報告番号	甲　第　14245　号

主　論　文　の　要　旨

論文題目　MULTI-SCALE TOPOLOGY OPTIMIZATION FOR TRANSIENT HEAT ANALYSIS IN POROUS SOLID MATERIAL CONSIDERING SIZE-DEPENDENT EFFECT
(多孔質構造体の寸法効果を考慮した非定常熱移動マルチスケールトポロジー最適化)

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論　文　内　容　の　要　旨

Topology optimization together with additive manufacturing is now broadly used to design and prototype high-temperature structures. In such a situation, many new challenges are opening up due to their advantages, e.g. free-form design, tailored shapes, and rapid fabrication. This allows for innovative and advanced designs that are complicated but promise high performance. For example, lattice and porous structures have originally good performance to dissipate heat from the structure and this attractive feature is significant in the design procedure.

To tackle these design problems, single-scale design approach may not be efficient for the full capability of this kind of structures. Alternatively, the multi-scale analysis, which includes heat characteristics from the microscopic lattice and porous structures, plays a significant role in the advanced design. In fact, a few studies have investigated multi-scale topology optimization with transient heat conditions.

In this dissertation, multi-scale topology optimization for three-dimensional transient heat transfer analysis including the size-dependent effect of microstructure from the porous material has been successfully developed. The robust and attractive performance of the proposed scheme was demonstrated through the design of various macro-and microstructures under transient heat analysis. The contents and achievements were listed as follows:

In Chapter 1, the research background, motivation, and literature review were presented to highlight the contribution of the current work. It can be seen that topology optimization under transient heat transfer analysis has not been extensively explored, especially for the multi-scale analysis, which is widely applied for a porous material.

In Chapter 2, the two-scale transient heat analysis for porous solid material was summarized and presented in a general framework that can be applied for high and low thermal conductivity materials. Homogenization and the highlight of this work, the size-dependent term, were introduced to deal with the heterogeneous material and reflex the characteristic of porous material.

In Chapter 3, we developed a two-scale topology optimization framework for designing the optimal microstructure in a porous material based on the analysis model introduced in Chapter 2. The optimization model, which can consider the surface area directly from microstructure topology as the size-dependent term, was introduced to enhance the heat transfer performance. A well-known material interpolation referred to as the SIMP approach and the linear function were adopted for smoothly interpolating intermediate material properties. The minimal transient heat compliance was established as an objective function, and it was used to derive transient sensitivity formulation by a coupled-adjoint variable method. The results show that the proposed topology optimization model performs better when considering the transient condition. Also, the size-dependent effect of the microstructure shows a robust feature, which can enhance the heat dissipation performance.

In Chapter 4, we extended the design framework from Chapter 3 to be capable of the concurrent two-scale topology optimization in which both macro-and microstructures were simultaneously optimized under macroscopic transient heat conditions. Two design variables as the continuous function for both scales were introduced to obtain optimal structures smoothly. The optimization problems were established for macro-and microstructures, which were solved sequentially to monotonically converged to optimal design. The analytical sensitivity formulations for gradient-based optimization algorithms were derived with the same strategy in Chapter 3. As a result, the design results demonstrated powerful performance. Furthermore, the optimized macrostructures show good agreement with the benchmark from the existing works, while the optimized microstructure was a similar trend to the design results obtained from Chapter 3. Remarkably, the design results also emphasize the significance of transient and size-dependent effects on both macro and microstructures.

Consequently, the developed design framework has the attractive feature which can be used for designing macro-microstructures along with size-dependent effects. As can be seen from the result, it shows the advantages compared to the conventional design framework. According to positive features, topology optimization for multi-scale analysis considering the size-dependent effect of microstructure should be extended to design the structure under multidisciplinary physics such as thermal-fluid, thermal-mechanical-fluid, thermal-chemo-mechanical, etc.