Generating Optimal Topology Designs With Optimal Placement of Gradient Material

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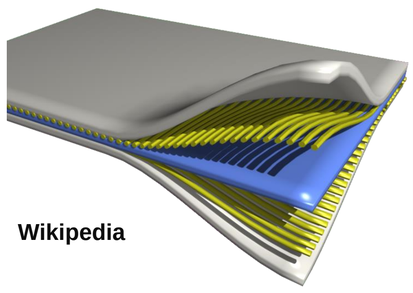
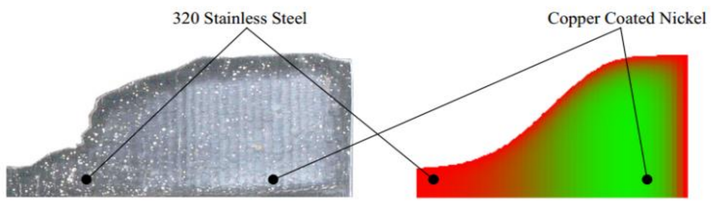
1. Goal of Research

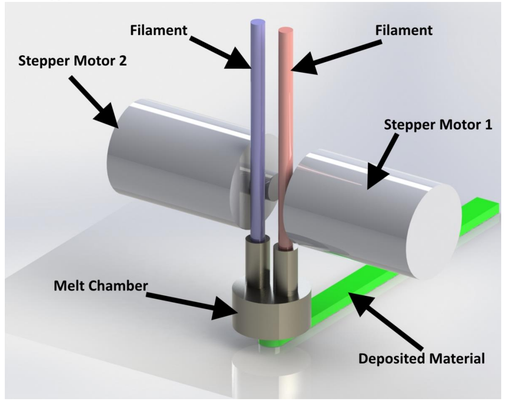
The goal of this research is to generate optimal topologies and optimal placement of material gradients within a single object while considering more than one objective.

Composite materials allow a single object to take advantage of the diverse properties of 2 or more materials within a single object. However, many parts need different properties in different regions of a single object. Gradient materials transition from one material to the next within a single part which allows the designer to customize the properties at each region of the part, and these parts can be fabricated using a point by point additive manufacturing process. In addition, designers seek to find the optimal shape (or topology) of an object that best meets design objectives.

Composite material	Gradient material
 Wikipedia	 [1]

Point by Point Additive manufacturing allows fabrication of gradient designs

Laser Engineering Net Shaping



Fused Deposition Manufacturing

2. State of the Art

Previous researchers have found optimal topologies, optimal placement of two district materials while considering single objectives [2]. Also, some researchers have used a different topology optimization approach (level-sets) to optimize topologies and material gradients with a single objective [3].

3. Method

3.1 Optimization Objective

The optimization seeks to minimize internal elastic strain energy and internal thermal strain energy with a constraint on amount of each material allowed.

Objective

$$Objective = (maximize\ stiffness) * w_1 + (1 - w_1) * (maximize\ heat\ transfer)$$

Subject to

- *Material constitutive equations*
- *Use 15% of material 1*
- *Use 15% of material 2*

3.2 Topology and Gradient Optimization

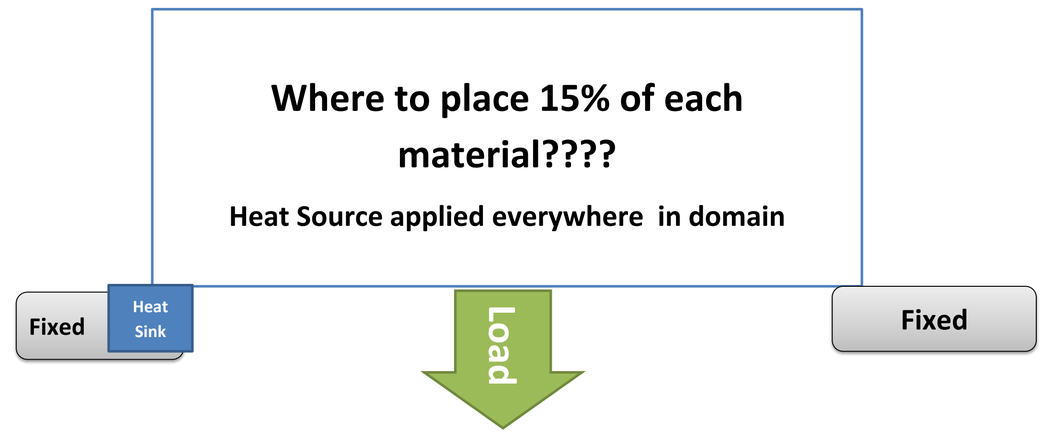
The topology optimization uses the SIMP method, where an artificial density is introduced as the design variable at each finite element. FEA guarantee's the material constitutive equations are satisfied. The sensitivities of the heat transfer optimization and elastic optimization are combined using weighted objective. The material gradient optimization finds the sensitive of each element with respect to a material change. Then using a augmented Lagrangian multiplier method, the material constraint is changed into a non-constrained optimization problem, and the direction of steepest descent of material composition change is found.

4 Problem – Find the optimal placement of gradient material in the domain

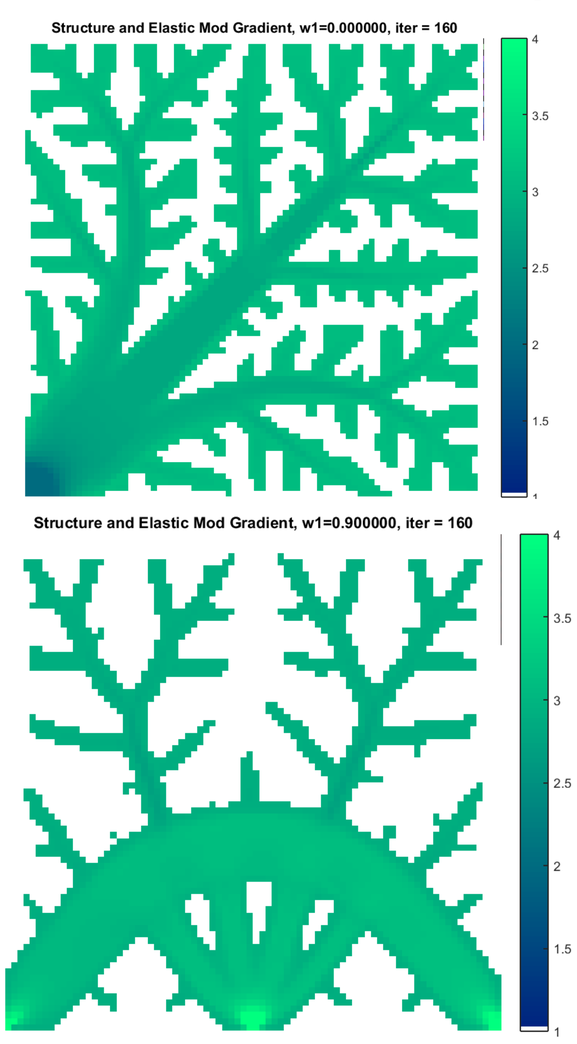
Material Properties and Volume Constraints

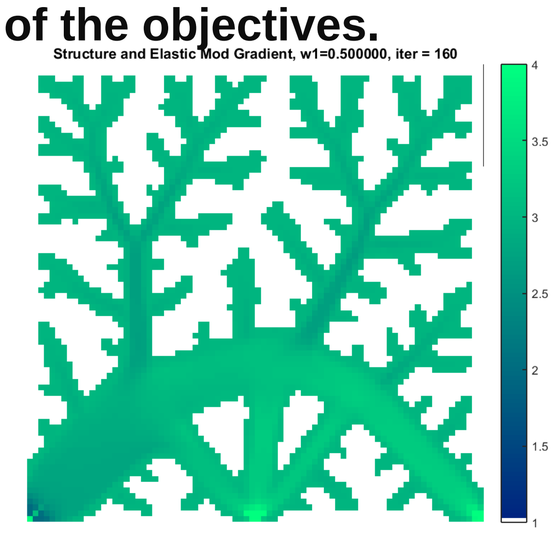
Design parameters	Value
E of material 1	4
K of material 1	2
Target percentage of material 1	15%
E of material 2	2
K of material 2	4
Target percentage of material 2	15%

Boundary Conditions

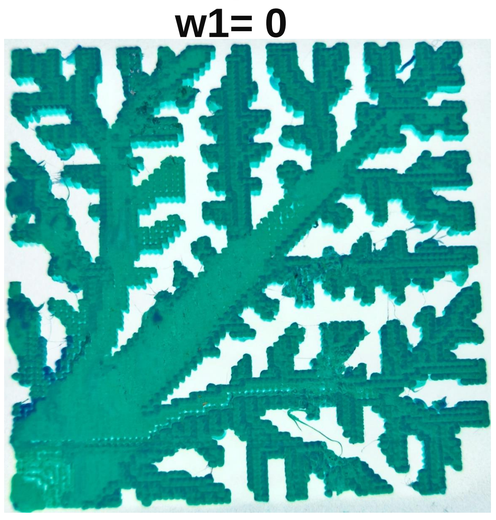


5. Results for different weights of the objectives.





3D Printed optimal result w1= 0



6. Conclusion

Optimal designs were found that maximize heat transfer and maximize stiffness. This method of optimization can be applied to help design parts in the aerospace and automotive industries where designs must be lightweight and maximize other objectives.

7. Future work

- Add a higher level control algorithm that determines the allowed volume fraction of each material based on stress and temperature constraints
- Incorporate thermal expansion into the elastic FEA
- Add a mesh refinement algorithm to produce higher quality results
- Find optimal 3D designs

References:
[1] Morvan, S., Fadel, G. M., Love, J., 2001, "Manufacturing of a heterogeneous flywheel on a LENS apparatus," Proceedings of the 12th solid freeform fabrication symposium, Austin, TX, Anonymous pp. 553-560.
[2] Gao, T., and Zhang, W., 2010, "Topology Optimization Involving Thermo-Elastic Stress Loads," Structural and Multidisciplinary Optimization, 42(5) pp. 725-738.
[3] Xia, Q., and Wang, M. Y., 2008, "Simultaneous Optimization of the Material Properties and the Topology of Functionally Graded Structures," Computer-Aided Design, 40(6) pp. 660-675.

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