Topology Optimization of a Tank Track Pad: Targeting Hyper-Elastic Compliance using an Elastic Material Structure

By: Zachary Satterfield
Advisor: Dr. Georges Fadel
Department of Mechanical Engineering, Clemson University, SC

Motivation:
High temperatures in elastomer pads of military tanks decrease their structural integrity, life and high maintenance costs:
- Temperature issue due to hysteretic nature of elastomers
- Highly dynamic and cyclic loading conditions assumed to cause hysteresis

Objectives:
- Replace hyperelastic rubber with equivalent metal meta-material by:
  - Obtaining constitutive parameters to be used in the design of meta-materials to meet specific mechanical requirements
  - Implementing topology optimization and tailor meta-material with the determined constitutive parameters
  - Procuring optimized part via additive manufacturing and validating on Abrams tank

Previous Work:
- Determine Elastomer Properties
  - FEA analysis completed in ABAQUS provided strain history of current hyperelastic material
  - 9 constants from the symmetric hyperelastic tangent elasticity tensors were determined for each strain levels for pure stress states
  - Tensors across multiple strain levels were evaluated due to nonlinearity of material

Hyperelastic Tangent Elasticity Tensors per Strain Level

<table>
<thead>
<tr>
<th>Strain State</th>
<th>$C_{11}$</th>
<th>$C_{12}$</th>
<th>$C_{13}$</th>
<th>$C_{22}$</th>
<th>$C_{23}$</th>
<th>$C_{33}$</th>
<th>$C_{44}$</th>
<th>$C_{55}$</th>
<th>$C_{66}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uniaxial Tension (ET)</td>
<td>1.1</td>
<td>2.0</td>
<td>0.6</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>1.1</td>
<td>2.0</td>
<td>0.6</td>
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<tr>
<td>Biaxial Tension (ET)</td>
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<tr>
<td>Pure Shear (PS)</td>
<td>1.1</td>
<td>1.1</td>
<td>1.1</td>
<td>1.1</td>
<td>1.1</td>
<td>1.1</td>
<td>1.1</td>
<td>1.1</td>
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</tr>
</tbody>
</table>

Current Work:
- Targeted Results for Meta-Material:
  - Elastic material (e.g. steel)
  - Non-linear behavior
  - Meets strain targets for 3 pure stress states:
    - Uniaxial tension
    - Equi-biaxial tension
    - Pure shear

- Main Research Questions:
  1. Can non-linear hyperelastic behavior be achieved with an elastic meta-material (e.g. steel)?
  2. Can a multi-objective optimization be solved such that the resultant meta-material achieves 3 targeted non-linear stress-strain curves?
     - Should the target curves be weighted for optimization?
     - Should 3 layers be created with independent geometries?

Example of Topology Optimization:
- Problem: 2D cantilever beam (linear)
- Material: steel ($E = 200$ GPa, $\nu = 0.30$)
- Objective: maximize stiffness
- Constraint: 0.25 volume fraction

Future Work:
- Procurement
  - Create optimized meta-material via additive manufacturing processes
  - Material will currently be steel. Other possibilities exist (i.e. aluminum, titanium, alloys, etc.)
- Tank Trials
  - Validate prototypes on Abrams M1 tank under normal operating conditions

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- Dr. Nicola Curtis
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- Mr. Anupam Bhagat

Meshed FBD of Cantilever Beam: Green is Design Space and Yellow is Non-Design Space

Resulting Topology: Truss Structure

Topology Optimization

Procure & Test

T158 Track Pad System