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# Topology optimization method for vehicle body structure to meet multiple performance requirements for body stiffness, crashworthiness and NVH at the same time

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In the development of automobile bodies, it is an essential task to achieve both performance improvement to enhance the attractiveness of products and weight reduction to reduce CO2 emissions and protect the global environment.

In the initial conceptual phase of development, topology optimization with a high degree of freedom in design gives a good help to a solution. As almost all commercial topology optimization tools specialize only in linear problems, however, they cannot handle nonlinear problems with large deformation such as a collision. For this reason, it is extremely difficult to optimize body stiffness, crashworthiness and NVH performances, key indicators in vehicle structure, at the same time.

In this study, we developed a large-scale nonlinear topology optimization method that simultaneously addresses linear (torsional stiffness and vibration) problems and nonlinear (crashworthiness) problems to control energy absorption by the vehicle body structure during a collision and give consideration to NVH optimization.

In phase optimization, we use the SIMP (Solid Isotropic Material with Penalization) method where the virtual density of each material in an element is used as a design variable.Young's modulus $E$, yield stress $\sigma$, and mass density $d$ of each element are scaled with mass density $\rho$ ($0<\rho\leq 1$), penalty coefficient $p=3$ and $q=1$ (Eq.1). Weighted linear combination of objective functions for each performance makes it possible to optimize nonlinear and linear problems at the same time (Eq. 2-3).

$$E=\rho^{p}E_0,\ \sigma_y=\rho^{p}\sigma_{y0},\ d=\rho^{q}d_0 \qquad (1)$$

$$\text{find}: \rho,\ \text{minimize}: \Theta,\ \text{subject to}: \int \rho dV \leq V_0 \qquad (2)$$

$$\Theta=\sum_{k}\left(w_k\theta_k^{Static}\right)+\sum_{l}\left(w_l\theta_l^{Crash}\right)+\sum_{m}\left(w_m\theta_m^{NVH}\right) \qquad (3)$$

Fig.1 shows the flow chart of topology optimization. Firstly the design area and the initial density are set for calculation models. Then calculations are run for each load case using a commercial solver and the sensitivity is derived from the obtained results. After the optimized overall sensitivity is calculated from the weighted sum in additions (Eq.2), the density of the design area is redistributed for optimization. The optimization of the entire vehicle body model produced a rigid truss-like structure, and all the objective functions converged to the desired level (Fig.2-3). Consequently, an optimal shape that can be used as a reference for designing a car body frame structure and that simultaneously satisfies stiffness, crashworthiness and NVH performance requirements was obtained.

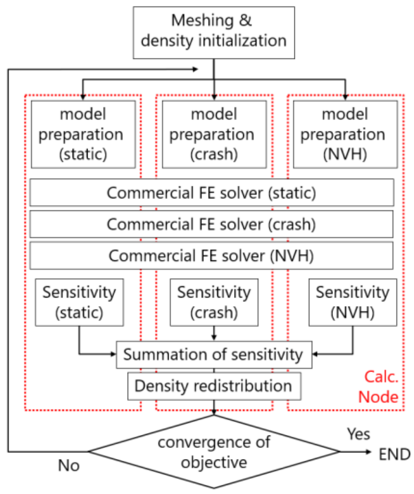


Fig.1 Flowchart of topology optimization

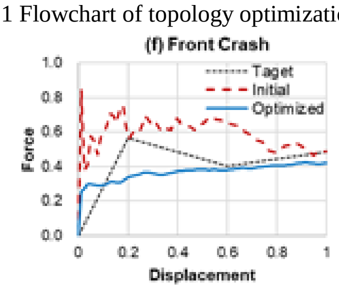


Fig.2 Load-displacement curve before and after optimization

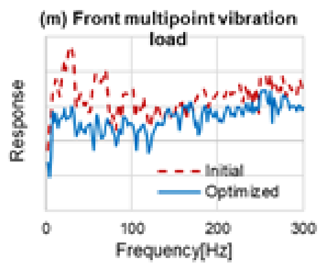


Fig.3 Frequency response of NVH case before and after optimization