Cyclical Loading Response of Novel 3D Composite for Soft Tissue Simulation

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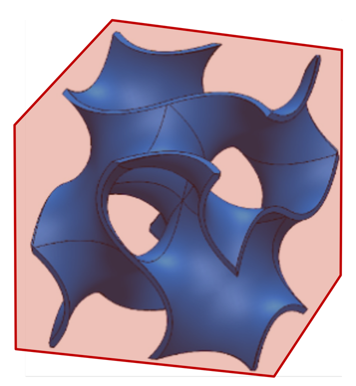
Objective

The goal of this project is to explore the mechanical behavior of a novel composite analog for soft tissue after cyclical loading. We propose an architected material comprised of a silicone matrix and a 3D printed thermoplastic polyurethane (TPU) scaffold with a "gyroid" structure. The Mullin's effect of the material with cyclic tensile load is observed with three different coupon configurations: isotropic, longitudinal anisotropic, and latitudinal anisotropic.

Introduction



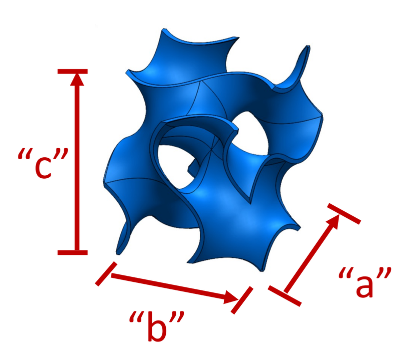
Scaffold/reinforcement material
- Stiff 3D printed polyurethane
- Gyroid structured

Matrix material
- Soft silicone

- The ***matrix material*** is the support material that surrounds the scaffold. We used an 00-30 Shore hardness silicone as the matrix.
- The ***scaffold*** refers to the 60A Shore hardness 3D printed thermoplastic polyurethane (TPU) used to induce nonlinear stress-stretch response. The structure uses a "gyroid" configuration, a 3D periodic open-cell geometry defined by the equation:

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

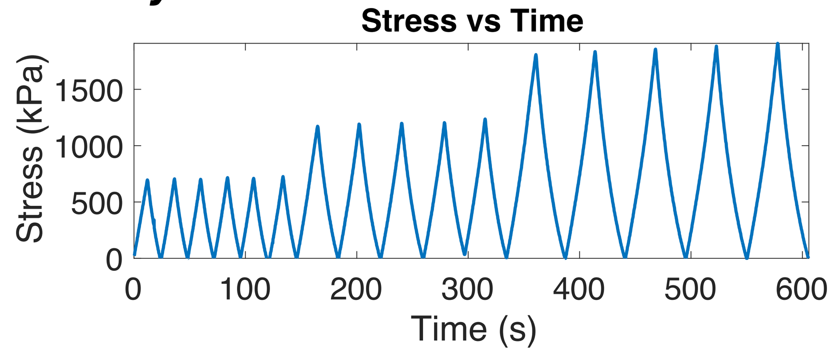
where "a", "b", and "c" are the unit cell lengths in 10mms.



- *Anisotropy* is introduced by increasing the unit cell lengths by setting the coefficients [abc] from [111] to [211] longitudinal extended and [121] latitudinal extended.
- Gyroids scaffolds are printed with 0.6mm wall thickness

Experimental setup

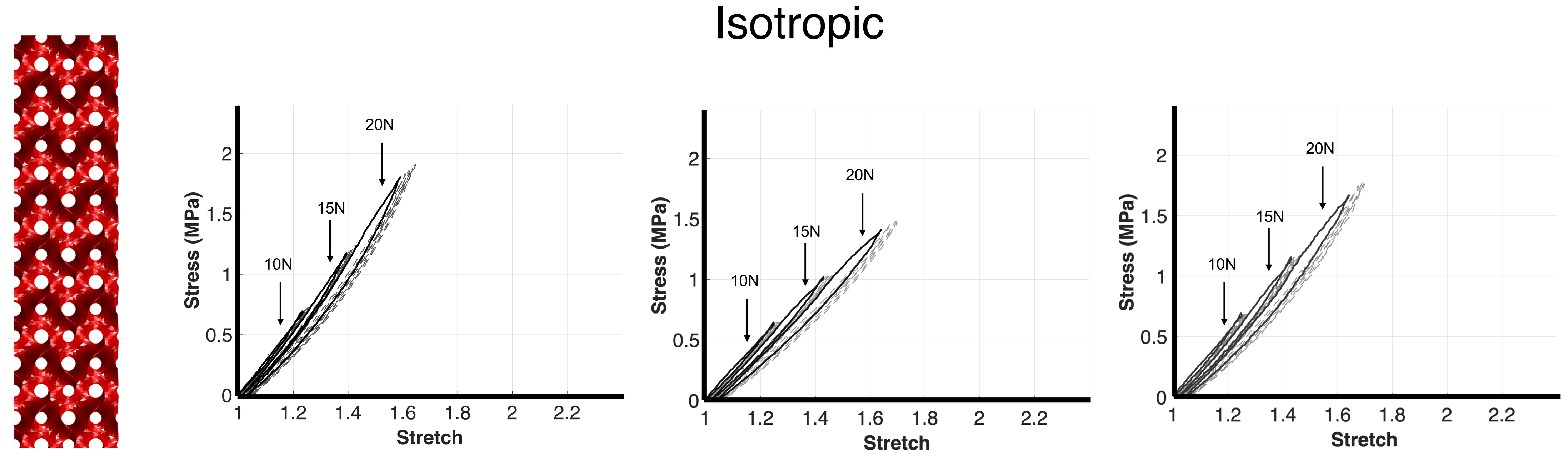
A uniaxial tensile loader was used to apply cyclic loading. Displacement rate was kept at 100 mm/min throughout. Coupons were loaded to 10N, 15N, and 20N for 5 cycles each to ensure the stress-stretch responses were stabilized. The cycles first load to a new maximum force is labeled as the ***primary load cycle***.



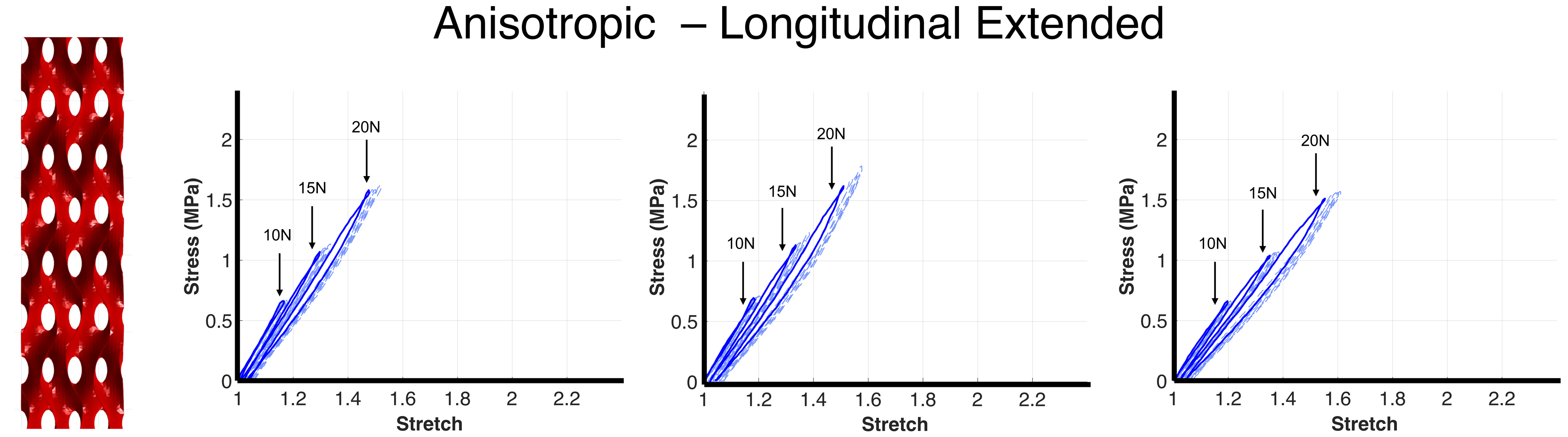
Digital image correlation, a contactless strain measurement technique, is used to collect strain and cross-sectional area for true stress analysis.

Experimental Cyclical Load Response

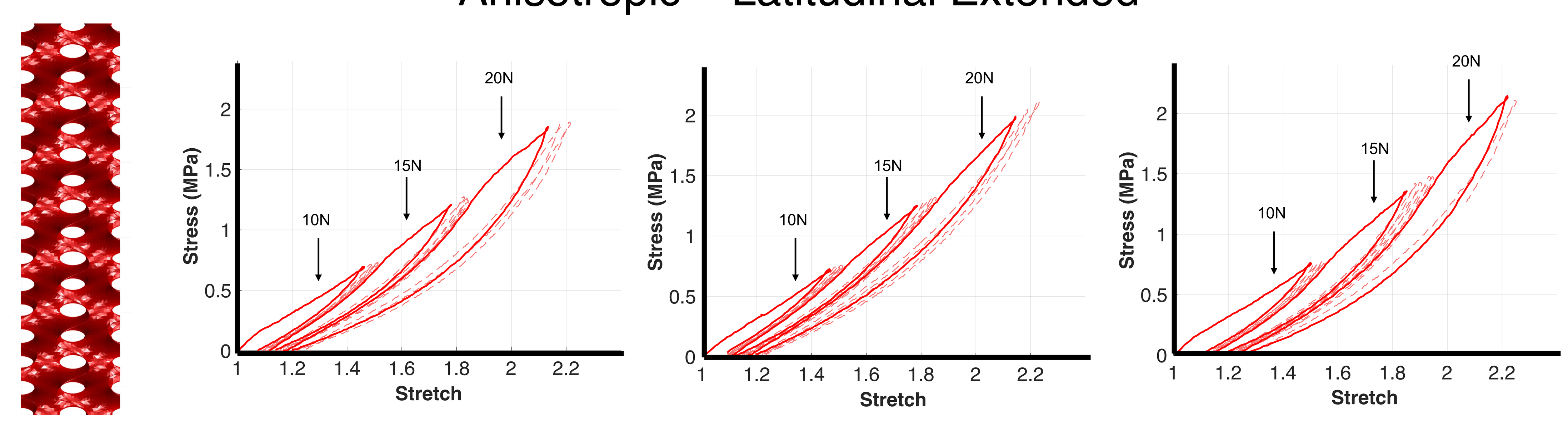
Isotropic



Anisotropic – Longitudinal Extended



Anisotropic – Latitudinal Extended



Average Energy Dissipation

Primary load cycle	[J/m^3]
• 10N	4.83
• 15N	63.2
• 20N	52.8

Primary load cycle	[J/m^3]
• 10N	1.10
• 15N	10.1
• 20N	37.2

Primary load cycle	[J/m^3]
• 10N	52.2
• 15N	88.5
• 20N	187

Discussion and Future Work

- Cyclical softening is observed in isotropic, anisotropic-longitudinal, and anisotropic-latitudinal coupons.
  - Most prominent softening occur in the anisotropic-latitudinal configuration, where the silicone matrix material contributes the most.
  - Large average energy dissipation and hysteresis curve found in Anisotropic–Latitudinal Extended coupon configuration is indicative of silicone dominated cyclical load behavior.
- Gyroid geometry of scaffold material affects stress stretch response as well as the hysteresis curve. These effects are observed from the energy dissipation.
- Cyclical loads after the primary load curves show softening and no hysteresis. Reliability studies are necessary to account for the drift of the soft tissue composite analog.
- Material model that accounts for viscoelasticity, non-linear high stress-stretch characteristic (hyperelasticity) and geometric contribution of the scaffold will be developed for the soft composite design

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