Material cloud method for topology optimization

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Summary A newly developed material cloud method (MCM) for topology optimization is presented to overcome some difficulties in traditional density distribution method and improve a numerical efficiency in topology optimization procedure. In MCM, an optimal structure can be found out through modifying sizes and positions of material clouds, which are lumps of material having specified properties. A design concept of MCM is presented and results obtained by MCM are compared with those of density distribution method.

INTRODUCTION

Topology optimization method has been a powerful design tool since first numerical implementation by Bendsoe and Kikuchi [1], due to its capability to find out a wonderful design under no restriction of topology change. Even though topology optimization method has been successfully applied into industrial design so far, it still has some difficulties to efficiently obtain better results. It is thought that these difficulties are mainly caused by its optimization concept. In widely used traditional density distribution method for topology optimization, optimal material distribution is found out through search of material densities in all elements in design domain. It can be computationally inefficient due to inclusion of not few elements having low importance and a capability to find out better design, having material out of initial design domain, may be limited. So far there have been many researches to overcome these difficulties [2-3].But most of these have some inefficiency due to still use of density concept. To overcome some difficulties in traditional density-based method, a material cloud method (MCM) for topology optimization is devised in this paper.

MATERIAL CLOUD METHOD

The material cloud is a lump of material having specified properties with a square shape (Ref. Fig. 1).
In material cloud method (MCM), optimal material distribution can be found out through optimizing central positions and sizes of material clouds (Ref. Fig. 2). Methodologies to apply this MCM into topology optimization are categorized as three. One is to optimize only sizes of material clouds (MCMS). Another is to optimize only positions of material clouds (MCMP). And the third is to sequentially optimize positions and sizes of material clouds (MCMPS).
A numerical analysis for a specific distribution of material clouds is carried out using fixed background finite element mesh (Ref. Fig. 2).
Through applying MCM into topology optimization, several advantages can be obtained against traditional density distribution method (MCM). The first is natural and efficient realization of expansion-reduction procedure of design space, which is needed to increase the possibility to find out better optimal solution. The second is that convergence of material distribution can be faster than that of density-based method. The third is a facility to control a minimum-member size in the final material distribution.

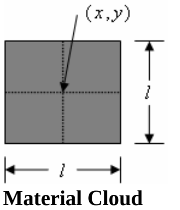


Fig. 1 Material Cloud

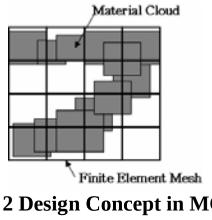


Fig. 2 Design Concept in MCM

NUMERICAL EXAMPLE 1 (MCMS)

A compliance of a structure under one concentrated load is to be minimized under an inequality constraint of total area of material. Topology optimization results of DDM and MCM are compared under same allowable amount of material and same mesh. In this example, MCMS is applied, in which only lengths of material clouds are adopted as design variables. Initially, one material cloud in each element is arranged at the center of the element. During the optimization procedure, sizes of material clouds with fixed center positions can be changed in a range of very small to size of mesh. A function, H like eqn. (1) is introduced to quantitatively measure a closeness of material distribution to 0-1 discrete one.

$$H = \int_\Omega \left(\rho^{ub} - \rho\right)\left(\rho - \rho^{lb}\right) d\Omega = \sum_{i=1}^{Nelem} \left(\rho_i^{ub} - \rho_i\right)\left(\rho_i - \rho_i^{lb}\right) A_i \qquad (1)$$

Optimal material distribution obtained by MCMS (Fig. 5) is much simpler than that of DDM (Fig. 4). In addition, it has somewhat lower value of objective function. In Fig. 6 and Fig. 7, convergences of both objective function and H-function of MCMS are much faster than those of DDM. Due to approximation of total amount of material into linear form about design variables in MCMS, a total amount of material is somewhat more than a specified value during first several iteration steps, but this constraint is correctly satisfied after being converged in H-function. The computational cost (time and memory requirement) of MCMS per iteration is very similar to that of DDM. So a total cost to complete optimization procedure can be smaller than that of DDM, because of its excellent convergence.

Fig. 3 Example 1

Fig.4 Optimal Result (DDM, Example1)

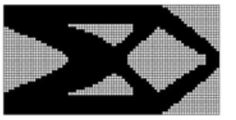


Fig. 5 Optimal Result (MCMS, Example1)

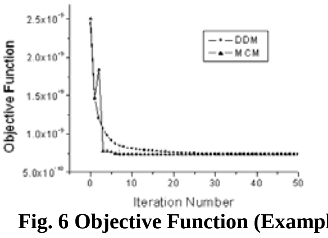


Fig. 6 Objective Function (Example1)

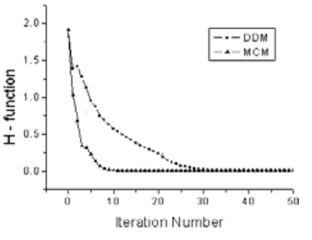


Fig. 7 H-Function (Example 1)

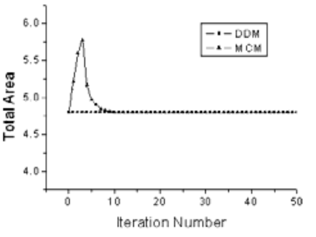
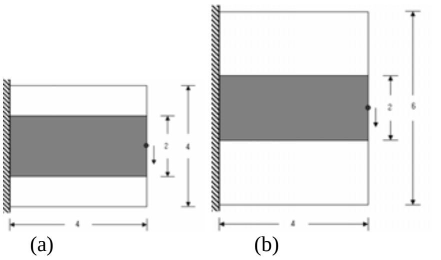


Fig. 8 Total Area (Example 1)

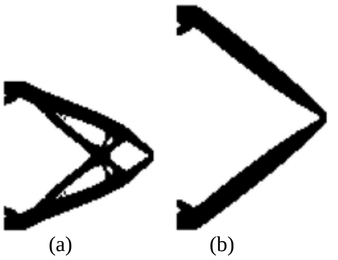
NUMERICAL EXAMPLE 2 (MCMPS)

In this example, MCMPS is applied for 2 different setting up of potential design domain, in which material may be moved to improve a performance of the structure. In MCMPS, firstly central positions of material clouds are optimized (MCMP), and then sizes of material clouds are additionally optimized (MCMS) to compensate clearness of material distribution obtained after MCMP. Through movements of material clouds, an expansion-reduction procedure of design domain can be naturally realized without any additional computations. At this procedure, only active elements, in which any portion of material clouds are contained, are included in analysis. In MCMS, initially, material clouds are arranged at center positions of active elements and have different sizes, which are defined considering amount of material in each active element from results of MCMP. In MCMP, initially material clouds are arranged in shadow region of Fig.9. At Fig. 9, potential design domains are sufficiently largely defined. Fig. 10 shows optimal material distributions through traditional DDM, in which potential domains are identical to fixed design domains. Fig. 11 shows optimal material distributions through MCMPS. Objective function value of Fig. 11(a) and (b) is somewhat less than that of Fig. 10(a) and (b) respectively. Total computational cost of MCMPS is much less than that of traditional DDM, because the number of active elements in optimization procedure is much less than that of DDM.



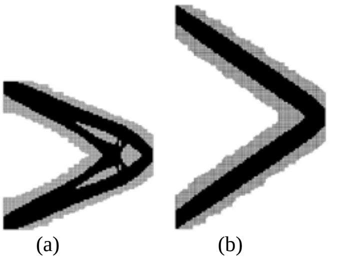
(a) (b)

Fig. 9 Example 2



(a) (b)

Fig. 10 Optimal Result (DDM, Example2)



(a) (b)

Fig. 11 Optimal Result (MCMPS, Example2)

CONCLUSIONS

A newly developed material cloud method (MCM) for topology optimization is presented. In MCM, an optimal structure can be found out through modifying sizes and positions of material clouds, which are lumps of material having specified properties. A numerical analysis for a specific distribution of material clouds is carried out using fixed background finite element meshes. In a case of optimizing only sizes of material clouds, convergences of objective function and H-function are much faster than those of DDM respectively. And in a case of sequential optimizing positions and sizes of material clouds, computational cost in each iteration is much less than that of DDM, because the number of active elements in optimization procedure is much less than that of DDM.

References

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