A METHOD FOR CONTINUOUS APPROXIMATION OF MATERIAL DISTRIBUTION FOR TOPOLOGY OPTIMIZAITON, AND ITS APPLICATION TO COMPLIANT MECHANISM DESIGNS

K. Matsui[a], **K. Terada**[b], **A. Hosoyama**[c] and **S. Nishiwaki**[c]

[a]National Institute of Advanced Industrial Science and Technology
1-1-1 Umezono, Tsukuba 305-8568, Japan
kzm-matsui@aist.go.jp

[b] Department of Civil Engineering, Tohoku University

[c]Department of Precision Engineering, Kyoto University

In this paper, we develop a novel topology optimization method based on the mathematical homogenization method for solid structures undergoing finite deformation. Since most of the hyperelastic constitutive models, such as for Mooney-Rivlin materials or Ogden's model, assume isotropic material behavior, the so-called SIMP method seems more suitable than the Homogenization Design Method (HDM) when applied to hyperelastic materials. However, it is a well-known fact that the SIMP method suffers from numerical instabilities leading to the appearance of gray-scale, checkerboards, or strong mesh dependencies. In order to incorporate isotropic hyperelastic materials while avoiding the checkerboards, we introduce a new topology optimization method using material definitions for the topological design of structures that are consistent with the variational formulation for a quasi-static equilibrium problem in the context of the FEM. This methodology does not need any additional constraint parameters or filtering schemes to avoid the instability.

The first issue addressed by this paper, to develop a checkerboard-free topology optimization method considering geometrical nonlinearities, is accomplished by relying on the presented method's conformity with homogenization theory, that is, we assume the continuous change and distribution of materials in a fixed design domain. Although this assumption was introduced by Suzuki and Kikuchi[1], the design variables were approximated by piecewise constants in their FE implementation. This type of discretization means that the design variables can be discontinuous between the elements, leading to the discontinuous distribution of material, appearing as checkerboard patterns and strong dependencies on the mesh properties. The proposed method, however, strictly approximates the continuous distribution of material in the domain for practical element sizes. That is, the continuous distribution of microstructures or, equivalently, design variables, is discretized with finite element interpolations and is realized across the entire design domain in the context of HDM. By virtue of this continuous FE approximation of design variables, discontinuous distributions such as checkerboard patterns disappear without the need to apply any filtering schemes. We call this proposed methodology the Continuous Approximation of Material Distribution (CAMD) method for topology optimization, to emphasize the continuity imposed on the material field.

After developing the CAMD method for the stiffness design problem with hyperelastic materials, the second issue of this paper focuses on the extension of the CAMD method to the design of compliant mechanisms. We first develop strategies for the design of compliant mechanisms in the context of linear elasticity using the CAMD method, and then extend them to geometrical nonlinear problems using a new type of multi-objective function different from linear cases. Some representative numerical examples are presented to demonstrate the capability and efficiency of the proposed method in preventing numerical instabilities for the simplest optimization problem, that is the stiffness design of structures, and show that we obtain novel optimal configurations of compliant mechanisms by considering geometrical nonlinearity effects in cases where large deformations provide essential functions for the mechanisms.

References

[1] K. Suzuki and N. Kikuchi, “A homogenization method for shape and topology optimization”, *Comput. Methods Appl. Mech. Engrg.*, Vol.93, pp.291–318, 1991.