Nanomechanics of Mycelium: A structure-property study of hierarchical biological networks

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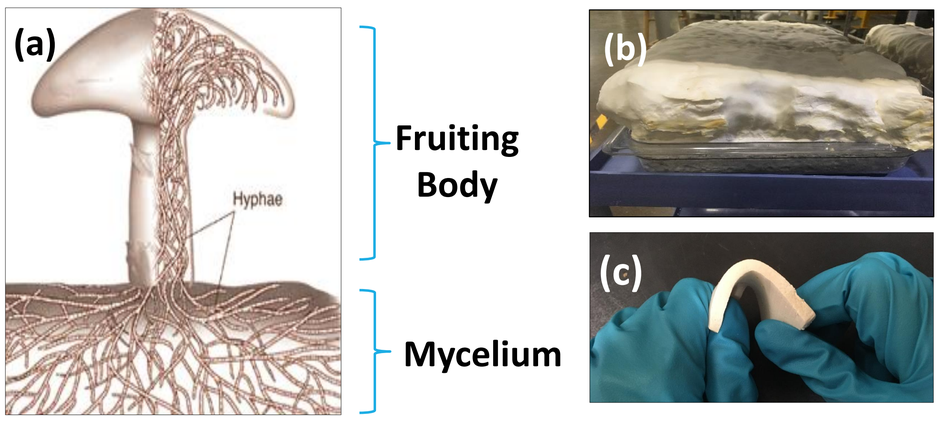
I. INTRODUCTION

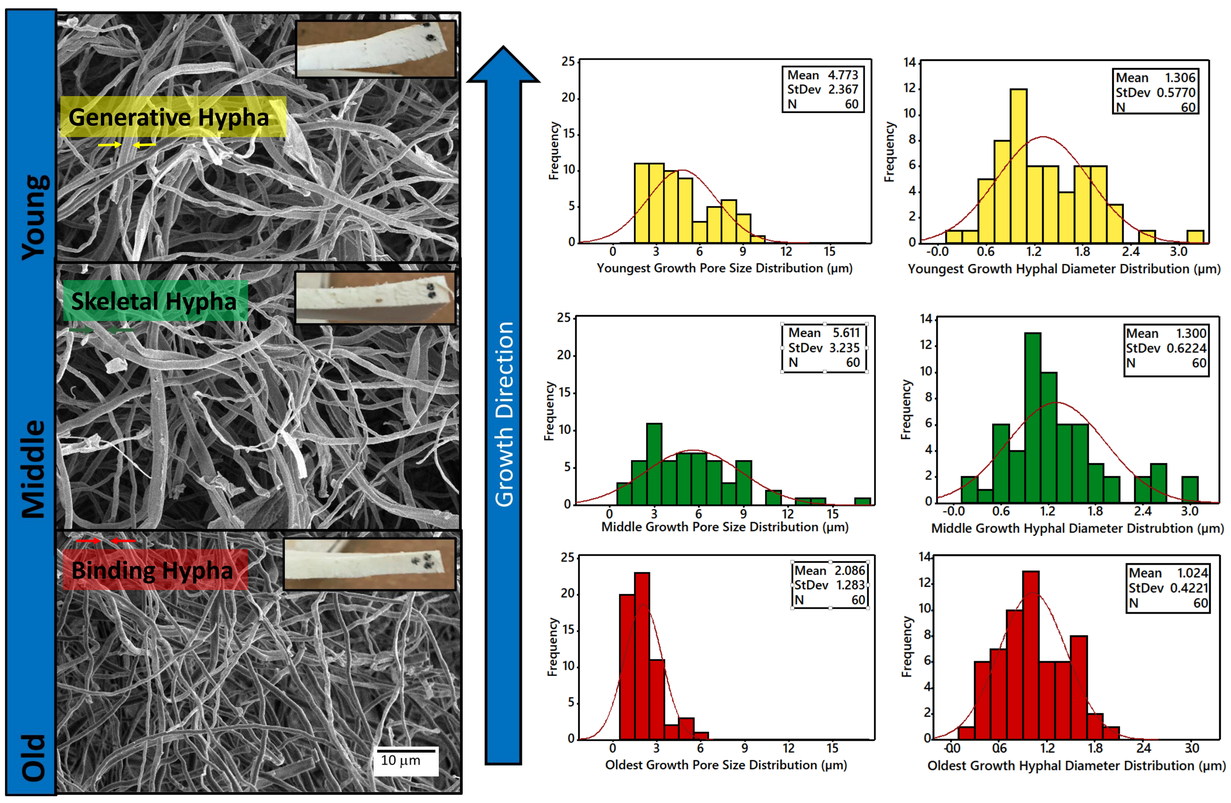
- In the race of finding the next sustainable material, ***Mycelium*** - the root-like fibers of fungi is emerging as one of the most promising materials that can reduce the ecological footprint.
- Mycelium is a **programmable porous matter** *i.e.* by controlling nutrients supply and environment during mycelium growth generates ***gradient*** in hypha filaments density along its thickness.
- Bottom - up elucidation of structure-property relation for mycelium biological network is important to make informed choices in developing Mycelium as structural material.



(a) Schematic representing the structure of multicellular fungus, (b) Side view of the tray showing mycelium growth, (c) Flexible, porous mycelium membranes cut out for analysis

II. STRUCTURE – MECHANICAL PROPERTY ANALYSIS

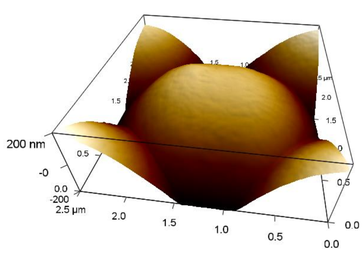
MICROSTRUCTURE ANALYSIS



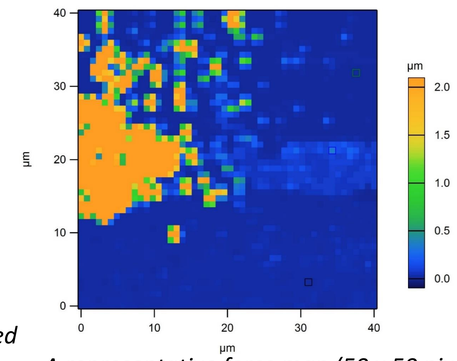
- This fungi-based biopolymer network forms a Trimitic system of hyphae. The most likely classification of the hyphae has been identified in the Scanning Electron Microscope (SEM) images.
- SEM images were captured at 3000X and structural analysis was performed using ImageJ analysis.
- Average hyphae diameter decreases significantly from the youngest and middle growth (~ 5µm) to the oldest growth (~ 2µm).
- Average pore size also shows a significant decrease in the oldest growth due to higher number of thin in the region hyphae.
- Solid volume fraction analysis for all the growth stages shows that total solids volume is similar at 70 ± 5%.

MECHANICAL ANALYSIS

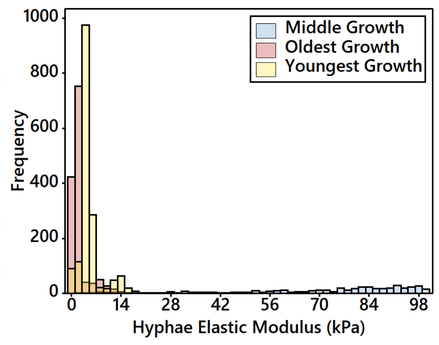
NANOMECHANICS



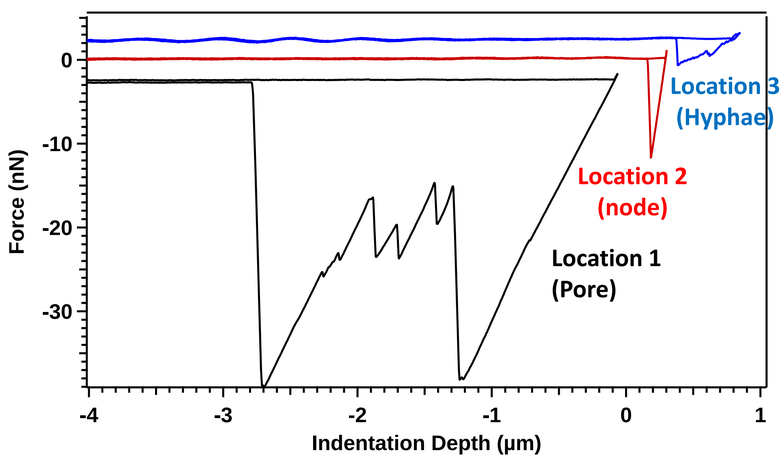
Colloid probe spectroscopy employed for nanomechanics (Silica colloid, R = 2.67 µm)

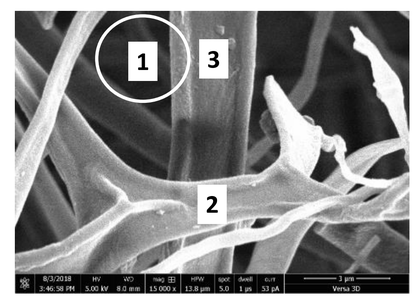


A representative force map (50 x 50 pixel) on the mycelium network.

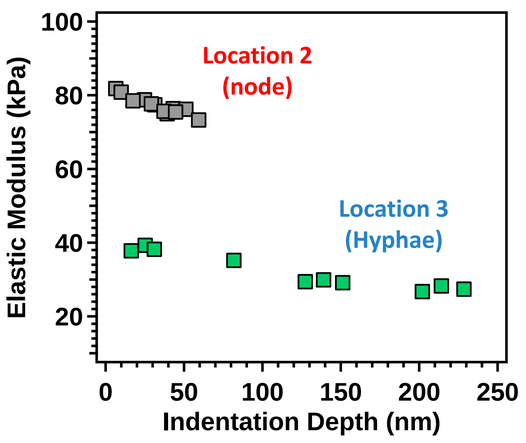


Histogram of Hyphae moduli measured across 4 force maps – JKR fit was employed



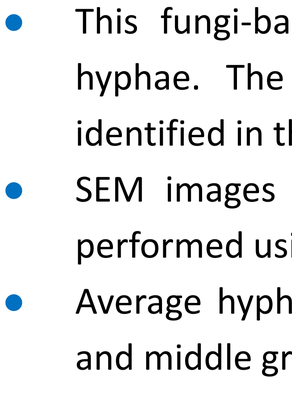


15000X SEM Image showing regions identified by the force map



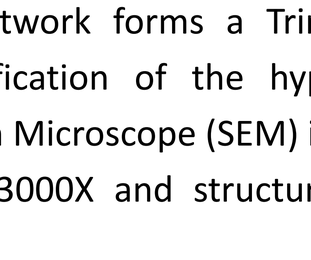
- Specific structural features such as hypha, node or pore have been identified from the modulus histogram
- Elastic moduli of the hyphae ranged between 40 – 90 kPa depending on the number of entanglements, and position of the measurement.

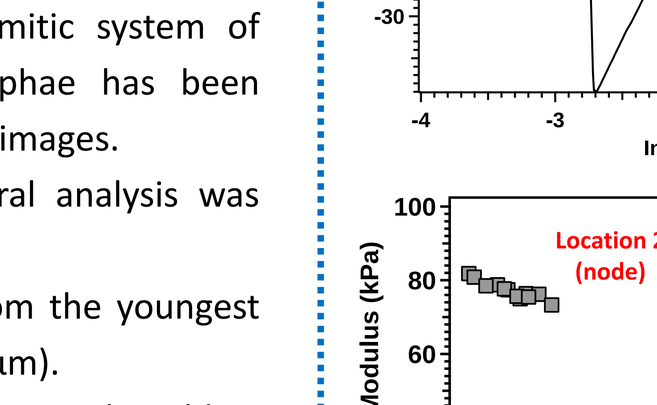
MACROMECHANICS



$$C\left(\frac{\rho^*}{\rho_s}\right)^{n} = \frac{E^*}{E_s}$$

E = Young's Modulus
ρ = Density
C = Constant
(S) refers to material property
(*) refers to structural property

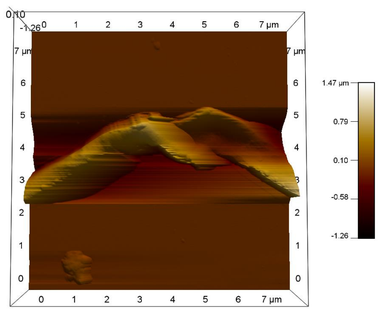




- Dog-bone tensile testing was carried out for different mycelium growth stages as per ASTM 638.
- Mycelium network behaves as an open foam network with a power law of ***n* = 2** (R^2 ~ 0.74) for elastic modulus.
- Macromechanical study shows a positive correlation between structural density and structural modulus.

III. FUTURE WORK

- Future work will involve mechanical and structural testing of individual hyphae
- Extensive statistical analysis to understand proportions of different hyphae at different growth stages and their impact on mechanical properties and pore size.



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