The Topology Optimization Design Research for Aluminum Inner Panel of Automobile Engine Hood

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Abstract. This article discusses the topology optimization methods for automobile engine hood design. The aluminum inner panel of engine hood and mucilage glue regions are set as design areas, and the static performances of engine hood included modal frequency, lateral stiffness, torsional stiffness and indentation stiffness are set as the optimization objectives. The topology optimization results about different objective functions are contrasted for analysis. And based on the reasonable topology optimization result, a suited automobile engine hood designs are raised to further study. Finally, an automobile engine hood that good at all of static performances is designed, and a favorable topology optimization method is put forward for discussion.

1. Introduction
The automobile engine hood is the important part for the car, and the static performances for automobile engine hood are crucial for the safety performance about the car [1]. Finite element analysis is an effective helper method for automobile engine hood design [2, 3]. The most important static performances that influence the design of the hood are: modal frequency, lateral stiffness, torsional stiffness and indentation stiffness [4]. Modal frequency is an important factor affecting the NVH performance; the performance of lateral stiffness and torsional stiffness can be evaluated as generated displacement when engine hood under certain external loads, and they are important factors to evaluate engine hood operation performance; indentation stiffness means the resistance capacity to deformation by unexpected forces, and it is related to pedestrian protection, suitable indentation stiffness can balance resistance capacity to deformation with pedestrian protection [5, 6].

With the development of Computer-Aided Manufacturing (CAM), topology optimization is widely used in modern manufacturing technology. Topology optimization is a conceptual design method, which aimed to find the optimal stiffener distribution of the structure, increasing the stiffness of the structure, without increasing the structure weight. And topology optimization can be used to find the best stiffener distribution of the engine hood inner panel [7, 8].

In recent years, energy saving has become the major research area in the field of automotive engineering. Weight reduction can reduce the energy consumption, because eliminate the influence of aerodynamic resistance, the energy required for moving a vehicle is mostly proportional to its weight [9, 10]. Using aluminum in engine hood could reduce vehicle weight, and it is of great influence to improve vehicle fuel economy under the premise of vehicle driving performance [11, 12].

In this article, the optimal stiffener distribution of different objective parameters is analyzed, and based on this, an automobile engine hood that good at all of static performances is designed. And the material of automobile engine hood inner panel is replaced by aluminum for reduce vehicle weight.
2. Optimization modal
The optimizing finite element modal of engine hood is shown in figure 1. The finite element modal is set up to topology optimization under help of Hypermesh. The outer and inner panels of engine hood are connected by mucilage glue. Hinge reinforcing plate and lock reinforcing plate are connected to inner panel by rigid element. The material of inner panel is aluminum, and the others are steel. In order to obtain a reasonable stiffener distribution of inner panel, outer panel, hinge reinforcing plate and lock reinforcing plate are keep unchanged, the voids between inner panel and outer panel are full with mucilage glue, inner panel and mucilage glue regions are set to design areas. Taking into account the manufacturing process requirement, the topology optimization considers are the symmetry restraint of structure.

3. Topology optimization
Topography optimization is a conceptual design method, which aimed to find the optimal stiffener distribution of engine hood, increasing the stiffness of the structure, without increasing the structure weight. The optimization analyzing constraints and loads set regions are shown in figure 2. As shown in figure 2, when modal frequency, torsional stiffness and indentation stiffness are set to the optimization objectives, the freedom of lock catch area and hinge area are completely constrained. And when lateral stiffness is set to the optimization objective, the freedom of hinge area is completely constrained, the freedom of lock catch area is released. When torsional stiffness is set as the optimization objective, a load of 100N is constrained in Z direction at the yellow circle region of engine hood. When indentation stiffness is set as the optimization objective, 5 loads of 20N are set constrained in Z direction at the blue circle region of engine hood. And when lateral stiffness is set as the optimization objective, a load of 100N is constrained in Y direction at the lock catch area.
When modal frequency is set as the optimization objective, the maximum volume fractions about inner panel and mucilage glue region are set as optimizing constrains, the maximum 1st torsional mode is taken as the optimization goal. When lateral stiffness, torsional stiffness and indentation stiffness are set to the optimization objectives, the maximum volume fractions about inner panel and mucilage glue region are set as optimizing constrains, the minimum compliance is taken as the optimization goal.

Just as shown in figure 3. (a. Element density distribution contours and b. Inner panel stiffener distribution as the value of element density sets upper than 0.5), when modal frequency is set to the optimization objective, the topology optimization results of inner panel is distributed as double herringbone. It means that this arrangement is beneficial to raise the frequency of 1st torsional mode.

![Contour Plot](a) ![Contour Plot](b)

**Figure 3.** The topology optimization result of inner panel as 1st torsional mode is taken as the optimization goal: (a) Element density distribution contours. (b) Inner panel stiffener distribution when the value of element density sets upper than 0.5.

As shown in figure 4. (a. Element density distribution contours and b. Inner panel stiffener distribution as element density sets upper than 0.5), when lateral stiffness is set to the optimization objective, the topology optimization results of inner panel are distributed as double forks. And this arrangement is similar with the results that shown in figure 3. This means that improving the torsional stiffness of engine hood is helpful to raise the frequency of 1st torsional mode.

![Contour Plot](a) ![Contour Plot](b)

**Figure 4.** The topology optimization result of inner panel as lateral stiffness is taken as the optimization goal: (a) Element density distribution contours. (b) Inner panel stiffener distribution when the value of element density sets upper than 0.5.

As shown in figure 5. (a. Element density distribution contours and b. Inner panel stiffener distribution as element density sets upper than 0.5), when torsional stiffness is set as the optimization objective, the topology optimization results of inner panel is distributed as single herringbone. It shows that these two stiffeners are very important to the torsional stiffness of engine hood.

![Contour Plot](a) ![Contour Plot](b)

**Figure 5.** The topology optimization result of inner panel as torsional stiffness is taken as the optimization goal: (a) Element density distribution contours. (b) Inner panel stiffener distribution when the value of element density sets upper than 0.5.
Figure 5. The topology optimization result of inner panel as torsional stiffness is taken as the optimization goal: (a) Element density distribution contours. (b) Inner panel stiffener distribution when the value of element density sets upper than 0.5.

As shown in figure 6. (a. Element density distribution contours and b. Inner panel stiffener distribution as element density sets upper than 0.5), when indentation stiffness is set as the optimization objective, the topology optimization results of inner panel is distributed as a stiffener located in the middle of the panel.

Muti-objective optimization analysis is proposed to obtain the most suitable optimal stiffener distribution of engine hood. Muti-objective function equation is enumerated based on compromise programming approach. The equation can be expressed as:

$$
\min F(\rho) = \{w_f^2 (f_{\max}^2 - f(\rho))^2 + w_l^2 (U_l^{\max} - U_l^{\min})^2 + w_t^2 (U_t^{\max} - U_t^{\min})^2 + w_i^2 (U_i^{\max} - U_i^{\min})^2\}^{\frac{1}{2}}
$$

where, $F(\rho)$ is the muti-objective function; $w_f$ is the weight of frequency objective function; $w_l$ is the weight of lateral stiffness objective function; $w_t$ is the weight of torsional stiffness objective function; $w_i$ is the weight of indentation stiffness objective function; $f_{\max}$ is the optimal frequency; $f(\rho)$ is the frequency objective function; $U_l^{\max}$ is the strain energy of optimal lateral stiffness; $U_l^{\min}$ is the strain energy of original lateral stiffness; $U_t^{\max}$ is the strain energy of optimal torsional stiffness; $U_t^{\min}$ is the strain energy of original torsional stiffness; $U_i^{\max}$ is the strain energy of optimal indentation stiffness that limited by pedestrian protection; $U_i^{\min}$ is the strain energy of original indentation stiffness; $U_i(\rho)$ is the strain energy of indentation stiffness objective function.
As shown in figure 7. (a. Element density distribution contours and b. Inner panel stiffener distribution as element density sets upper than 0.5), when $F(r)$ is set to the optimization objective, the topology optimization results of inner panel is distributed as double forks, and a stiffener across the middle of the panel.

4. Discussion

An automobile engine hood is designed based on the result of muti-topology optimization. More specifically, the result of muti-topology optimization can be simplified as 9 stiffeners, which can be marked as A, B, C, D, E, F, G, H, M, as shown in Figure 8. The stiffeners, which marked as A, B, C, D, are bigger than the other stiffeners. For the stiffeners, which marked as E, F, are smaller than the stiffeners that marked as G, H.

From the upward optimization analysis, it can be deduced that the stiffeners marked as A, B, E, F, G, H are helpful to raise the 1st torsional modal, the stiffeners marked as A, B, C, D, E, F, G, H are helpful to raise the lateral stiffness, the stiffeners marked as A, B, C, D are helpful to raise the torsional stiffness, and the stiffener marked as M is helpful to raise the indentation stiffness singly.
Table 1. Static performances of designed engine hood.

|                        | Steel inner panel | Aluminum inner panel | $\Delta$ (Percentage difference) |
|------------------------|-------------------|----------------------|----------------------------------|
| 1st torsional modal    | 33.4              | 30.6                 | 8.4%                             |
| (HZ)                   |                   |                      |                                  |
| Lateral stiffness (mm) | 1.70              | 1.85                 | 8.8%                             |
| Torsional stiffness (mm)| 2.11              | 2.27                 | 7.6%                             |
| Indentation stiffness (mm)| 4.46            | 4.28                 | 4.0%                             |
| Weight (kg)            | 22.3              | 17.8                 | 20.2%                            |

Analyzing static performances of designed engine hood, the results show that the designed engine hood is excellent for both stiffness performances. And just as shown in table 1, replacing the material of inner plate from steel to aluminum, and adding the thickness of inner panel from 0.7mm to 0.9mm, the frequency of 1st torsional modal only reduced 8.4%, the lateral stiffness only reduced 8.8%, the torsional stiffness only reduced 7.6%, and the indentation stiffness only reduced 7.6%, and all of that static stiffness performances are greater than the target values. It means that, replacing the material of inner plate form steel to aluminum can achieve engine hood weight reduction of 20.2%, and static stiffness performances keeping well.

5. Conclusions
This study explored topology optimization method for automotive engine hood. Stiffener distributions of different optimization objectives are examined in this work. In this article, it is first proposed that mucilage glue region should be considered as design region, when taking topology optimization analysis for automobile engine hood. An automobile engine hood, which is excellent for both stiffness performances, is designed based on the results of topology optimization. Replacing the material of inner plate from steel to aluminum, and comparing the difference of these two engine hoods, they have similar stiffness performances, and it shows that replacing the material of inner plate form steel to aluminum can achieve engine hood weight reduction of 20.2%. It is believed that this work has guiding significance for the future research of topology optimization method and the design of automotive engine hood.

6. Reference
[1] Ishitobi H 2010 Automobile hood: US, US7810877.
[2] Darwish S M, Elseufy and Ahmad A 2013 Finite Element Analysis of an Automobile Engine Hood, Iems 2013 International Conference on Industry, Engineering, and Management Systems.
[3] Darwish S M, Elseufy S M and Ahmad A 2014 J. Manag. Eng. 7(1) 62.
[4] Shojaeefard M H, Najibi A and Ahmadabadi M R 2014 Thin-Walled Struct. 77(4) 77-85.
[5] Zhou J, Wang F and Wan X 2015 Mater. Today Proc. 2(10) 5029-36.
[6] Zhang J, Shen G Z, Du Y, et al. 2013 Appl. Mech. Mater. 281 364-9.
[7] Krishnamoorthy R 2012 Math. Geosci. 44(6) 651-72.
[8] Teng T L, Liang C C, Shih C J, et al. 2013 Int. J. Vehic. Des. 63(2/3) 185-98.
[9] Mathaudhu S N, Luo A A, Neelameggham N R, et al. 2016 A Lightweight Automobile Body Concept Featuring Ultra-Large, Thin-Wall Structural Magnesium Castings, Essential Readings in Magnesium Technology. Springer International Publishing, 55-63.
[10] Li M H, Li Z R and Jiang L 2016 Preliminary Study of Automobile Lightweight Technology, International Conference on Mechanical Materials and Manufacturing Engineering.
[11] Kong C, Lee H and Park H 2016 Polym. J. 91(2) 18-26.
[12] Li Y and Liu H 2010 Material and Structural Optimization for Engine Hood Inner Panel of Car Body Aimed to Lightweight, Wase International Conference on Information Engineering. IEEE Computer Society, 291-4.