

Free Material Optimization of Composite Structures

Weldeyesus, Alemseged Gebrehiwot

Publication date: 2014

Document Version Peer reviewed version

Link back to DTU Orbit

Citation (APA): Weldeyesus, A. G. (Author). (2014). Free Material Optimization of Composite Structures. Sound/Visual production (digital)

General rights

Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

• Users may download and print one copy of any publication from the public portal for the purpose of private study or research.

- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal

If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.



Free Material Optimization of Composite Structures

Alemseged G Weldeyesus, PhD student

Wind Turbines section



DTU Wind Energy Department of Wind Energy

Structural optimization

- Find the lightest structure that is able to carry a given set of loads. minimize weight
 - s.t. compliance \leq given value
- Find the stiffest structure that is able to carry a given set of loads with limited amount of material.

minimize compliance

s.t. weight \leq given value

Structural optimization

- Find the lightest structure that is able to carry a given set of loads. minimize weight
 - s.t. compliance \leq given value
- Find the stiffest structure that is able to carry a given set of loads with limited amount of material.

minimize compliance

s.t. weight \leq given value

In Free Material Optimization (FMO)

The design variable is the full material tensor which can vary almost freely at each point of the design domain.

Structural optimization

- Find the lightest structure that is able to carry a given set of loads. minimize weight
 - s.t. compliance \leq given value
- Find the stiffest structure that is able to carry a given set of loads with limited amount of material.

minimize compliance

s.t. weight \leq given value

In Free Material Optimization (FMO)

The design variable is the full material tensor which can vary almost freely at each point of the design domain.

FMO yields optimal distribution of material as well as optimal local material properties.



A 2D example





Design Domain, bc and force

Optimal density distribution

The obtained design

- can be considered as an ultimately best structure,
- is difficult and expensive to manufacture,
- can be used to generate benchmarks and to propose novel ideas for new design situations.

DTU

FMO formulations

Mechanical assumptions

- static loads
- linear elasticity

FMO formulations

Mechanical assumptions

- static loads
- linear elasticity

Basic FMO formulations for solid structures

Minimum compliance problem

$$\begin{split} & \inf_{u \in V, E \in \tilde{\mathcal{E}}} & \sum_{l \in L} w_l f_l^T u_l & \inf_{u \in V, E \in \tilde{\mathcal{E}}} \\ & \text{Subjec to} & A(E) u_l = f_l, \quad , l \in L, \\ & \sum_{i=1}^m Tr(E_i) \leq \overline{V} \\ & \tilde{\mathcal{E}} = \left\{ E \in (S) |, \underline{\rho \leq Tr(E_i) \leq \overline{\rho}, E \succeq 0} \right\} \end{split}$$

Minimum weight problem

$$\inf_{\substack{u \in V, E \in \tilde{\mathcal{E}} \\ \text{Subjec to}}} \sum_{i=1}^{m} Tr(E_i) \\
\sum_{i=1} V(E_i) \\
\sum_{l \in L} W_l f_l^T u_l \leq \overline{\gamma} \\
\leq \overline{\rho}, E \geq 0 \\$$

Other different formulations can also be derived.



Additional constraints

Depending on the problem formulation additional constraints can be included such as constraints

• on local stresses

$$\sum_{k=1}^{G} \left\| E_i B_{ik} u \right\|^2 \le s_{\sigma}$$

• on local strains

$$\sum_{k=1}^{G} \left\| B_{ik} u \right\|^2 \le s_{\sigma}$$

• on displacement

 $Cu \leq d$

• etc



Optimization method

The resulting optimization problem is a nonlinear semidefinite program, a non-standard problem with many matrix inequalities.

Existing robust and efficient primal-dual interior point methods for nonlinear programming has in this project been extended to solve FMO problems.

Numerical Results



Design domain, bc and loads

Optimal material density distribution

4-loads







With out stress constraints

Design Damain, bc and forces



Density distribution of optimal design





With stress constraints,

- max stress is decreased by 50%
- 11 more iterations





Optimal stress norms



Higher stresses are distributed to the neighbor regions,So is also material distribution

Density distribution of optimal design



Numerical Results



Design domain, bc and loads

4-layers





optimal material density distribution



Density distribution, Layer=3







- Symmetric laminate
- High material distribution on top and bottom layers



Design domain, bc and loads

optimal material density distribution

4-layers









- Symmetric laminate
- High material distribution on top and bottom layers





Corner supported half cylinder, length to width ratio 1:1



Corner supported half cylinder, length to width ratio 4:1





Edge supported saddle surface shell





- Provide physical interpretation of the optimal solution
- Propose models and methods for FMO for beams with advanced cross

sectional analysis (with José Blasques and Mathias Stolpe at DTU Wind Energy)

- Include large deformations (geometric nonlinearity)
- Write articles, and PhD thesis.