution equations for both design variables are derived. In the search for ideal numerical parameters, a parameter study has been performed, identifying the best values for a stable convergence. To obtain reasonable results, further adjustments to the optimization have been made, delaying the density evolution after a first graded porosity distribution has formed.

Obtained results show an optimized bone-like structure with low (or no) porosity in areas where forces are applied and on the outer surface of the component, with continuously increasing porosity towards the inner areas of the component.

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