

Development of a Design Space Exploration Method for Structural Members under Manufacturing Constraints

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In automotive body development, structural member cross sections strongly influence crash performance, mass, and manufacturability. However, early-stage design exploration is often limited by reliance on existing cross-sectional shapes. This study proposes a design space exploration method that combines manufacturing-constrained cross-section generation with surrogate models based on simplified side-impact CAE results (Fig. 1).

The method was applied to a roof center reinforcement. Cross sections were represented as combinations of flat (F), downward (D), and upward (U) regions. Under manufacturing constraints on fillet radius R , draft angle α , and spot-welding flat width w , six feasible cross-sectional patterns were defined. Sobol sampling was used to distribute geometric parameters, generating approximately 100,000 manufacturable candidates, including both existing and new patterns (Fig. 2).

Gaussian Process Regression (GPR) was used to predict the peak axial force F_y and mass from 28 geometric and pattern-related parameters. The F-D-F and F-D-F-D-F patterns were excluded because their responses were dominated by local buckling near the loading point. Using 200 CAE results for training and 32 unseen candidates for validation, the GPR models achieved R^2 values of 0.95 for F_y and 0.99 for mass.

Using the surrogate models, a high F_y -to-mass candidate was selected from the new F-D-F-U-F-D-F pattern and compared with an existing-pattern candidate of similar mass. CAE re-evaluation confirmed good agreement with the predictions, and the new-pattern candidate showed a 5.6% higher F_y -to-mass ratio. These results demonstrate that the proposed method can support early-stage candidate selection from a large manufacturable design space, including patterns not used in existing designs. However, further improvement of the evaluation model is required for fair comparison across diverse cross-sectional patterns.

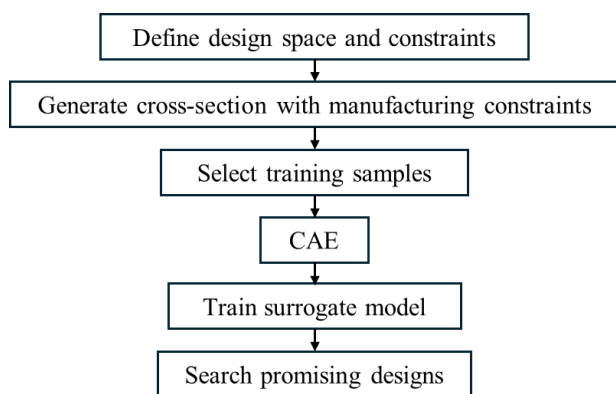


Fig.1 Proposed design space exploration process

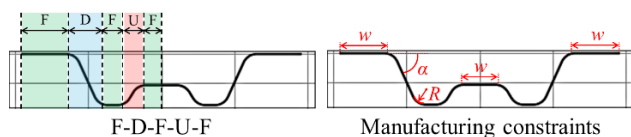


Fig.2 Cross-sectional pattern and manufacturing constraints

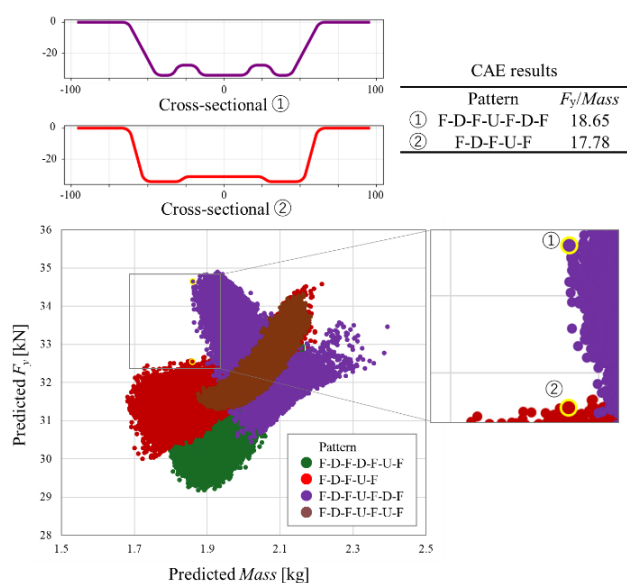


Fig.3 Pareto front candidates and CAE validation