

Constitutive and Predictive Modeling of cDLP Additively Manufactured Hyperelastic Polymers for Soft Robotics

Kevin Lawson, Dr. Robert Lowe, Virtual Brother Joseph W. Stander Symposium
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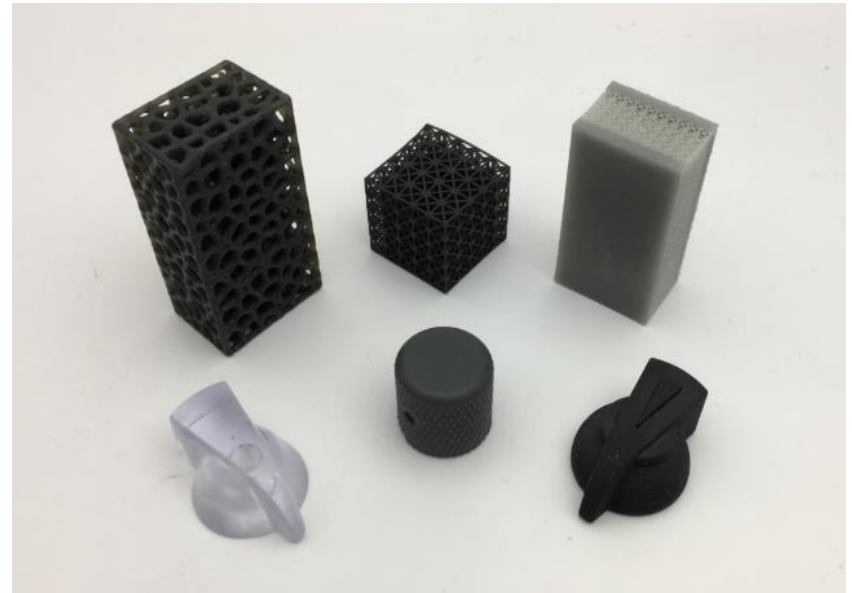
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Key Points

- Background
 - Elastomers
 - Applications
 - Digital Light Processing
- Material Modeling
 - Constitutive Modeling
 - Finite Element Analysis
- Next Steps
 - Mechanical Testing
 - More Material Modeling

Elastomers

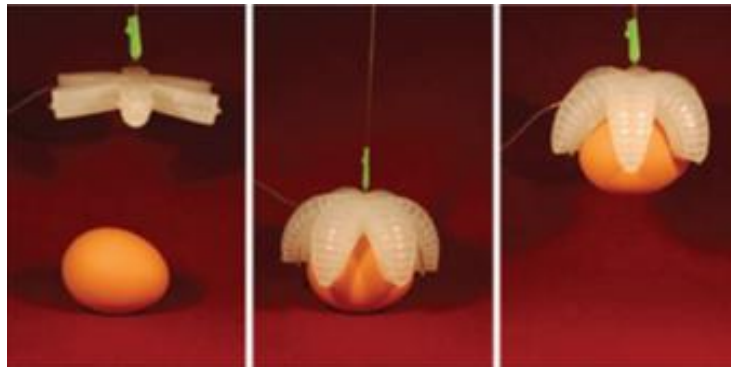
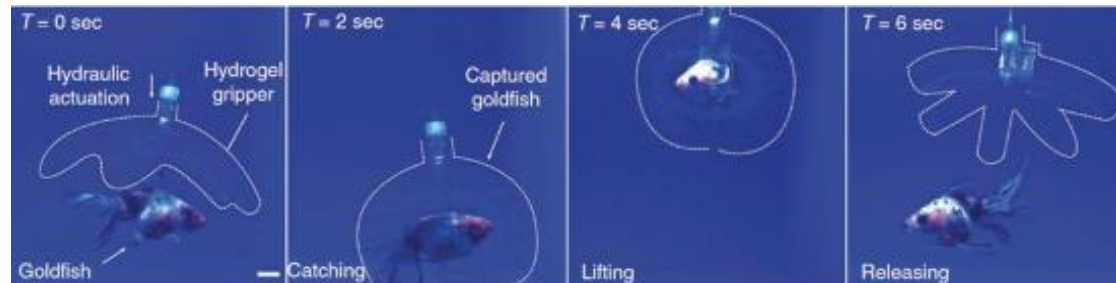
- Soft, stretchy polymers
 - Deformable
 - Electrical and thermal insulators
- Applications
 - Lattice Structures
 - Honeycomb geometries
 - Metamaterials
 - Soft Robotics



Courtesy of the Additive Manufacturing Technology Development (AMTD) Group at the University of Dayton Research Institute

Soft Robotics

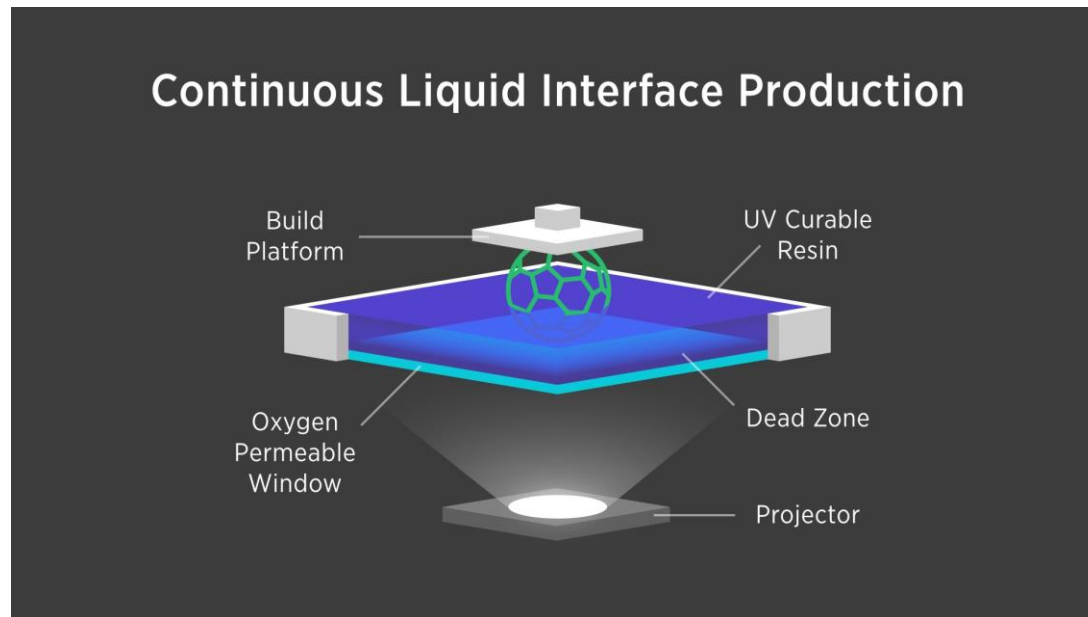
- Actuators made of hyperelastic materials
- Multiple avenues for activation
 - Pneumatic, electronic, hydraulic
- Safe for interaction with fragile items



Courtesy of Shintake et al, *Adv. Mater.*,
30, 1707035 (2018)

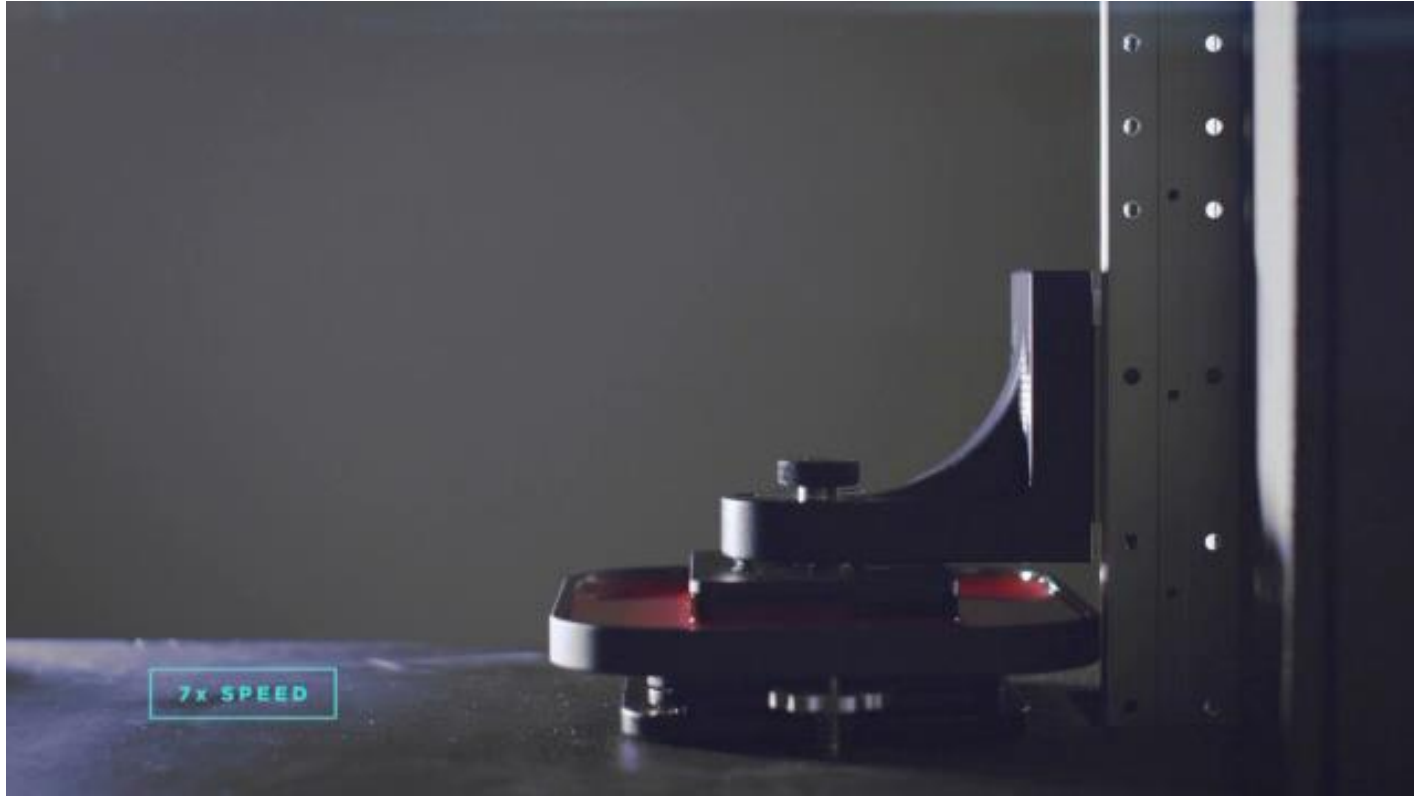
DLP 3D Printing

- Digital Light Processing (DLP)
 - Continuous Digital Light Processing (cDLP)
 - 3D Systems Figure 4 printers housed at UDRI
- Higher efficiency, capability



Courtesy of <https://www.tth.com/carbon-clip/>

cDLP 3D Printing



Courtesy of

<https://www.businesswire.com/news/home/20150316006482/en/3448395/Carbon3D-Introduces-CLIP-Breakthrough-Technology-Layerless-3D>

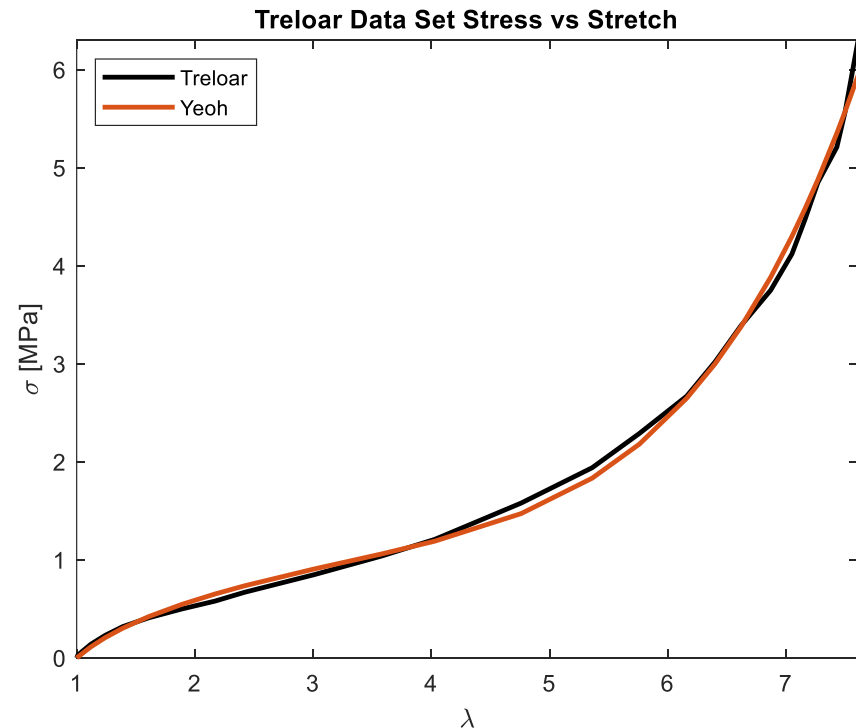
Hyperelastic Modeling

- Derivations of a strain energy equation (Ψ)

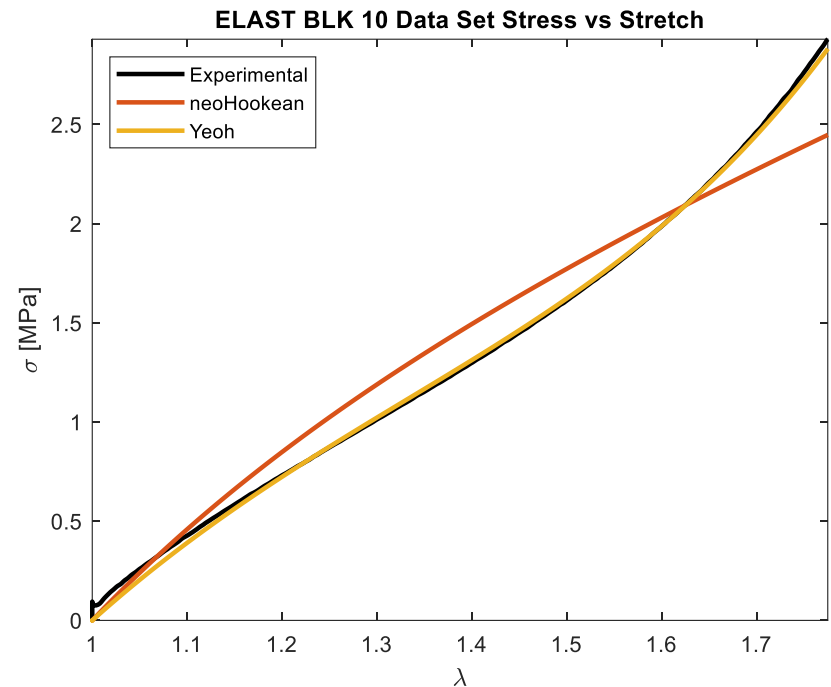
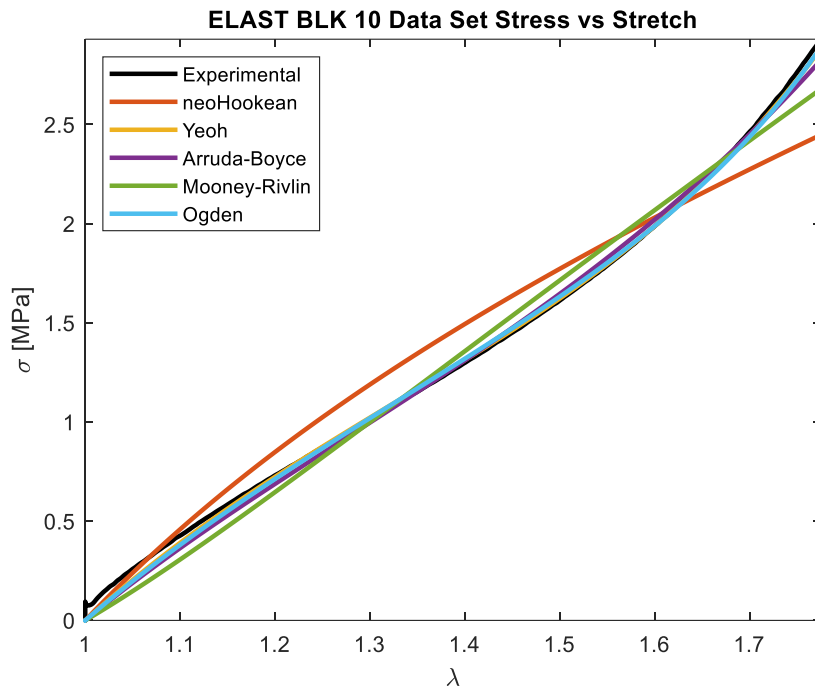
$$\Psi_{\text{Yeoh}} = c_1(I_1 - 3) + c_2(I_1 - 3)^2 + c_3(I_1 - 3)^3$$

$$\sigma_{\text{Yeoh}} = 2 \left(\lambda^2 - \frac{1}{\lambda} \right) (c_1 + 2c_2(I_1 - 3) + 3c_3(I_1 - 3)^2)$$

- Used to predict the stress-stretch relationship for hyperelastic polymers

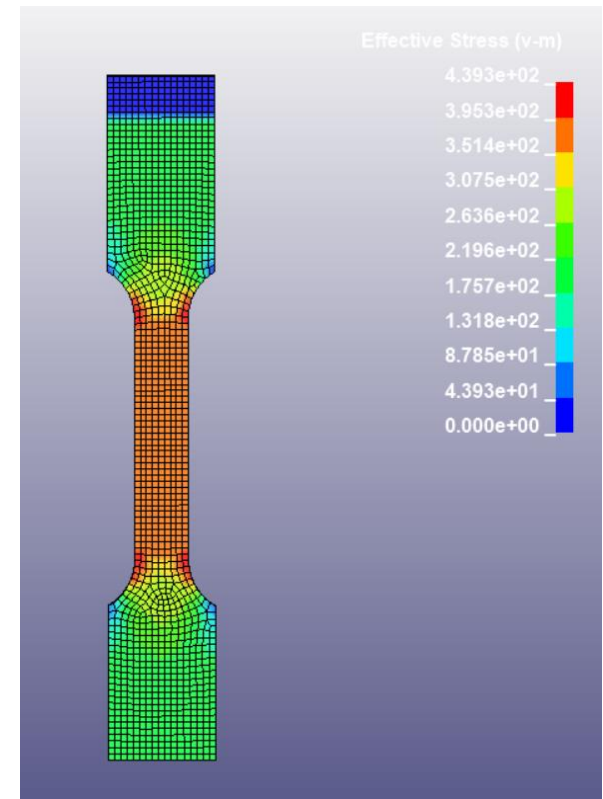
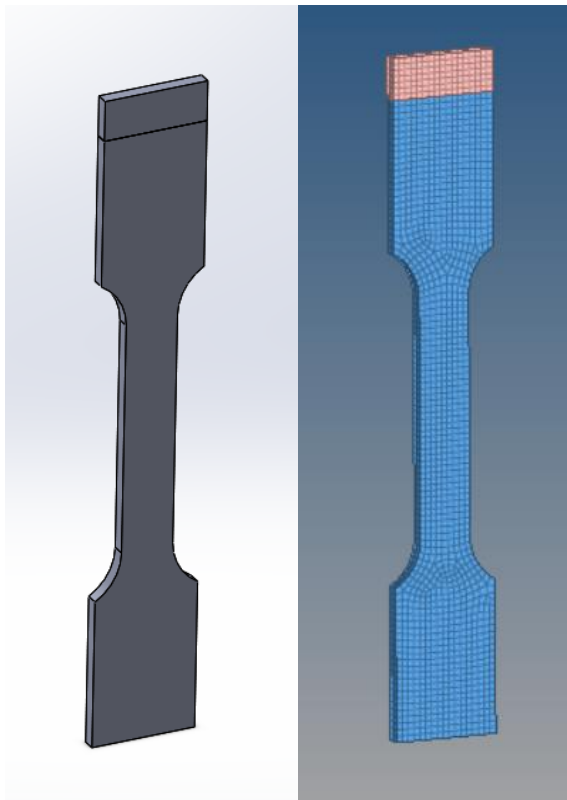


Hyperelastic Modeling



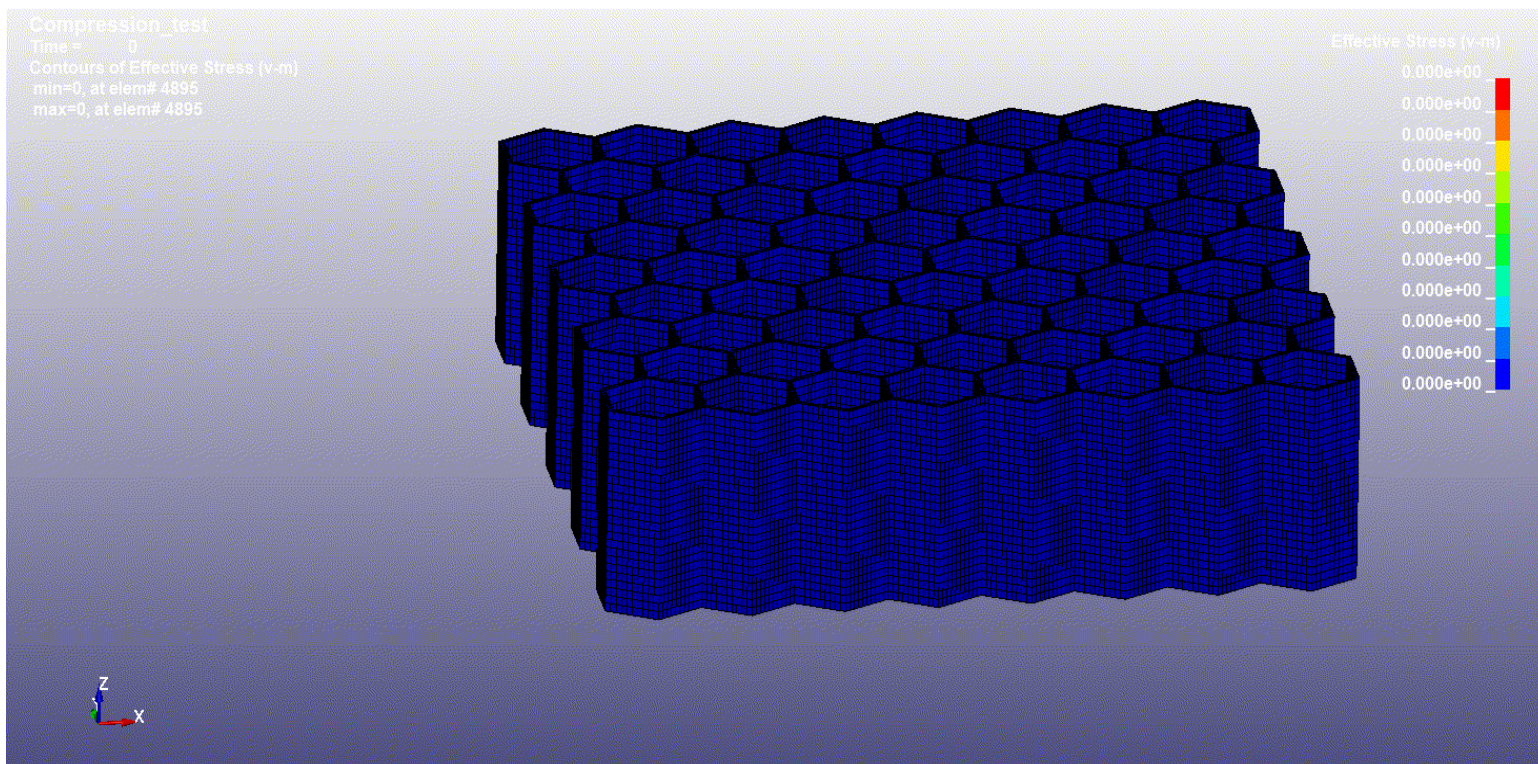
- Calibration of various hyperelastic material models to ELAST BLK 10 uniaxial tension test data

Finite Element Analysis



With LS-DYNA

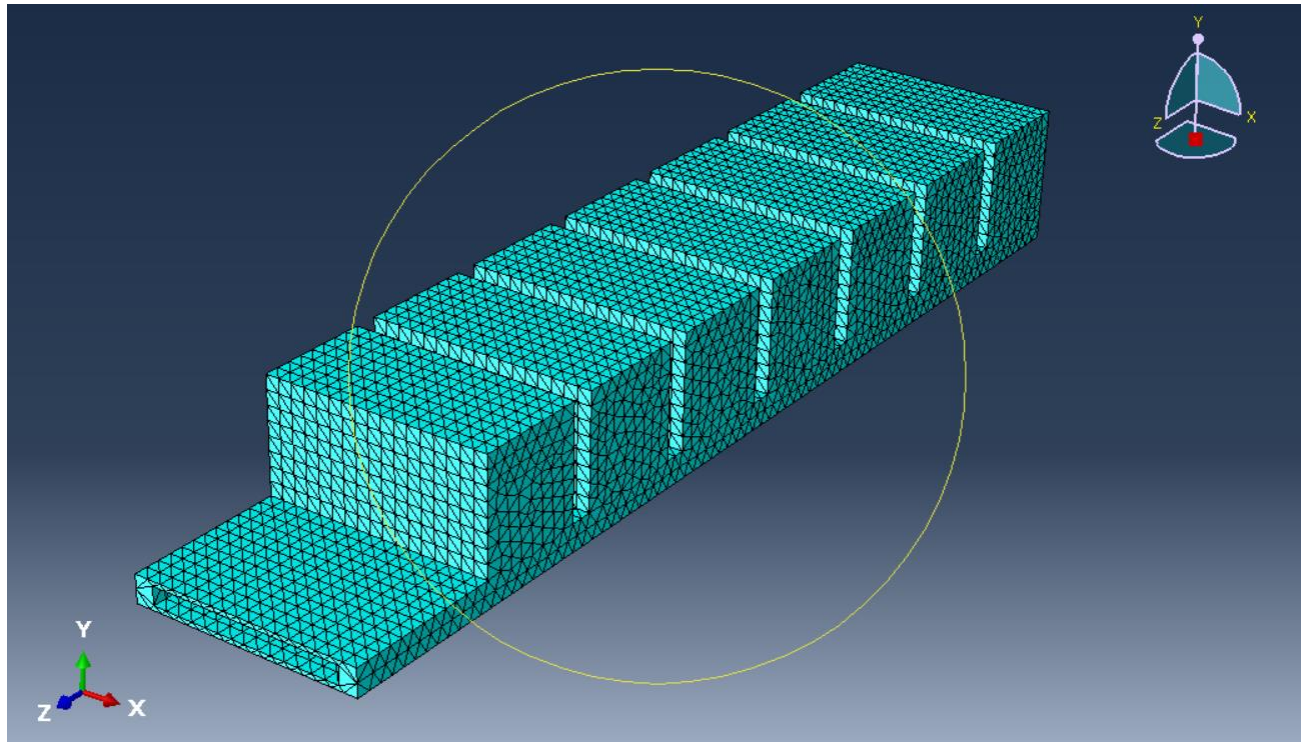
Honeycomb Simulation



With LS-DYNA

Next Steps

- Finite Element simulation of a soft material

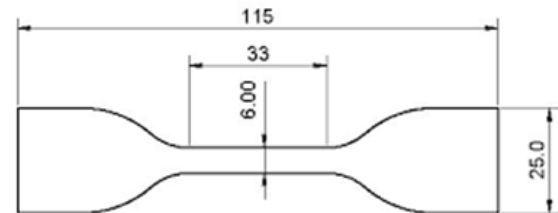


With Abaqus

Next Steps

- Mechanical testing and material modeling for SilOHflex
- Investigate the effectiveness of different models and material card simulation inputs
 - The Gent Model (below)

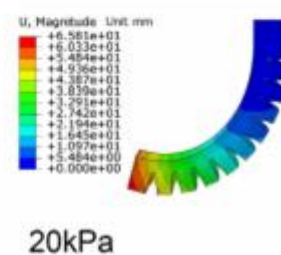
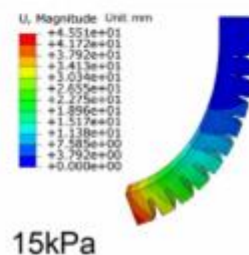
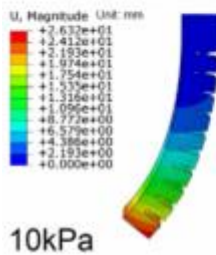
$$\Psi = -J_m \frac{\mu}{2} \ln\left(1 - \frac{(I_1 - 3)}{J_m}\right)$$



ASTM D412 Type C Specimen

Next Steps

- Fabricating and testing soft robotic actuators



Courtesy of Ge et al, *Sensors and Actuators A: Physical*, 273, 285–282 (2018)

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- University of Dayton
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Thank You

Questions?

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