FTMD.PN-6-104-2026

Multi-Material Robust and Reliability-Based Topology Optimization

PRIMA 2026 | Uncertainty-Aware Structural Design

Optimasi Topologi Realistik Untuk Rekayasa dengan Memperhitungkan Keandalan dan Efek Ketidaktunakan Aliran

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Abstract

- This study develops a unified multi-material robust and reliability-based topology optimization (MMRRBTO) framework for structures under uncertain loading.
- Ordered-SIMP represents multiple materials with one density field.
- Polynomial chaos expansion (PCE) quantifies compliance variability, while the first-order reliability method (FORM) enforces stress-based safety.
- Numerical L- and Y-bracket benchmarks demonstrate reduced response variability while satisfying target reliability.

Keywords: topology optimization, multi-material, PCE, FORM, uncertainty.

Introduction

- Deterministic topology optimization may produce efficient but vulnerable structures when the load direction varies.
- Robust design reduces the sensitivity of compliance to uncertainty; reliability-based design controls the probability of stress failure. Neither objective alone necessarily guarantees both properties.
- The proposed MMRRBTO approach unifies these criteria and simultaneously selects topology and material phases. Four strategies are compared: deterministic (MMDTO), robust (MMRTO), reliability-based (MMRBTO), and combined (MMRRBTO).

Research Method

Minimize $J = \mu C + k\,\sigma C$

Subject to $\beta \geq \beta target$ *and volume limit*

$\beta target = 3$; *volume fraction* $= 0.20$.

Ordered-SIMP → finite-element analysis → PCE response statistics → FORM material-specific reliability → MMA density update.

Discussion & Results

- Increasing robustness weight k reduces compliance variability, with a trade-off in mean compliance.
- Reliability constraints redistribute stronger material near stress-critical regions and reshape structural load paths.

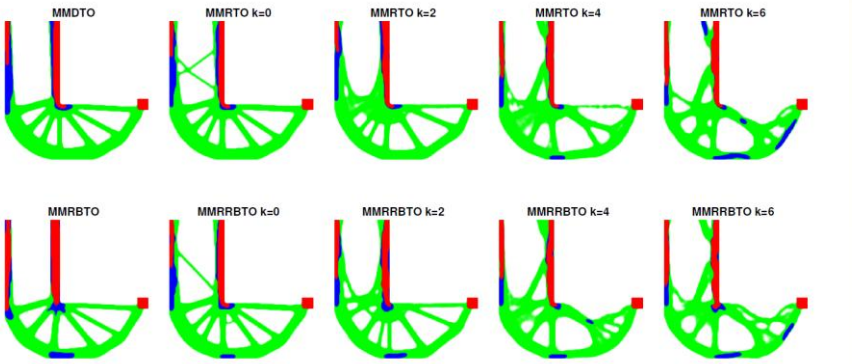


Fig. 2. Three-material L-bracket topologies.

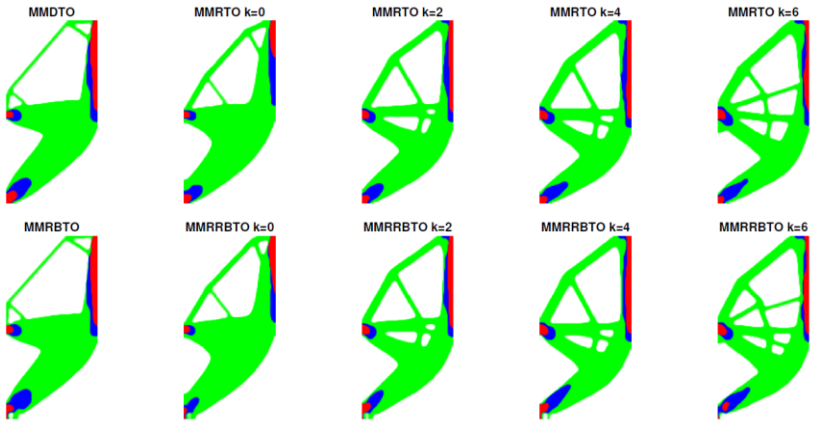


Fig. 3. Three-material Y-bracket topologies.

Conclusion

- The MMRRBTO framework integrates multi-material allocation, robustness, and stress-based reliability within a single optimization procedure.
- PCE efficiently estimates compliance moments while FORM and smooth-min aggregation enforce material-specific reliability.
- Robustness promotes alternative and interconnected load paths while stronger materials are placed selectively in critical stress regions.
- Both L-bracket and Y-bracket studies demonstrate the value of combining robustness and reliability under load uncertainty.