Characterization of the Structure and Behavior of Gyroid Geometry for Simulating Human Tissue in Composite Materials

CMRR Center for Magnetic Recording Research

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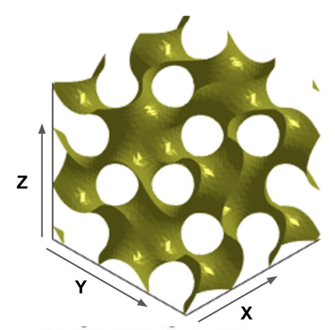
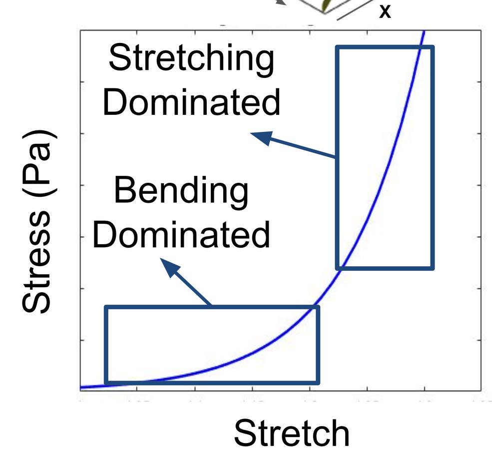
Medical Motivation

- Soft living tissue displays strain-hardening behavior
  - Tangent modulus increases during stretching, resulting in a J-shaped stress-strain response
- Current medical models, typically made of solid silicone, display strain-softening behavior
- Developing a “tunable” composite material using gyroid geometry is essential to accurately replicate the mechanical properties of soft tissue for improved medical models

Gyroid



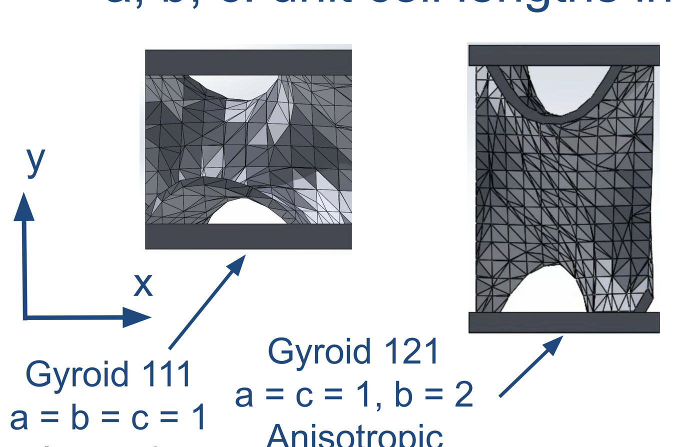
- 3D periodic open-cell structure composed of curved surfaces
- Exhibits nonlinear stress-strain behavior, transitioning from bending-dominated elongation to stretching-dominated elongation under increased tension
- Defined by the following equation:



$$t = sin(\frac{2\pi}{a}x)cos(\frac{2\pi}{b}y) + sin(\frac{2\pi}{b}y)cos(\frac{2\pi}{c}z) + sin(\frac{2\pi}{c}z)cos(\frac{2\pi}{a}x)$$

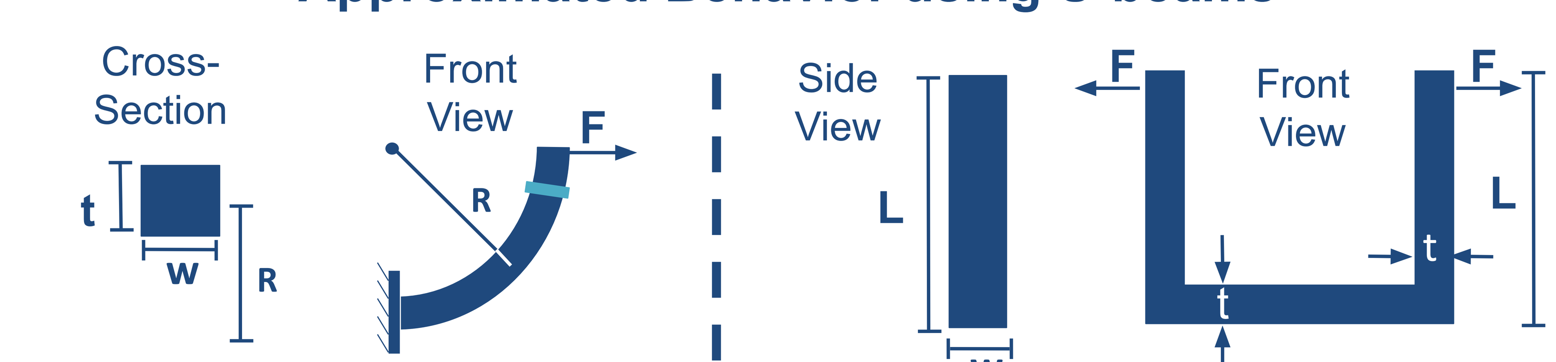
t: scalar field of gyroid surface

a, b, c: unit cell lengths in the x, y, and z direction



- If a = b = c, the generated gyroid is isotropic
- Varying these values can induce anisotropy.

Approximated Behavior using U-beams



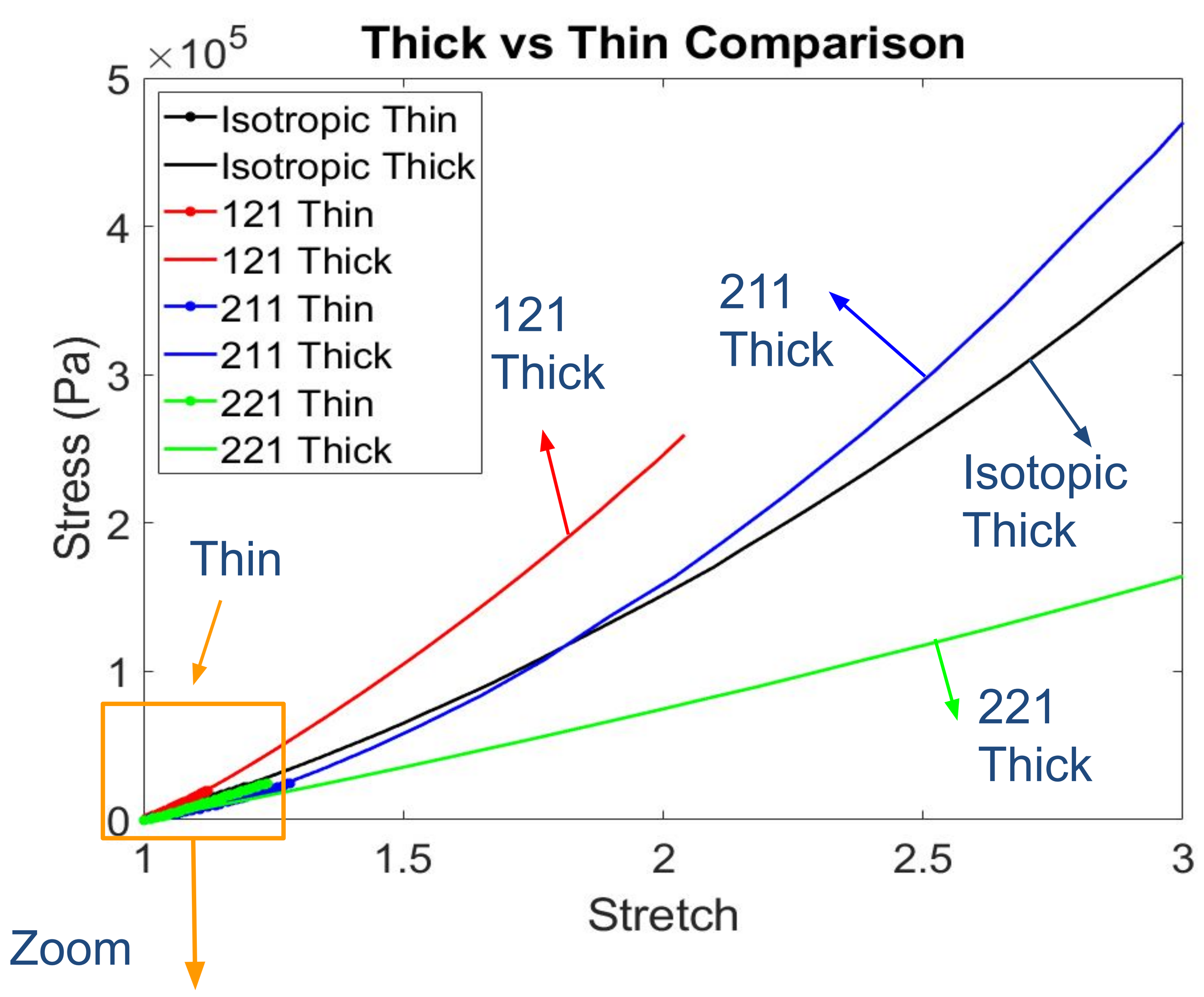
$$\frac{\Delta d_{bend}}{\Delta d_{stretch}} \propto \frac{R^2}{t^2}$$

$$\frac{\Delta d_{bend}}{\Delta d_{stretch}} \approx \frac{4FL^3}{t^2 d(F-Ewt)}$$

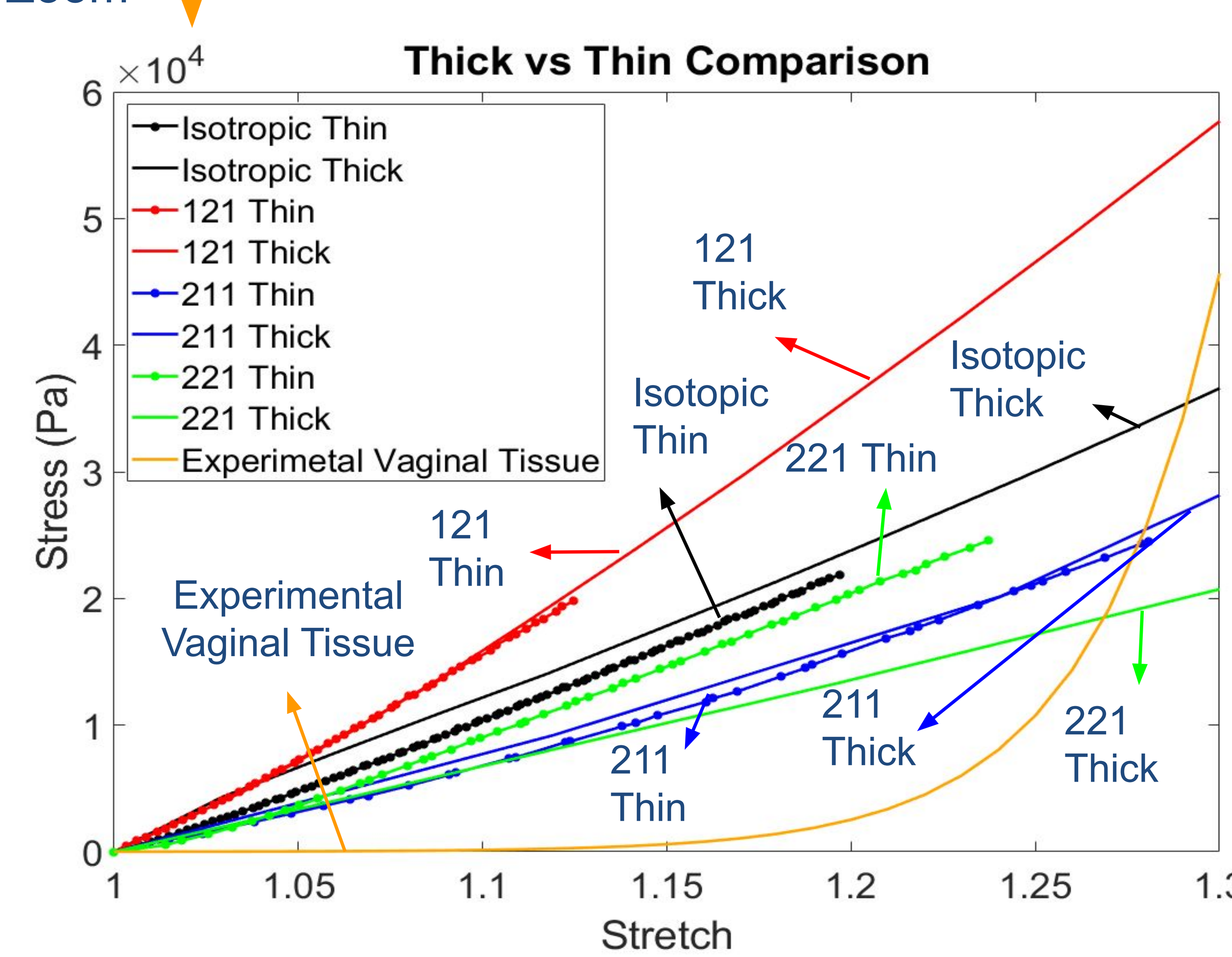
- $\Delta d_{bend} > \Delta d_{stretch}$ to produce bending-dominated behavior
- Expect that **increasing L or R** and **decreasing t** leads to strain-hardening

Finite Element Analysis

- Simulations of gyroids under tension were performed to assess the impact of design parameters on the stress-strain behavior
- Done in LS-Dyna with silicone as the gyroid material
- Approximately 45,000 elements per simulation, 2D element size of 0.2mm, and run time between 2-4 days



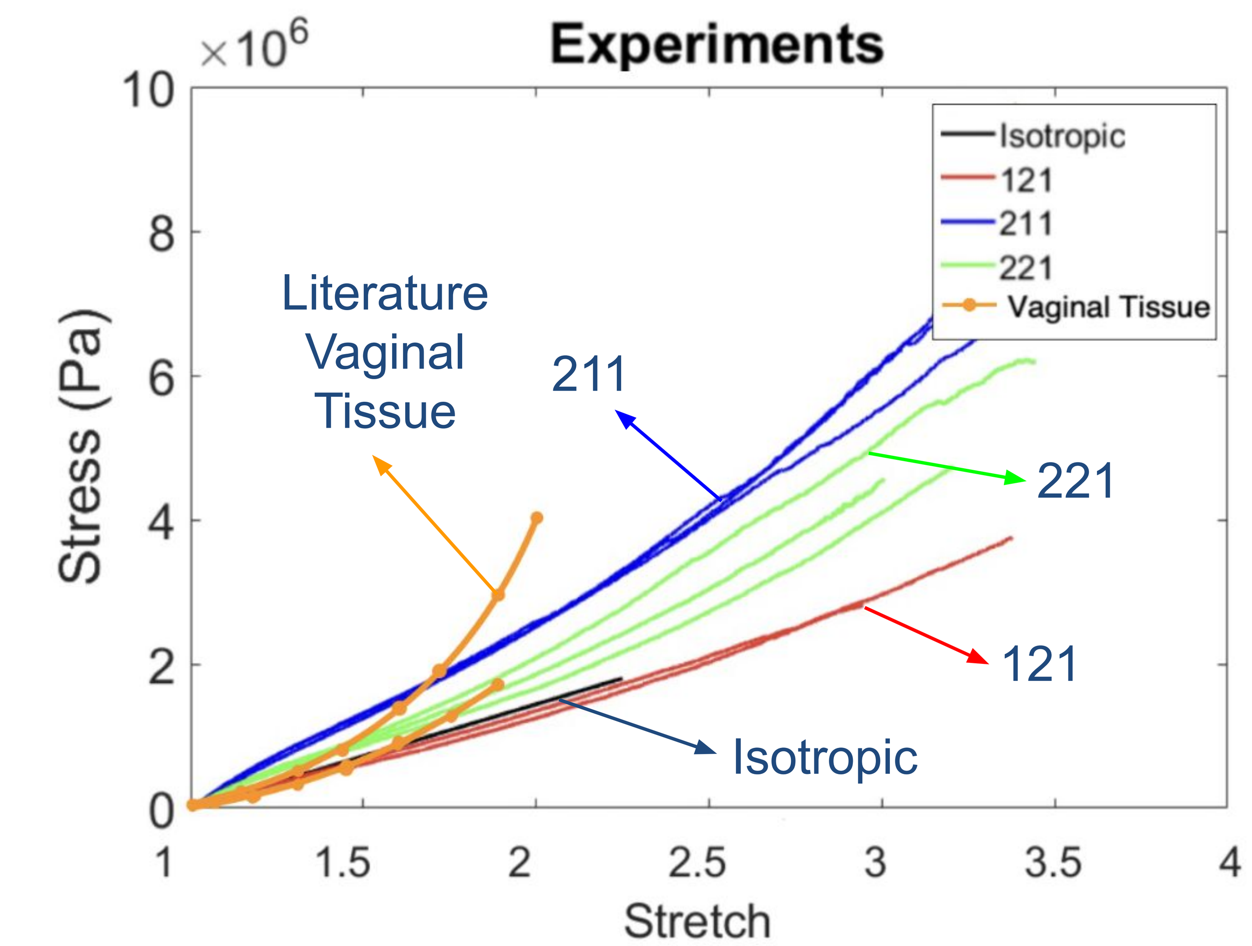
- Thick = 0.2 mm wall thickness
- Thin = 0.05 mm wall thickness

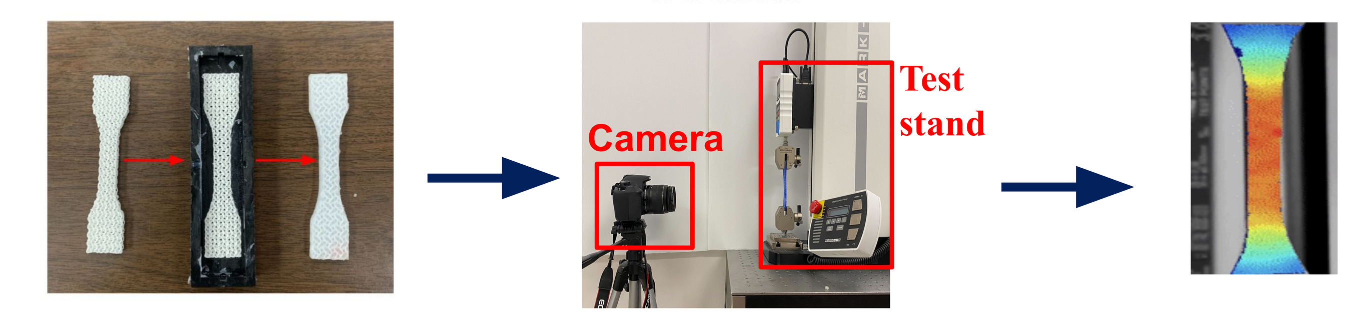


Stretch = Current Length / Original Length

- Strain-hardening behavior can be observed in the anisotropic gyroids, specifically the 211 Thick gyroid
- This can be used to create even more pronounced strain-hardening behavior with different a, b, and c values and different materials

Experiments





- Thermoplastic polyurethane gyroid encased in soft silicone
- Multiple trials plotted for each configuration
- Digital image correlation for strain calculations

Conclusions & Future Work

- Modifying the gyroid design parameters influences stress-strain behavior, observed in both simulations and experiments
- Direct comparison between simulations and experiments is challenging due material differences
- Future work includes simulations with TPU material, incorporating a soft matrix encasing the gyroid, and transitioning from 1-cell to multi-cell gyroids

Acknowledgements

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