Mechanics of Anisotropic Biological Networks: A Structure-Mechanical Property Study of Mycelium

Mugdha R. Kasarekar, Prathima C. Nalam

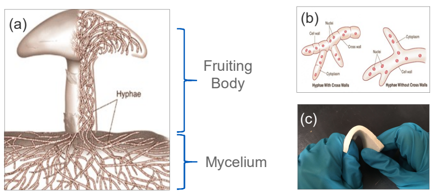
University at Buffalo
Department of Materials Design and Innovation
School of Engineering and Applied Sciences
College of Arts and Sciences

Goal: To develop an understanding of the impact of structural anisotropy in porous biological matter on their mechanical properties.

Highlights:
- Mycelium is a **programmable porous matter** *i.e.* by controlling the nutrients, environment or DNA, the porosity of the network can be tuned. This enables generation of structures with tunable mechanical properties.
- Nanomechanical analysis is employed for measuring heterogeneity in the mechanical strength of mycelium network.
- Multiscale microstructure analysis is employed for quantification of anisotropic structure of mycelium.

Introduction

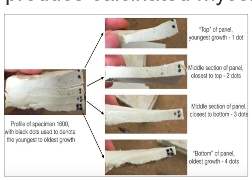
- Flexible porous solids undergo bi-phasic interactions *i.e.* with air or solvent; and hence find applications in membrane filtration, biomedical applications and as structural material, among few.
- Mycelium is an emerging bio-based construction material with objectives for development of sustainable products.



(a) The schematic representing the structure of multicellular fungus (b) Structure of Hyphae (c) Flexible, porous mycelium membranes

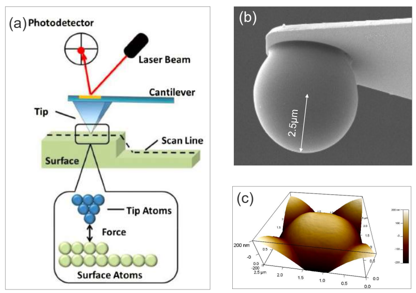
Sample Preparation

- Nutrients are placed at the bottom of the mold and the mycelium network is grown for several days in a controlled environment.
- Cross-sections are made along the thickness of the structure. The youngest naturally grown mycelium *i.e.* the section farthest away from the bottom of the mold is used for the measurement.
- Naturally grown network is exchanged with calcium chloride and methanol solution to produce calcinated mycelium.



Mycelium membrane showing the youngest to the oldest growth (1 dot to 4 dots) mycelium

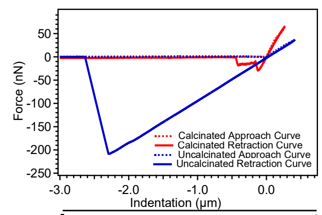
Nanomechanical Characterization



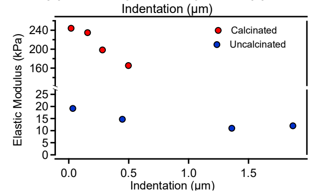
(a) Working Principle of AFM (b) Colloid attached to AFM tip (c) Reverse 3D image of colloid tip

Atomic force microscope (AFM) is employed to measure the nanomechanical deformation of the network.

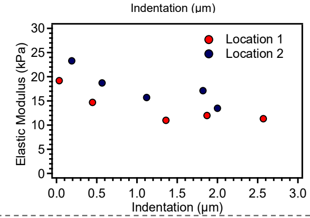
Colloid probe spectroscopy is employed to lower the contact pressure during the indentation of soft mycelium structures.



Representative force – distance curves are obtained on calcinated (red) and uncalcinated (blue) mycelium networks using AFM.

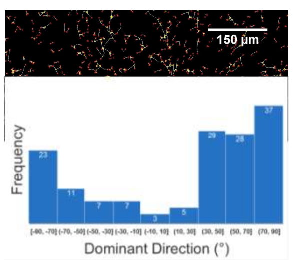


Calcination of mycelium increased the average elastic modulus of the network by a factor of ~13. JKR contact mechanical model is employed.

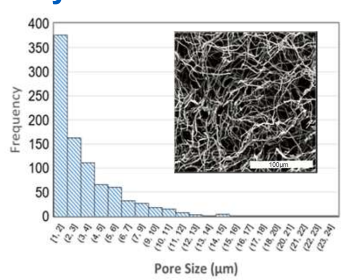


A scatter in the elastic moduli is observed at different locations with same indentation force demonstrating mechanical heterogeneity of the network at local scales.

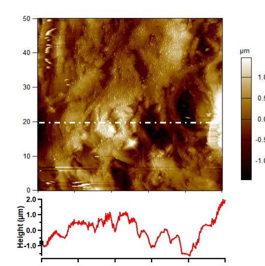
Multiscale Structural Analysis



Optical microscopy of epoxy-embedded mycelium: ImageJ analysis determines the dominant growth direction, and node density of the network locally.



SEM images of mycelium: Distribution of pore diameter (μm) is estimated for samples of different age growths.



AFM topographical images of mycelium: Section profiles determine the heterogeneity of surface features

Conclusion

- Methods and tools are developed to probe the structural anisotropy of the polymer network.
- The nanomechanical indentation studies show a strong depth-dependent elastic modulus for both uncalcinated and calcinated mycelium networks, indicating the impact of structural heterogeneity on the network mechanical properties.

Future Work

- Scaling laws using experimental methods to predict deformation of anisotropic porous structures will be established.
- Calcination has shown to improve the network strength and water wettability (below). Thus mycelium networks will be explored as candidates for the development of eco-friendly filtration membranes

Uncalcinated Mycelium
Contact Angle: 124°

Calcinated Mycelium
Contact Angle: 74°

- Flow rate, contaminant adsorption and biofouling performance of mycelium-based membranes will be investigated.

References

- Islam, M. R., Tudryn, G., Bucinell, R., Schadler, L., & Picu, R. C, Morphology and mechanics of fungal mycelium., 2017 *Sci Rep*, 7(1), 13070.
- Puspoki, Z., Storath, M., Sage, D., & Unser, M., Transforms and operators for directional bioimage analysis: A Survey. *Adv. Anat. Embryol. Cell Biol.*, *2016*, *219*, 69-93.