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학술논문

무게절감을 위한 차량 최적 설계 기법

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The Optimized Design Method of Vehicle for Weight-Reduction

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ABSTRACT

The geometric configuration in the weight-reduced structure is very required to be started from the conceptual design with low cost, high performance and quality. In this point, a structural-topological shape concerned with conceptual design of structure is important. The method used in this paper combines three optimization techniques, where the shape and physical dimensions of the structure and material distribution are hierachically optimized, with the maximum rigidity of structure and lightweight.

Key words : weight-reduced structure, size optimization, shape optimization, topology optimization

1. Introduction

Recently, developing a design configuration that fulfills various performance requirements, such as strength, stiffness and cost, must be necessary in an extensive amount of structural designs. Thus, it becomes important that the concept design takes into account a minimum weight structure with maximum or feasible performance based on the given constraints. Optimization techniques are useful design tools, in this point. Structural optimization can be categorized into the following three classes. First is referred to as sizing optimization, which chooses the sizes of structure as design variables, such as cross sectional dimensions of members (thickness, width, height, moment of inertia, torsional constant) in the given domain. The next important design is the shape optimization, in which the geometry of structure is varied to obtain the optimal structural shape. In shape optimization, the boundary of structure is variable, so parametrization of geometry is the most important aspect[1,2]. In both sizing and shape optimization, the topology (connectivity and hole of element in a microstructure) is predefined. In other words, topology optimization is to find a preliminary structural configuration that meets a predefined criterion. Topology optimization can be identified into two general approaches. The first approach (microstructure approach) is to find the microstructure parameters (size and orientation of hole) of each designed element in a finite element model[2]. The second approach is find the material properties of each discretized part of design domain[3,4]. Traditional shape optimization is based on the assumption that the geometry of structure is defined into the shape in its boundary and that an optimal design can be found by varying the shape of an existing initial design. Thus, this formulation cannot remove existing boundaries or add new boundaries to the design. The solutions obtained from the same topology as the initial design are far from optimal because other competing topologies cannot be explored. For these reasons, in order to be able to come up with good initial designs, topology optimization is becoming increasingly important.

The paper presents the integrated optimization procedure to generate solutions to weight-reduced structure design and the effectiveness in the sizing, shape and topology designs of continuum structures for least weight and maximum stiffness. This design procedure can efficiently be applied to the typical

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components in cases where the appropriate treatment of structural details arise in connection with inner panels or where the inner and outer panels are adhesively bonded to form a weight-reduced structure.

2. Integrated Optimization Procedure

The integrated optimization approach combines the optimum design techniques for maximum stiffness design of structures. In the optimization procedure, the objective function to minimize is the total elastic strain energy with a constraint on the total available volume.

$$\begin{aligned} &\textit{Minimize} \quad U(x_1, x_2, \ldots, x_n) \\ &\textit{Subject to} \quad V(x_1, x_2, \ldots, x_n) \\ &x_i^{\min} \le x_i \le x_i^{\max}, \quad i = 1, \ldots, n \end{aligned} \tag{1}$$

In the loop of topology optimization, material densities and orientations are solved in two separate steps for reaching the optimum. First is to define the material layout in the design domain. Second is to define the local layout in the global topological layout, which is the main topology maintaining the structural rigidity. Since the stiffness may change dramatically when local curvature is modified, if this separate approach is used, the shape and material distribution can be geometrically optimized. And then, the sizing and shape optimization are used as the detailed optimization design. The sizing optimization is concerned with the physical dimensions and the shape optimization is concerned with the robust local profile on the design domain. Both the detailed optimizations are inter-complemented, since the changes of local geometry on the domain can improve the stiffness relative to the increase of physical dimensions.

Through this method, the subsequent changes of geometry and material distribution in the sublevel can help to find the optimum convergence, without the influence on each other and the change of global stiffness.

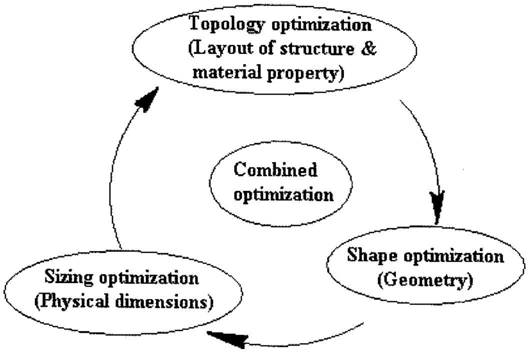

Fig. 1. Combined sizing, shape and topology optimization.

3. Example

Based on the proposed approach, an example is presented to demonstrate the capability and effectiveness of this implemented combined optimization method. This integrated procedure can be applied to the double-layered shell structure such as hood, door, tailgate and roof.

For topology, sizing and shape optimizations, the commercial finite element code ALTAIR/OPTISTRUCT and MSC/NASTRAN are used.

3.1 Basic Panel Structure

Fig. 2 shows the finite element model of closed double-layered shell structure. The descriptions of model are as follows. Nodes on four edges of outer and inner panels have the same motions as the condition of closed structure. The corners of outer panel are fixed and the load, ***F***, is acted at the center of inner panel. Thickness of panels is 1.0 mm. The

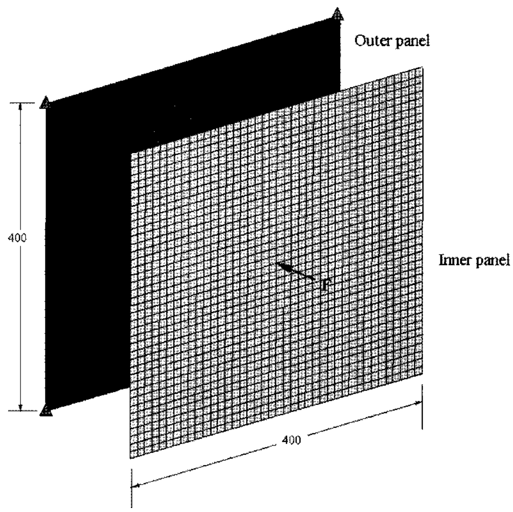

Fig. 2. Loading and boundary condition on double-layered periodic structure.

outer panel is the skin and non-design domain. Thus, the geometries of inner panel is studied for the improvement of stiffness. The optimal pattern is obtained as shown in Fig. 3.

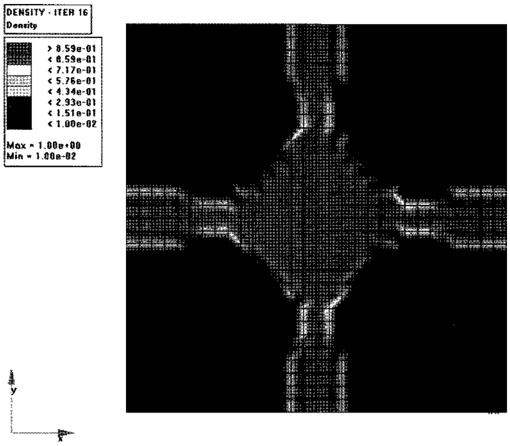

Fig. 3. Topology pattern on the inner panel.

From that pattern, reinforcement boundaries are generated. Using the shape optimization, the width and height of reinforcement on the inner panel are defined as 80 mm and 10 mm as shown in Fig. 4, which, in comparison with the initial model, increase up to 30%.

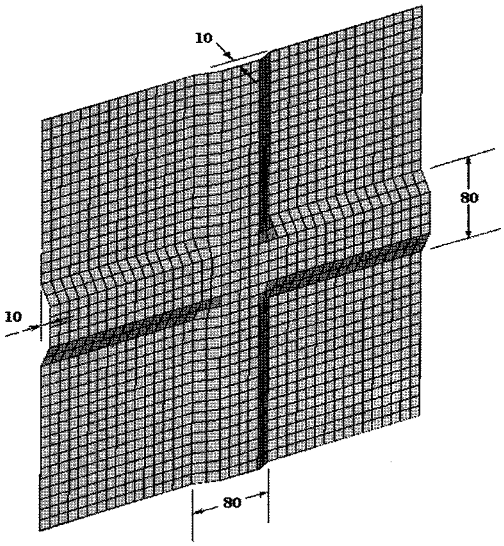

Fig. 4. Isotropic structure with reinforcement.

From Fig. 4, the topology optimization of local domain is performed as the optimization of sublevel. The optimal topology of local domain is shown in Fig. 5. Through the local topological pattern and shape optimization, the reinforcement on the center domain is studied. The geometries of main reinforcement channel are changed and the geometries of center domain have the beads, as shown in Fig. 6. At last, using the sizing optimization, the thickness of inner panel is defined as 0.8 mm. Table 1 shows the structural performances of three models shown in Fig. 2, 4 and 6. Fig. 7 shows another sample of isotropic structure with reinforcement inner door. Fig. 8 and Fig. 9 are topology optimization pattern of reinforcement inner door. This inner door is a commercial part of vehicles. The commercial reinforced hood of optimized topology pattern shows from Fig. 10 to Fig. 13.

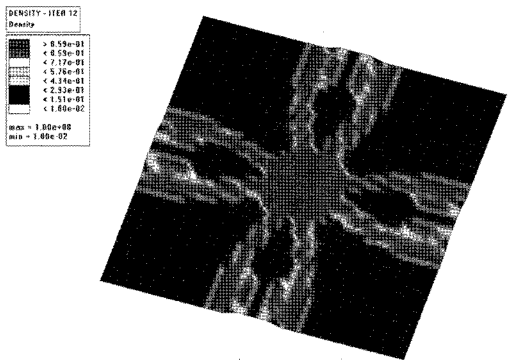

Fig. 5. Topology pattern of reinforcement inner panel.

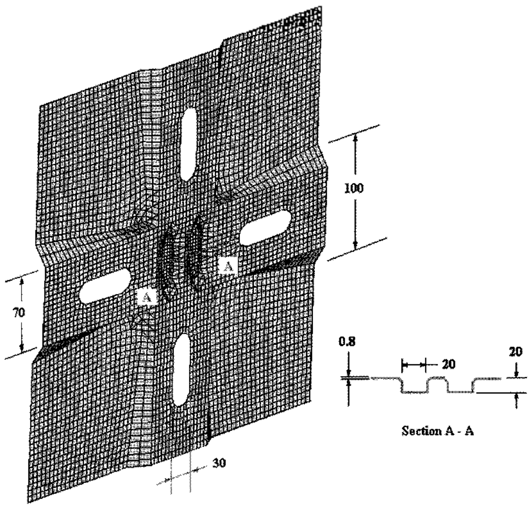

Fig. 6. Isotropic structure with local profile.

Table 1. Comparison of structural performance

Model	Mass (kg)	Deflection (mm)
Fig. 2	3.85	3.10
Fig. 4	2.95	2.43
Fig. 6	2.38	1.87

3.2 Inner Panel of Door

The door typically consists of the outer panel and the inner panel. The inner panel divides pieces of parts, which are the blank parts, reinforcement parts and connection parts. The blank parts and connection parts to body does not change. Therefore, the reinforcement parts are the design domain for the structural rigidities. In the conceptual design, topology optimization is performed for several constraints to figure out the tendency of the stiffest structure. In the detailed design, sizing and shape optimization are simultaneously performed from the part selection process. The sizing optimization is concerned to the thickness of panel and the shape optimization to the configuration dimensions of reinforcement parts. The configuration optimization problem is to find the width and height of the channel of each inner panel. The assembly model of door is used for the topology, sizing, and shape optimization. The load conditions are the sagging, torsion, the side intrusion and the longitudinal crush. The equations used optimization for optimized maximum deflections subject to weight, optimized thickness, optimized shape are expressed as follows. And iteration models of topology pattern of reinforcement considering below equations are presented Fig. 8 and Fig. 9. But Fig. 9 (Design iteration=22) is more optimization for h and w than Fig. 8.

Minimize the max *imum deflections*
subject to weight ≤ *original weight*
for sizing optimization
thickness
for shape optimization

$$h^L \le \textit{change of height}\ (\mathrm{h}) \le h^u$$
$$w^L \le \textit{change of width}\ (\mathrm{w}) < w^u$$
$$a_j^L \le \textit{configuration vector}\ (a_j) \le a_j^u \quad j = 1, \ldots, n$$

Where, h and w are the dimensions of reinforced rib in the inner panel. a_j is the move vector of reinforced bead.

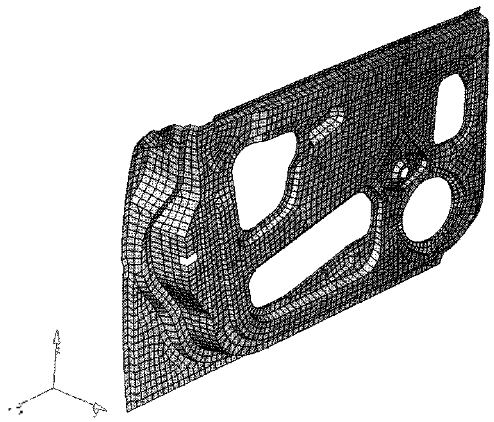

Fig. 7. Isotropic structure with reinforcement inner door.

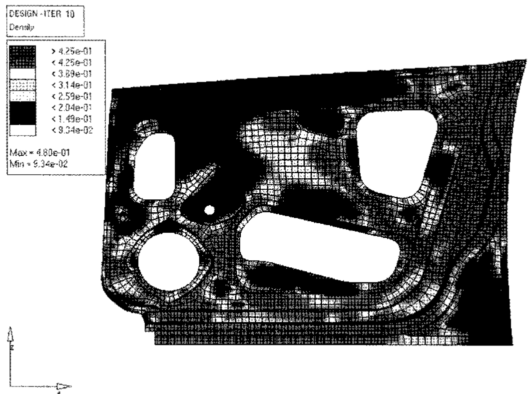

Fig. 8. Topology pattern of reinforcement inner door (Design iteration=10).

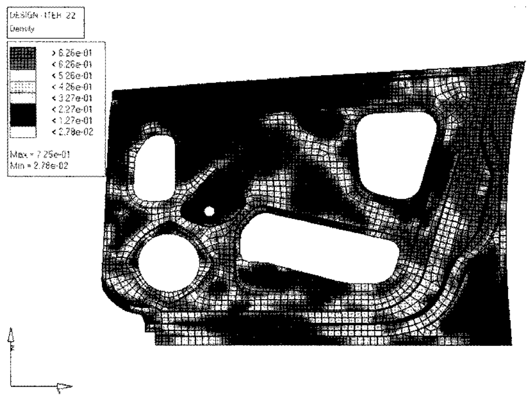

Fig. 9. Topology pattern of reinforcement inner door (Design iteration 22).

3.3 Inner Panel of Hood

The hood design is done for the topology shape optimization of stiffener, which is the inner panel. In this case, the hood outer panel is chosen as the initial design domain as the panel model shown in Fig. 11. Both bending and twisting loads are considered for the topological distribution of elements. The object of the shape optimization is to reduce the maximum deflections without increasing its weight. The configuration optimization problem is to find the width and height of the channel of each inner panel. The equations used optimization for optimized maximum deflections subject to weight, optimized thickness, optimized shape are expressed as follows. And iteration models of topology pattern of reinforcement considering below equations are presented from Fig. 10 to Fig. 13. But Fig. 13 is the best topology pattern of reinforcement hood considering h and w than Fig. 11 and Fig. 12.

Minimize the max *imum deflections*
subject to weight $\leq$ *original weight*
for sizing optimization
thickness
for shape optimization

$$h^L \leq \textit{change of height}\ (\mathrm{h}) \leq h^u$$
$$w^L \leq \textit{change of width}\ (\mathrm{w}) \leq w^u$$
$$a_j^L \leq \textit{configuration vector}\ (a_j) \leq a_j^u \quad j = 1, \ldots, n$$

Where, h and w are the dimensions of reinforced rib in the inner panel. a_j is the move vector of reinforced bead.

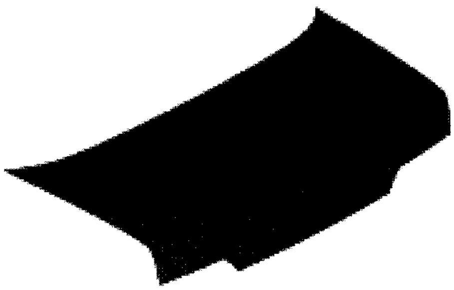

Fig. 10. Topology pattern 1 of reinforcement hood.

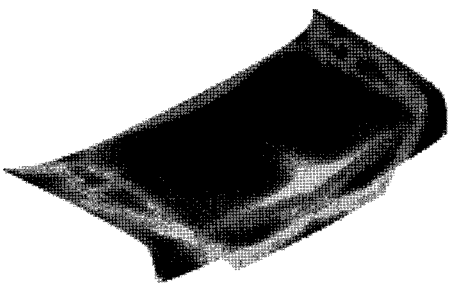

Fig. 11. Topology pattern 2 of reinforcement hood.

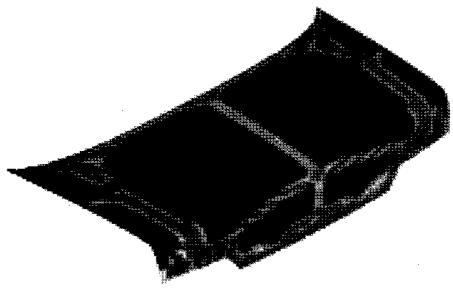

Fig. 12. Topology pattern 3 of reinforcement hood.

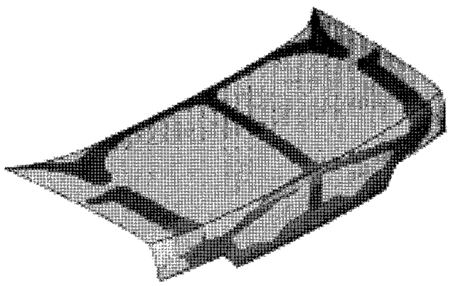

Fig. 13. Topology pattern 4 of reinforcement hood.

The design variables of shape optimization are the width and the height of each channel of inner panel. The number of design variables is 14.

4. Conclusion

This paper presents the optimization design methodology in order to secure the structural rigidities and lightweight of weight-reduced structure. The optimum design of these kinds of structures is very difficult to predict since stiffness changes dramatically with the curvature and profile of reinforcement. The initially structural topology is determined by topology optimization, the detailed profiles are designed by the shape optimization, and the detailed dimensions such as panel's thickness and mounting location are studied by sizing optimization. This method seems to provide an efficient tool to predict the maximum stiffness design of weight-reduced structures. These optimization method and objective function used in this paper are not presented other research. And optimization design methodology for more diverse and universe of vehicle parts is considered for the future study.

References

1. Ding, Y. L., "Shape Optimization of Structures: A Literature Survey", *Computers & Structures*, Vol. 24, No. 6, pp. 985-1004, 1986.
2. Bendsoe, M. P. and Kikuchi, N., "Generating Optimal Topologies for Structural Design Using a Homogenization Method", *Computer Methods in Applied Mechanics & Engineering*, Vol. 71, pp. 197-224, 1988.
3. Bendsoe, M. P., "Optimal Shape Design as a Material Distribution Problem", *Structural Optimization*, Vol. 1, pp. 193-202, 1989.
4. Bendsoe, M. P., Guedes, J. M., Haber, R. B., Pedersen, P. and Taylor, J. E., "Analytical Model to Predict Optimal Material Properties in the Context of Optimal Structural Design", *Journal of Applied Mechanics-Transactions of ASME*, Vol. 61, No. 4, pp. 930-937, 1994.
5. Jog, C. S. and Haber, R. B., "Stability of Finite Element Models for Distributed Parameter Optimization and Topology Design", *Computer Methods in Applied Mechanics & Engineering*, Vol. 130, pp. 203-226, 1996.
6. Yang, R. J., "Multidisciplinary Topology Optimization", *Computers & Structures*, Vol. 63, No. 6, pp. 1205-1212, 1997.
7. Yang, R. J. and Chahande, A. L., "Automotive Applications of Topology Optimization", *Structural Optimization*, Vol. 9, pp. 245-249, 1995.
8. Shinji Nishiwaki, Seungjae Min, Jeonghoon Yoo and Noboru Kikuchi, "Optimal Structural Design Considering Flexibility", *Computer Methods in Applied Mechanics and Engineering*, Vol. 190, pp. 4457-4504, 2001.
9. Suzuki, K. and Kikuchi, N., "A Homogenization Method for Shape and Topology Optimization", *Computer Methods in Applied Mechanics & Engineering*, Vol. 93, pp. 291-318, 1991.
10. Yasuhiko, S. and Takashi, M., "Structural Reinforcement Optimization Using a Material Distribution Approach", *Third Asian-Pacific Conference on Computational Mechanics*, Vol. 1, pp. 637-642, 1996.
11. Ruben Ansola, Javier Canales, Jose A. Tarrago and John Rasmussen, "An Integrated Approach for Shape and Topology Optimization of Shell Structures", *Computers & Structures*, Vol. 80, pp. 449-458, 2002.

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