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Topology optimization for thermal problems including design-dependent heat convection loads

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ABSTRACT

Topology optimization [1] is considered the most flexible structural optimization method because it allows changes in topology as well as shape, and most studies focus on structural problems such as stiffness maximization. Thermal problems have mainly been discussed in terms of their application in the construction of a basic optimization theory using a homogenization method [2], due to their relatively simple constitutive equations. Topology optimization methods based on the SIMP method [3,4] have recently been proposed for actual heat transfer engineering problems, however due to the inabillity to precisely define structural boundaries in the fixed design domain, boundary conditons such as heat transfer boundry contitions, which should be set on the structual boundaries, can not be defined for the usual topology optimizaiton methods.

To overcome the above isuees, Chen and Kikuchi[5], and Sigmund and Causen[6] proposed a mixed displacement-pressure formulation for structural problems, but this has not been applied to thermal problems. Yoo et al., proposed the Element Connectivity Parameterization method [7], but this leads to theoretical inconsistencies with continuum mechanics. Bruns[8] proposed a way to extract the structual boundaries for thermal problems, but this does not consider the shape dependencies with respect to heat transfer coeffients.

In this paper, a topology optimization method is constructed for thermal problems with generic heat transfer boundaries in a fixed design domain that includes design-dependent effects. First, the topology optimization method for thermal problems is briefly explained using a homogenization method for the relaxation of the design domain, where a continuous material distribution is assumed, to suppress numerical instabilities and checkerboards. Next, a method is developed for handling heat transfer boundaries between material and void regions that appear in the fixed design domain and move during the optimization process, using the Heaviside function as a function of node-based material density to extract the boundary of the target structure being optimized so that the heat transfer boundary conditions can be set. Shape dependencies concerning heat transfer coefficients are also considered in the topology optimization scheme. The optimization problem is formulated using the concept of total potential

energy and an optimization algorithm is constructed using the Finite Element Method and Sequential Linear Programming. Finally, several numerical examples are presented to confirm the usefulness of the proposed method. The conclusions of our paper are as follows.

(1) The homogenization design method was expanded to thermal problems, in which a continuous material distribution is assumed using C^0 continuous interpolation functions in the fixed design domain.

(2) The maximization problem for the thermal diffusivity was formulated using an objective function of total potential energy that can be treated as a maximization problem for both Neumann and Dirichlet type boundary conditions.

(3) An optimization problem was constructed based on the above objective function and sequential linear programming.

(4) Design-dependent loads such heat convection loads were formulated using material density in elements and the Heaviside function, to extract the boundary of the structure being optimized in order to set heat convection boundary conditions.

(5) Several examples were provided to examine the characteristic of the optimal configurations for typical thermal boundary conditions, and the results were free of checkerboards in all examples, confirming the usefulness of the proposed method.

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