Relationship between Structural Complexity, Objective Function, and Smoothness in Topology Optimization

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KEY WORDS: **vehicle development, CAD/CAM/CAE, design optimization/robust design (B2)**

This study investigates the relationship between the geometric complexity of optimal shapes obtained via level-set-based topology optimization, the objective function, and the boundary smoothness by varying the regularization parameter τ. Generally, complex geometries are considered advantageous for improving the objective function, whereas simpler geometries tend to be favorable in terms of smoothness. Our computational results reflect these tendencies. Furthermore, we identified and report cases where geometrically simple shapes demonstrate superior performance in minimizing the objective function.

Figure 1 illustrates the FEM model and boundary conditions. The topology optimization aimed to minimize mass, with a compliance constraint set to approximately three times the average compliance of the initial configuration. The regularization parameter τ was systematically varied during the optimization process, and the resulting optimal shapes are shown in Figure 2. While a large value of τ yields a simple geometry, decreasing the parameter leads to the emergence of complex, truss-like structures. Interestingly, further reduction of τ causes these truss structures to vanish, resulting again in a simple geometry. The smoothness of the isosurface shows a strong dependence on the parameter, with pronounced roughness observed at smaller values.

Subsequently, shape optimization was conducted using the optimal shape obtained at τ = 0.0005 as the initial geometry. The overall configuration remained nearly unchanged, while the isosurface became significantly smoother. These results indicate the existence of geometrically simple shapes that nonetheless exhibit high performance relative to the objective function.

Similar tendencies were observed under other loading conditions. In torsion of circular tubes and in cantilever beams subjected to vertical and lateral loads, pipe-like or box-like optimal shapes were obtained in some cases. However, even with a comparable number of nodes, such characteristic shapes were not always reproduced, suggesting the influence of factors other than loading conditions. Further investigation on calculation settings and discretization effects is required.

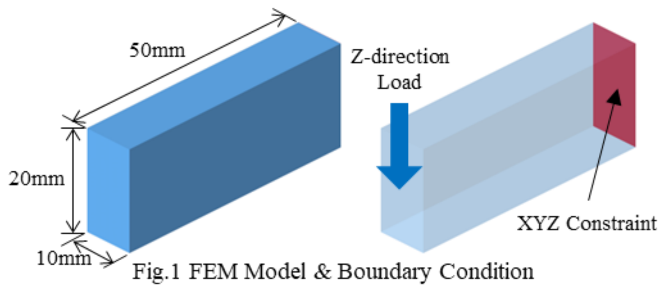

Fig.1 FEM Model & Boundary Condition

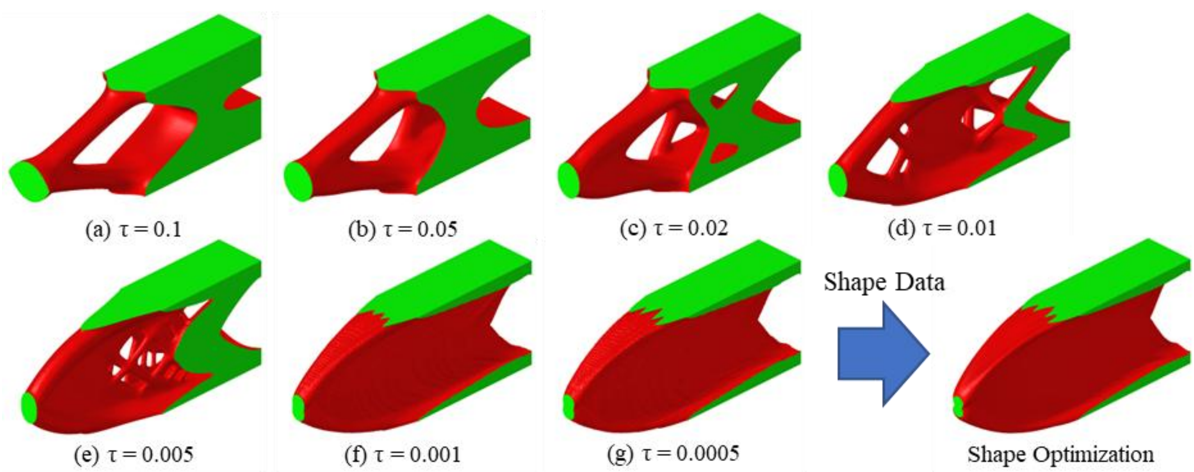

Fig.2 Optimal Result of Topology Optimization for Each Parameter and Shape Optimization