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Multi-Material Topology Optimization of Structures Using Peridynamics

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Abstract
This study presents a multi-material topology optimization based on Peridynamics (PD). The conventional topology optimization mainly used a mesh-based numerical method, i.e., Finite Element (FE) method. Moving boundaries, large deformations, and cracks/damages are some limitations of the mesh-based numerical method. In this study, PD as a meshless method is proposed to employ in the topology optimization to remove limitations of the mesh-based topology optimization. The minimization of compliance, i.e., strain energy, is chosen as the objective function subjected to the volume constraint. The design variables are the relative density of the candidate materials defined at particles employing gradient based optimization approach. A filtering scheme is also adopted to avoid the checkerboard issue and maintain the optimization stability. The proposed approach is an alternative and powerful tool for multiple additive manufacturing in finding multi material optimal topologies of the structures with embedded crack.

Introduction
Topology optimization provides the most potential design space among the structural optimization methods. Topology optimization finds an optimal material layout within a predefined design domain to maximize or minimize given objectives while satisfying design constraints. Most of these optimization techniques mainly employed a mesh-based numerical method, i.e., Finite Element (FE) method. However, some limitations are encountered when performing the topology optimization analysis using FE method especially for moving boundary problems, large deformations, and crack presence. In recent years, mesh-free methods have received attention to overcome these difficulties. A set of particles can be arbitrarily distributed within the design domain using mesh-free methods. This leads to easily define the design domain using particles without mesh connectivity constraints. Nevertheless, mesh-free methods have been rarely used with the aim of the topology optimization. Peridynamics (PD) theory is another fast-growing meshless approach that is introduced by Silling (Silling, 2000) and Silling et al. (Silling et al., 2007). PD is considered as a nonlocal reformulation of the Classical Continuum Mechanics (CCM) equations. This paper proposes a multi-material topology optimization approach for the design of continuum structures based on PD. The advantage of the proposed method is its utilization for the nonlinear topology optimization problems. The approach is applied to the cracked structures as a nonlinear optimization problem for multiple material topology optimization.

Methods/Model Formulations

The topology optimization problem for the PD method is stated as a minimum strain energy or compliance problem with a material volume constraint as:

$$
\begin{gathered}
min\, C(\boldsymbol{x}) = \frac{1}{2}\boldsymbol{f}^T\boldsymbol{U} \\
such\ that\ \sum_{i=1}^{m} x_i v_i = \bar{V} \\
\sum_{i}^{nm} x_{i,p} = 1;\ \forall\ (p) \\
x_{i,p} \epsilon\ [x_{min}, 1];\ \forall\ (p)
\end{gathered}
\tag{1}
$$

here x_i is the design variables, nm is the number of candidate materials for each particle, $\bar{V}$ is the maximum allowable volume constraint of the specified material and m is the total number of particles. v_i represents the particle volume. C is the mean compliance, $\boldsymbol{f}$ and $\boldsymbol{U}$ are the global force and displacement vectors. The Bi-Evolutionary Structural Optimization (BESO) method is used in this study. Use of a small value for x_{min} instead of 0 avoids removing the particles in the design domain during the optimization process.

Results and Discussions

A cantilever beam is selected to validate the topology optimization approach for single material with a dimension ratio of 2:1. The maximum allowable volume is 50%. The proposed approach is compared with the optimal results of the BESO approach based on the finite element method reported in (Huang and Xie, 2010). It can be seen from Fig. 1 that the current approach predicts very close topology designs compared to the results obtained by FEM. The topology optimization of the multi-material case studies will be presented in the full paper.

PD FEM

Figure 1. Comparison of design space discretization of FEM and PD for 100×50 particles in PD and elements in FEM.

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