Design Optimization and Testing of Meta-Material Tank Track System

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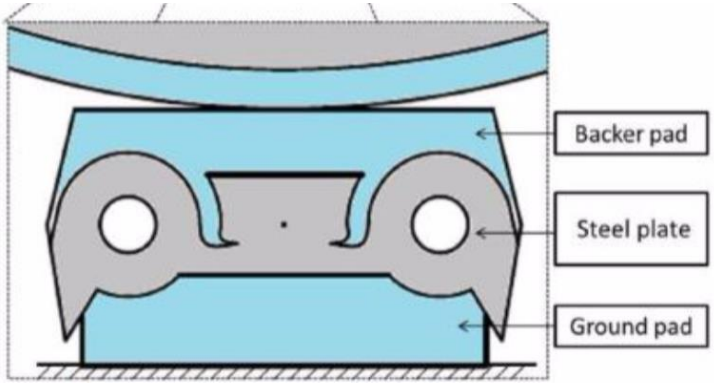
Outline

1. Background
2. Discrepancy Investigation Conclusions
3. High Cycle Fatigue Testing
4. Current Work: Pad/Wheel System
5. Future Work

BACKGROUND

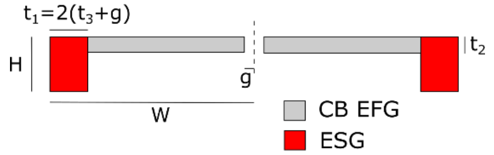
Background

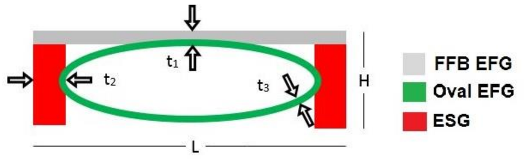
- Furthering the work of Neehar Kulkarni & Zach Satterfield
  - Original Goal: Develop/design a meta-material that exhibits non-linear deformation responses under loading conditions.
- A unit cell synthesis method was developed for the design of meta-materials with non-linear responses
  - Utilizes several types of beams, set up in both series and parallel, much like resistors and capacitors in circuits

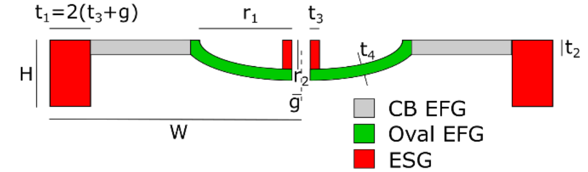


Background

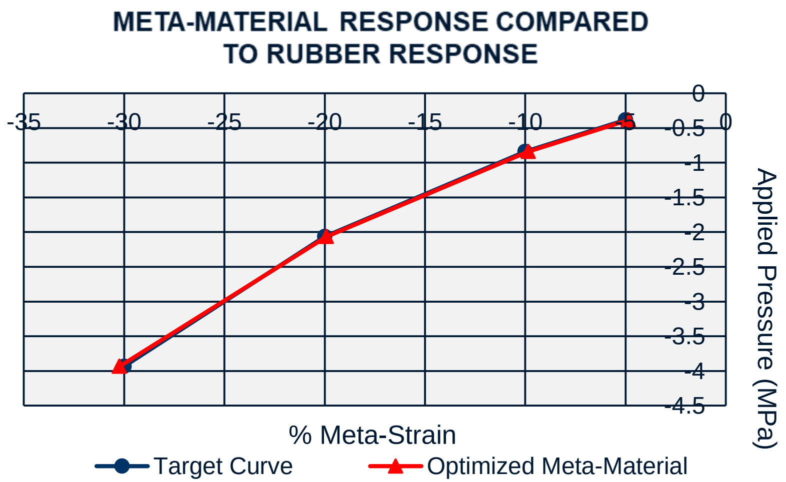
- Several designs were considered
  - Ultimately a canti-oval design was found to provide the closest mechanical response





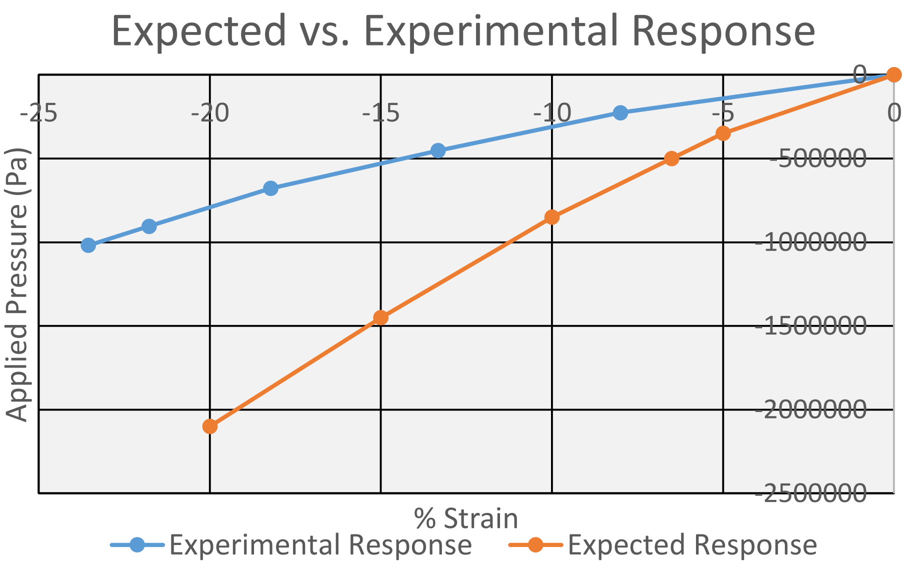


- Titanium characteristics were used in the models, and a titanium alloy powder was used to print a physical specimen for testing.



Background

- Subjected the titanium pad to 5 loading conditions
  - 5kN, 10kN, 15kN, 20kN, 25kN
- Testing revealed that the pad does behave non-linearly when subjected to loading
- The displacements are much larger than expected at each loading increment
  - The displacement experienced at 2MPa in Abaqus was experienced at 1MPa in the testing



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DISCREPANCY INVESTIGATION CONCLUSIONS

Discrepancy Investigation

- Identified three potential influential factors in the pad manufacturing and testing that could be deviating results
  - Printing accuracy for interior geometries
  - Inaccurate FEA boundary conditions
  - Material properties of 3D printed parts

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Sensitivity Analysis of Dimensions

- Established the 15 free variables of the pad optimization in a DOE
- Either added or subtracted the accuracy of the printer, 0.1mm, to each variable
- Used to determine the importance values of the dimensions, telling us which variables have the most influence on performance

$L_{16}(2^{15})$ ORTHOGONAL ARRAY TABLE

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2
3	1	1	1	2	2	2	2	1	1	1	1	2	2	2	2
4	1	1	1	2	2	2	2	2	2	2	2	1	1	1	1
5	1	2	2	1	1	2	2	1	1	2	2	1	1	2	2
6	1	2	2	1	1	2	2	2	2	1	1	2	2	1	1
7	1	2	2	2	2	1	1	1	1	2	2	2	2	1	1
8	1	2	2	2	2	1	1	2	2	1	1	1	1	2	2
9	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
10	2	1	2	1	2	1	2	2	1	2	1	2	1	2	1
11	2	1	2	2	1	2	1	1	2	1	2	2	1	2	1
12	2	1	2	2	1	2	1	2	1	2	1	1	2	1	2
13	2	2	1	1	2	2	1	1	2	2	1	1	2	2	1
14	2	2	1	1	2	2	1	2	1	1	2	2	1	1	2
15	2	2	1	2	1	1	2	1	2	2	1	2	1	1	2
16	2	2	1	2	1	1	2	2	1	1	2	1	2	2	1

IMPORTANCE VALUES FOR DESIGN PARAMETERS

Var	Load 1	Load 2	Load 3	Load 4	Average
t_4	0.59	1.09	1.49	1.81	1.25
E	0.36	1.02	1.42	1.77	1.14
t_3	0.41	0.78	1.10	1.38	0.92
t_2	0.48	0.83	1.07	1.22	0.90
G	0.32	0.59	0.81	0.98	0.67
H	0.22	0.40	0.53	0.64	0.45
r_2	0.15	0.32	0.50	0.67	0.41
f_2	0.11	0.19	0.25	0.47	0.26
f_4	0.11	0.18	0.21	0.24	0.18
f_3	0.07	0.14	0.20	0.25	0.17
W	0.06	0.13	0.20	0.27	0.17
f_1	0.07	0.13	0.16	0.18	0.14
BT	0.05	0.08	0.10	0.11	0.08
TT	0.03	0.04	0.05	0.05	0.04
r_1	0.03	0.04	0.03	0.02	0.03

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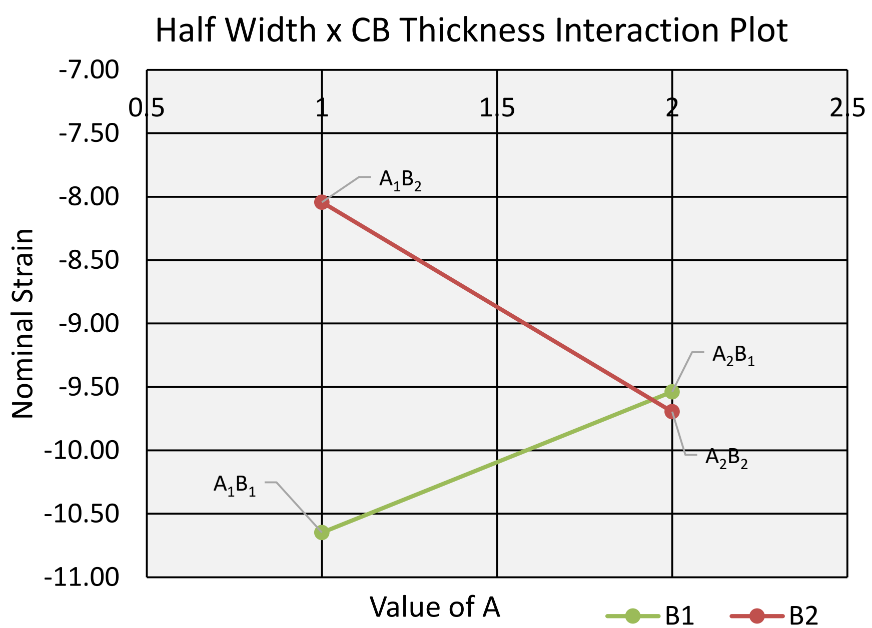
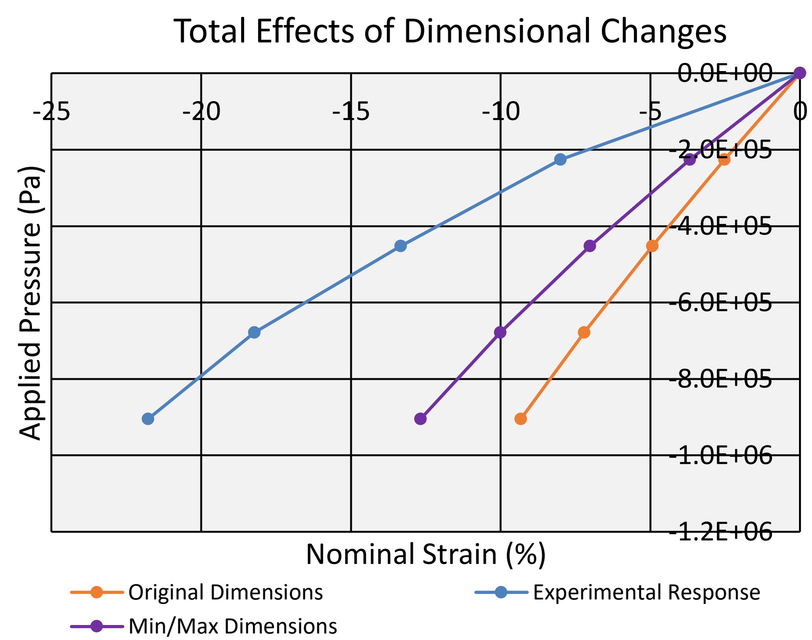
Sensitivity Analysis of Dimensions

- Using interaction plots, relationships between variables could be identified.
- Most importantly, identified which variables need to be increased to soften the response
- Provided combination of changes that would produce softest response

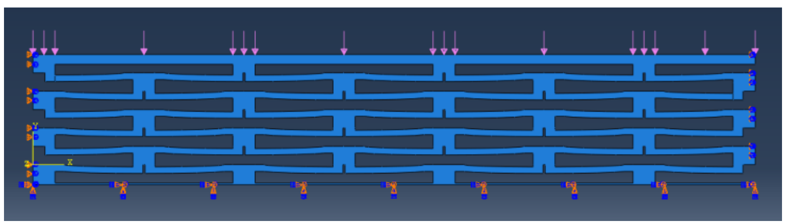


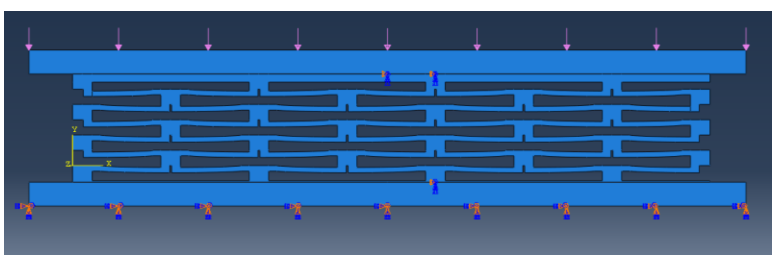


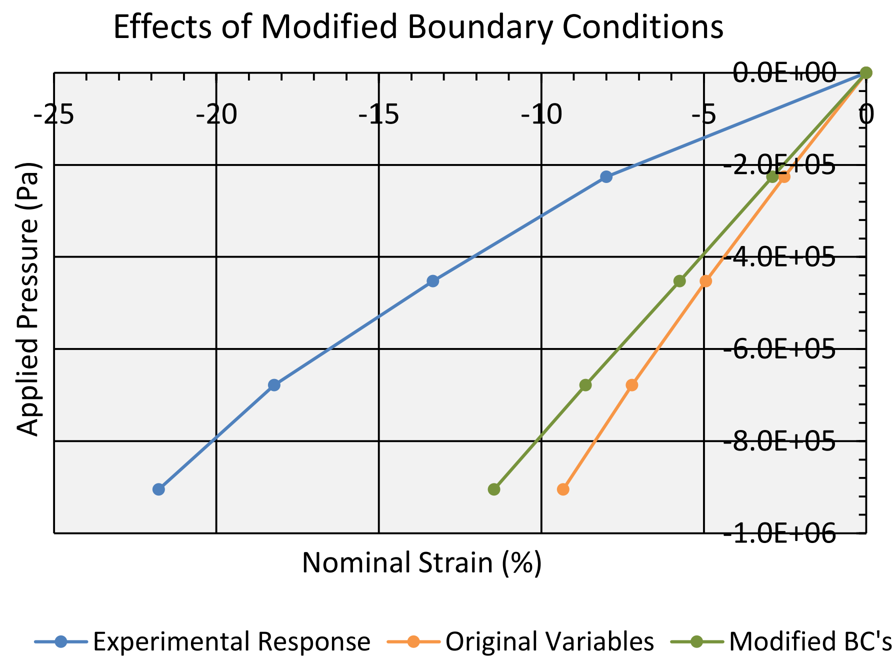
Boundary Condition Correctness

- FEA model needed updated boundary conditions to accurately represent the experimental setup.

- Added upper and lower compressive plates, introducing contact into the simulation







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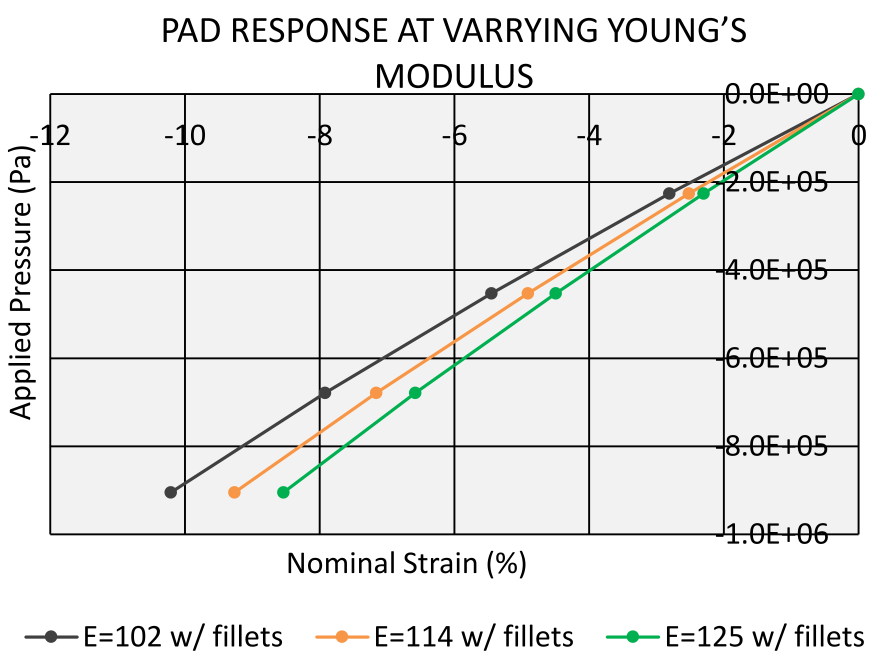
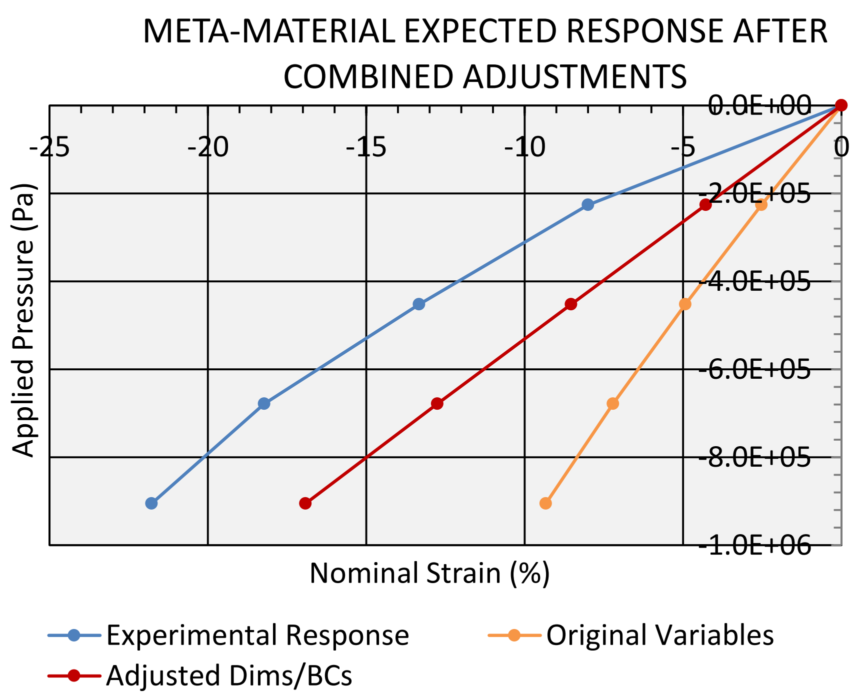
Boundary Condition Correctness

- The effects of material properties were investigated via FEA
- Tensile tests could not be conducted to confirm material properties of 3D printed parts
- Because of this, E remained at 114GPa for the combined figure





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FATIGUE TESTING

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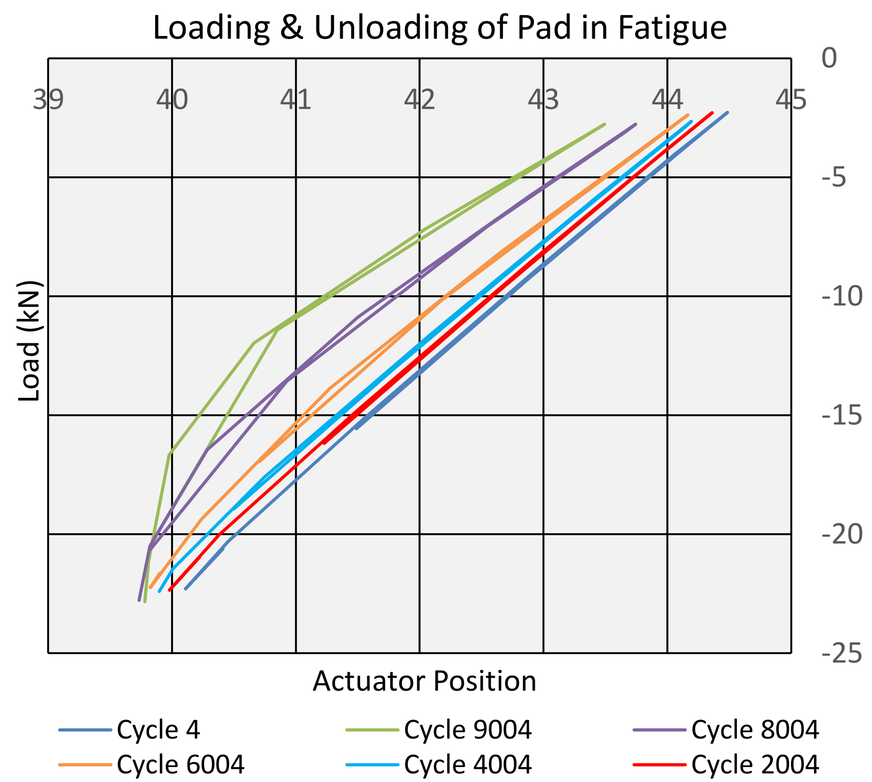
HCF

- Subjected the pad to cyclic loading to asses performance under high cycle fatigue conditions
- A load ratio of 0.05 was used for the test, with a max load of 22.5kN
- Models indicated that the pad would reach the 400,000 cycle goal at 22.5kN, with infinite life predicted at loads >13.5kN
- However, with experimental strains x2 higher than anticipated by the models, failure occurred at somewhere around 8000 cycles



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PAD/WHEEL SYSTEM

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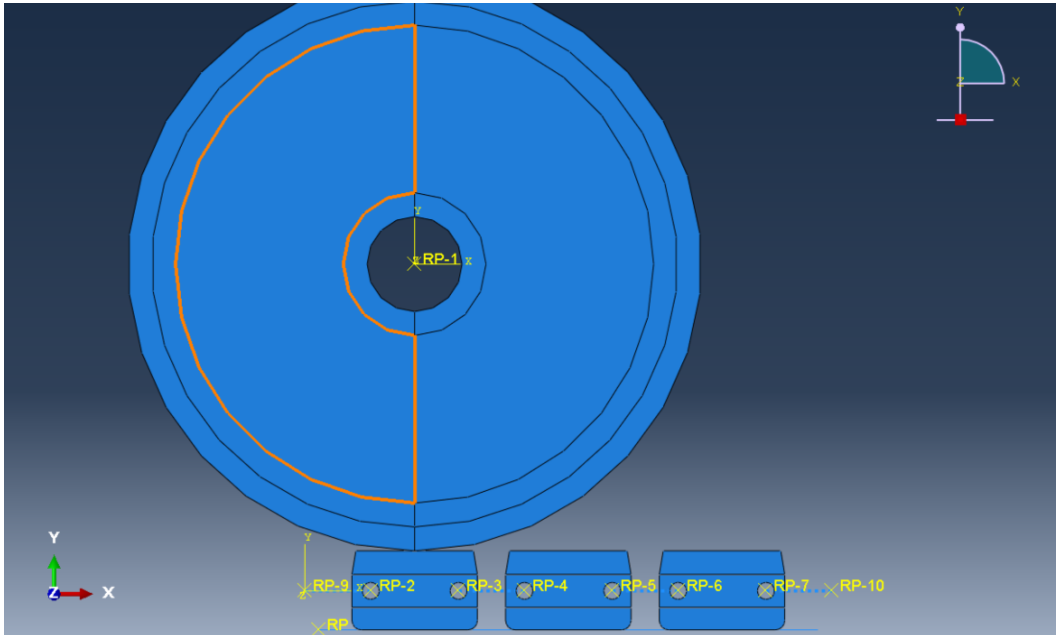
Pad/Wheel System Optimization

- Current tank uses rubber for both the pad and a thin strip along the perimeter of the wheel
- Is it possible to replace the thin rubber with a similar cellular design, and optimize both to mimic the overall system response



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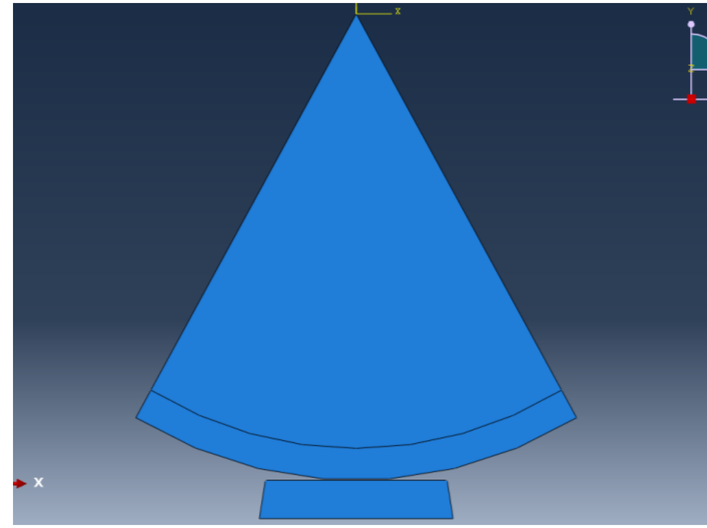
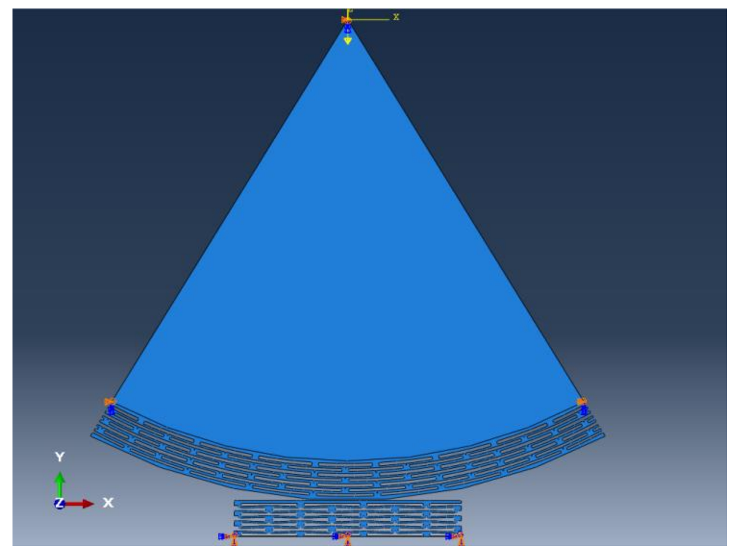
Pad/Wheel System Optimization

- Used the original cant-duo design, mapped in spherical coordinates, to replace the rubber perimeter
- Using smaller slice of the whole wheel to save computational resources
- Goal is to match the displacement of the original rubber-rubber model at 5 loads – 5, 10, 15, 20, 22.5kN
- Currently, 13 design variables across the two designs, based on previous documentation





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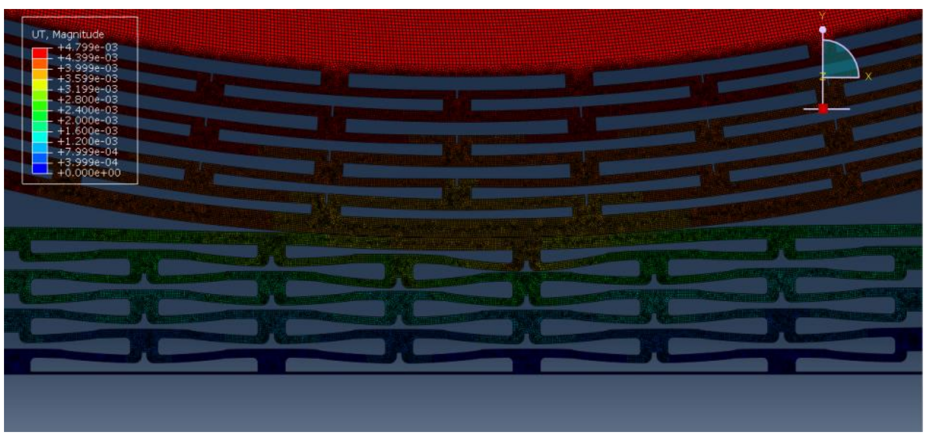
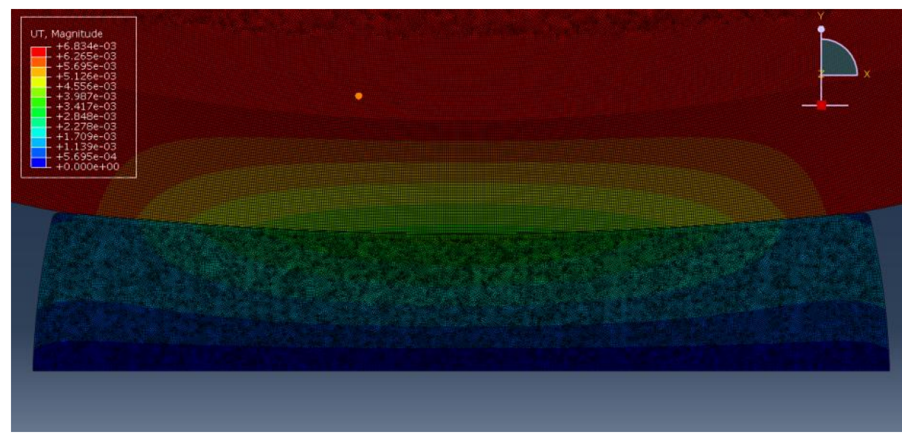
Pad/Wheel System Optimization

- Currently, comparisons between the two models have been observed for the 5 loads, with corresponding strains

Meta-Meta					Rubber-Rubber			
Load (N)	Disp (m)	Strain (%)	diff		Load (N)	Disp (m)	Strain (%)	diff
0	0	0			0	0	0	
-5000	-1.11E-03	-4.89			-5000	-2.69E-03	-10.76	
-10000	-2.16E-03	-9.50	-4.61		-10000	-4.13E-03	-16.50	-5.74
-15000	-3.12E-03	-13.75	-4.25		-15000	-5.33E-03	-21.31	-4.81
-20000	-4.05E-03	-17.83	-4.08		-20000	-6.34E-03	-25.37	-4.06
-22500	-4.50E-03	-19.84	-2.01		-22500	-6.81E-03	-27.23	-1.86





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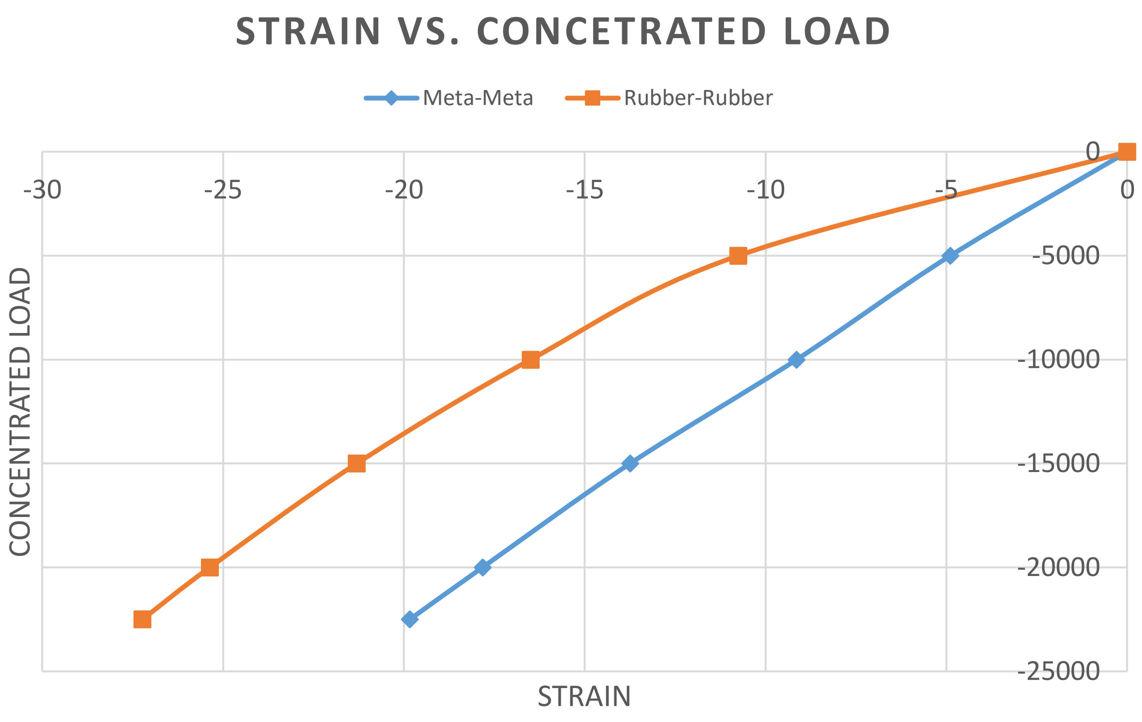
FUTURE WORK

Next Steps

- Next: Optimize both the pad and the band around the wheel to match the displacement curve of the rubber-rubber system



- After vertical quasi-static loads, model a rotating wheel passing over the pad, introducing shear forces and more accurately modeling the system

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Thank You!

Thank you for your attention!

Questions??

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