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

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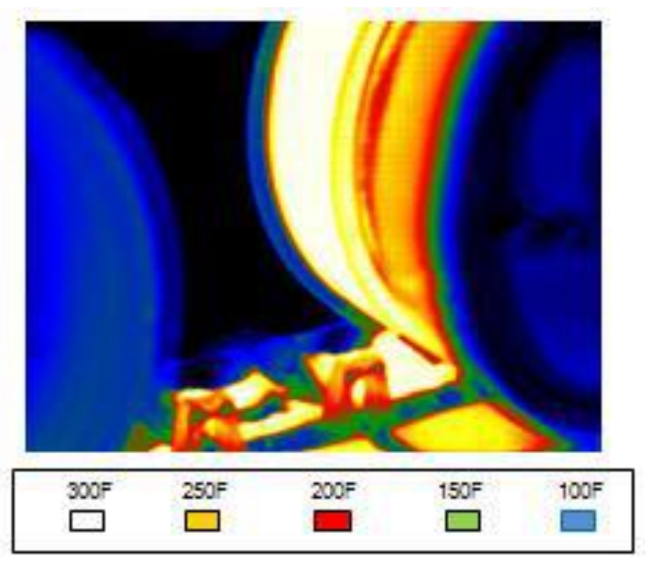
Motivation:

High temperatures in elastomer pads of military tanks decrease their structural integrity, life and high maintenance costs:

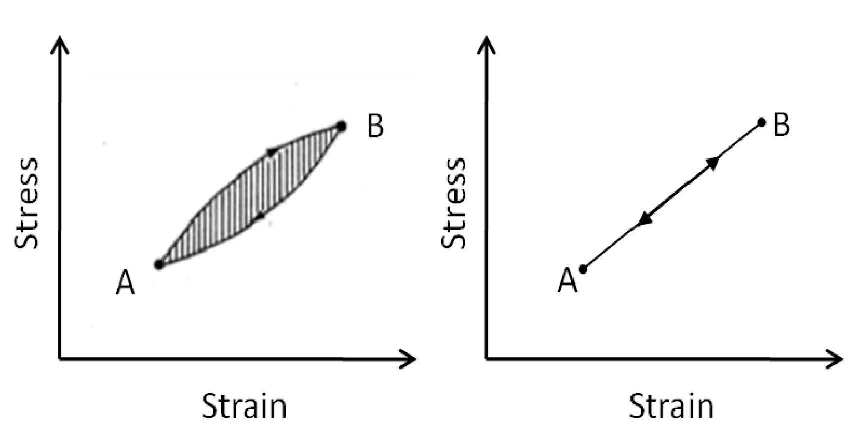
- Temperature issue due to hysteretic nature of elastomers

T158LL Track Pad Components



Thermal Map - Abrams left side (Bradford and Ostberg, 2009)

- Highly dynamic and cyclic loading conditions assumed to cause hysteresis



Stress-Strain diagram for elastomers and elastic materials (Clark and Dodge, 1979)

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

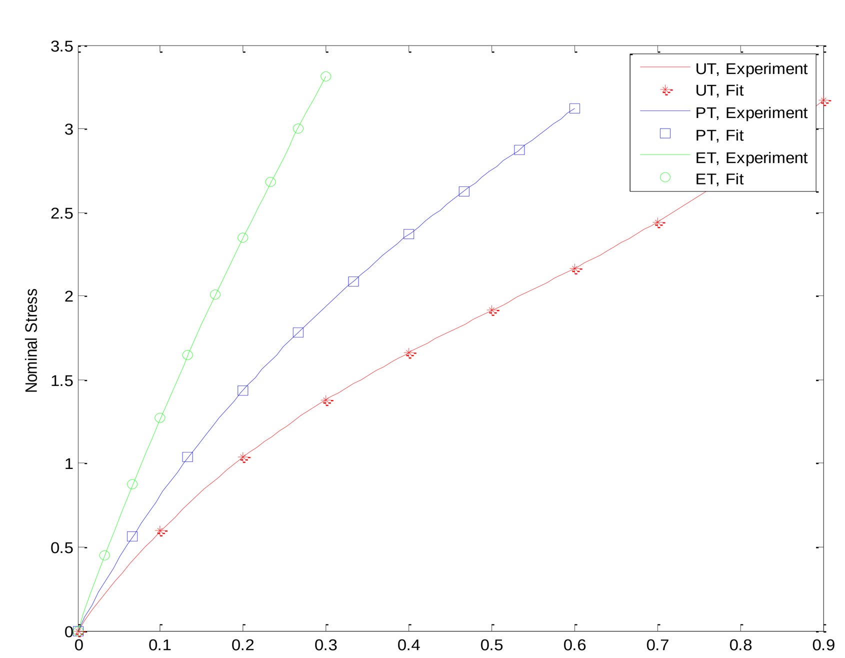
Previous Work:

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

Stress State	λ	$\mathbb{C}_{11}$	$\mathbb{C}_{22}$	$\mathbb{C}_{33}$	$\mathbb{C}_{44}$	$\mathbb{C}_{55}$	$\mathbb{C}_{66}$	$\mathbb{C}_{12}$	$\mathbb{C}_{23}$	$\mathbb{C}_{13}$
Uniaxial Tension (UT)	1.1	2.59	4.59	4.59	1.80	2.57	1.80	-0.26	-0.54	-0.26
	1.2	2.16	6.46	6.46	1.42	2.84	1.42	0.67	0.78	0.67
	1.3	1.83	8.83	8.83	1.15	3.16	1.15	1.37	2.51	1.37
	1.4	1.58	11.94	11.94	0.95	3.58	0.95	1.89	4.77	1.89
	1.5	1.42	16.15	16.15	0.81	4.17	0.81	2.30	7.81	2.30
	1.6	1.32	22.06	22.06	0.69	5.06	0.69	2.61	11.94	2.61
	1.7	1.27	30.60	30.60	0.62	6.43	0.62	2.87	17.74	2.87
Equi-biaxial tension (ET)	1.1	4.35	4.35	13.64	0.85	2.19	0.85	2.64	4.19	4.19
	1.2	4.72	4.72	42.15	0.12	2.04	2.04	4.49	12.30	12.30
	1.3	4.73	4.73	110.3	-0.24	1.90	1.90	5.22	23.30	23.30
Pure Shear (PS)	1.1	3.16	4.63	6.78	1.31	2.66	1.92	0.88	1.01	0.94
	1.2	2.97	6.16	12.78	0.63	3.01	1.61	2.46	4.50	3.26
	1.3	2.71	7.75	22.14	0.16	3.38	1.36	3.50	9.08	5.48
	1.4	2.46	9.48	36.42	-0.15	3.75	1.17	4.17	14.97	7.60
	1.5	2.26	11.44	57.91	-0.36	4.13	1.02	4.61	22.49	9.66
	1.6	2.09	13.76	90.16	-0.51	4.51	0.90	4.90	32.06	11.67

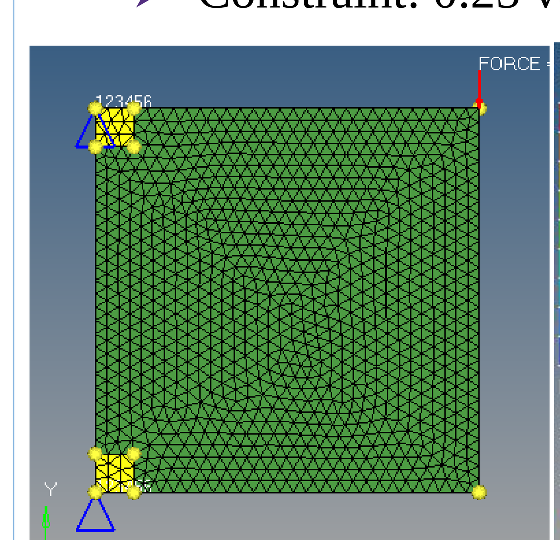


Stress-Strain Diagram for Uniaxial Tension, Equi-Biaxial Tension, and Pure Shear

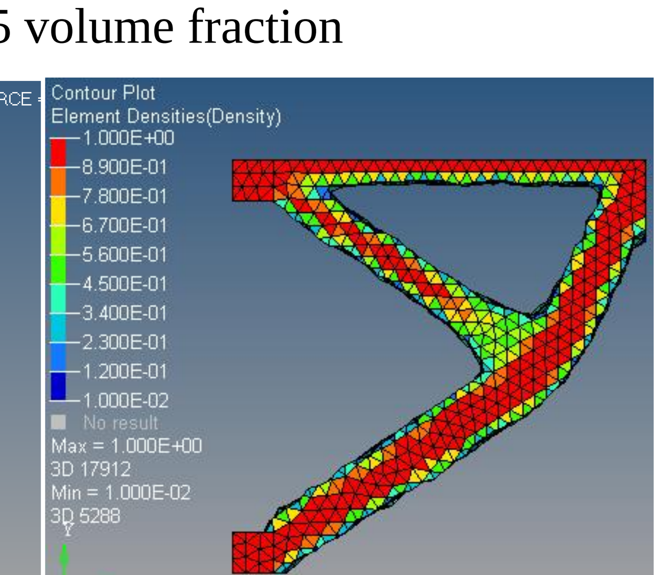
Current Work:

Topology Optimization

- 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?
     1. Should the target curves be weighted for optimization?
     2. Should 3 layers be created with independent geometries?
- Example of Topology Optimization:
  - Problem: 2D cantilevered beam (linear)
  - Material: steel (E = 200 GPa, ν = 0.30)
  - Objective: maximize stiffness
  - Constraint: 0.25 volume fraction



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



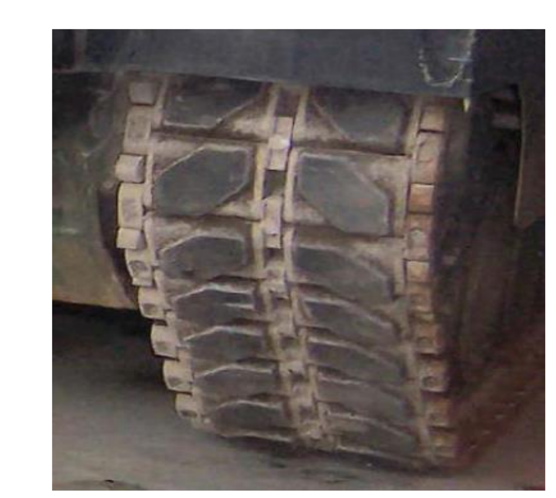
Resulting Topology: Truss Structure

Future Work:

Procure & Test

- 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



T156 Track Pad System

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