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

<table>
<thead>
<tr>
<th>3D Stainless Steel</th>
<th>Copper Coated Nickel</th>
</tr>
</thead>
</table>

Point by Point Additive manufacturing allows fabrication of gradient designs

### Gradient material

<table>
<thead>
<tr>
<th>3D Printed optimal result</th>
</tr>
</thead>
</table>

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**

\[
\text{Objective} = (\text{maximize stiffness}) \times w_1 + (1 - w_1) \times (\text{maximize heat transfer})
\]

**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

<table>
<thead>
<tr>
<th>Design parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>E of material 1</td>
<td>4</td>
</tr>
<tr>
<td>K of material 1</td>
<td>2</td>
</tr>
<tr>
<td>Target percentage of material 1</td>
<td>15%</td>
</tr>
<tr>
<td>E of material 2</td>
<td>4</td>
</tr>
<tr>
<td>K of material 2</td>
<td>4</td>
</tr>
<tr>
<td>Target percentage of material 2</td>
<td>15%</td>
</tr>
</tbody>
</table>

#### Boundary Conditions

<table>
<thead>
<tr>
<th>Heat</th>
<th>Fixed</th>
</tr>
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<td>Fixed</td>
</tr>
</tbody>
</table>

**Where to place 15% of each material????**

Heat Source applied everywhere in domain

5. Results for different weights of the objectives.

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:


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