# On the Structural Origins of the *Chaetopterus* Tube Resilience

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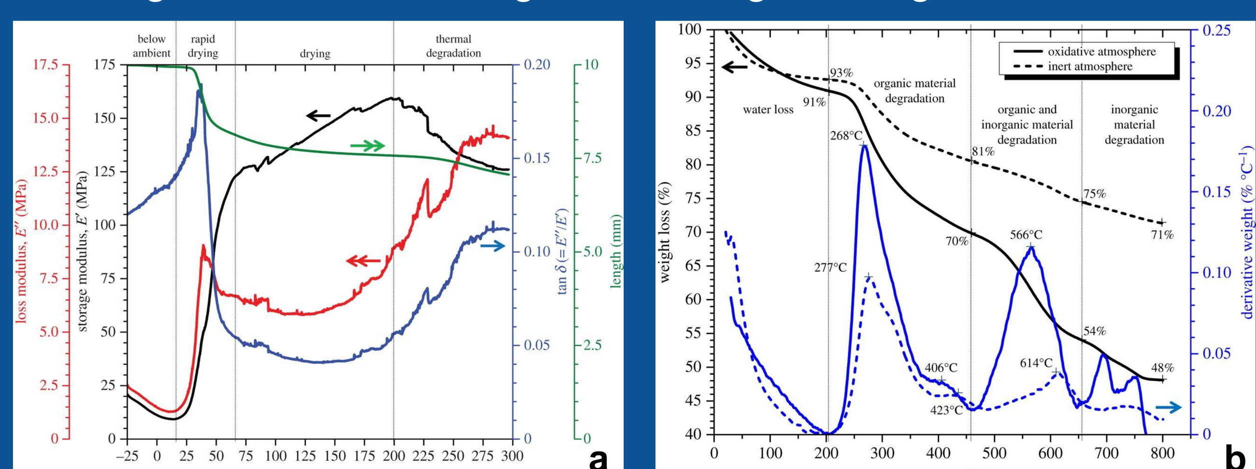
## Abstract


- The structure and composition of the *Chaetopterus sp.* housing tube was analyzed using scanning electron microscopy (SEM), MATLAB image processing and fourier transform infrared (FTIR) spectroscopy;
- The material is comprised of highly oriented layers of parallel nanofibrils stacked in a bouligand arrangement;
- FTIR spectra exhibits little variance in composition of tube material over time, and supports the role of mucus as the primary constituent of the tube material.


## Background

- The marine parchment tubeworm *Chaetopterus sp.* lives in a self-constructed U-shaped housing tube, typically partially buried in shallow seafloor sediment;
- The tube material exhibits remarkable thermal stability up to 250ºC (in reference to its mechanical properties).[1]
- No glass transition is observed in the tube material through dynamic mechanical thermal analysis and its viscoelastic properties were observed to be highly stable and reversible.[1]
- Tube growth occurs in segments along the longitudinal axis.[1]



(**a**) DMTA profiles of the tubes describing the viscoelastic properties tested in air.[1] (**b**) TGA profiles of the tubes measured in both oxidative and inert atmospheres.[2]

## Goals of Study

- To investigate the ultrastructural arrangement of the tube in relation to its mechanical properties;
- To investigate the chemical and proteinic composition of the tube and assess their contribution to the mechanical properties.

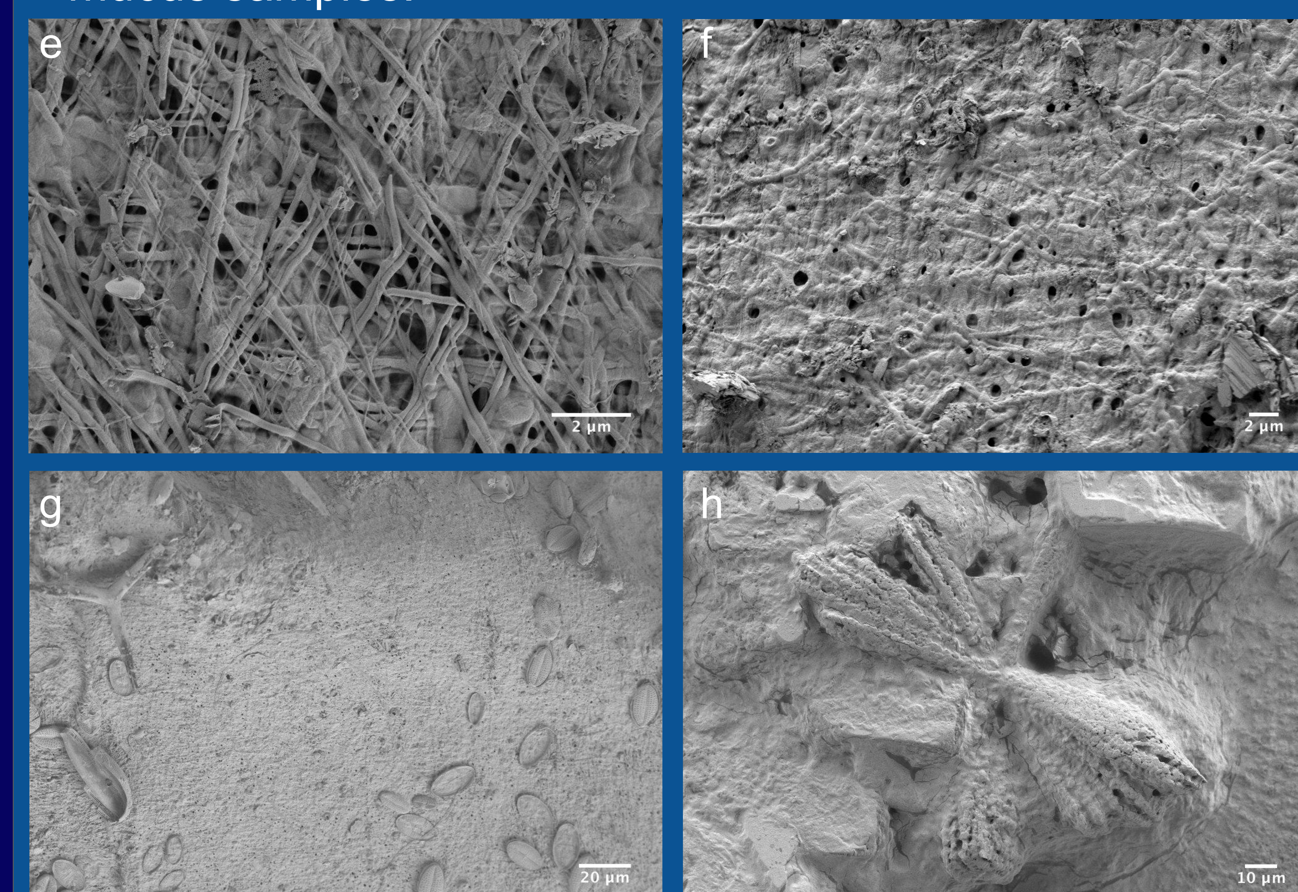
## Methods

**FTIR Spectroscopy**: Spectra were taken of samples of each tube segment and the mucus. Both the interior and exterior sides of tube specimens were analyzed.
**SEM**: Samples were sputter coated with iridium and imaged at 1kV and working distance of 5 mm.
**Image Processing via MATLAB**: An image processing algorithm based on the Hough transform function was used to generate a cumulative distribution of angles formed by the nanofibril layers.

Samples taken from each segment of a *Chaetopterus* tube (**c**) were dried at critical point. Mucus from the same specimen was harvested and dried under ambient conditions (**d**) (left to right: tube material and dried mucus).

## Microstructure of Nanofibril Layers

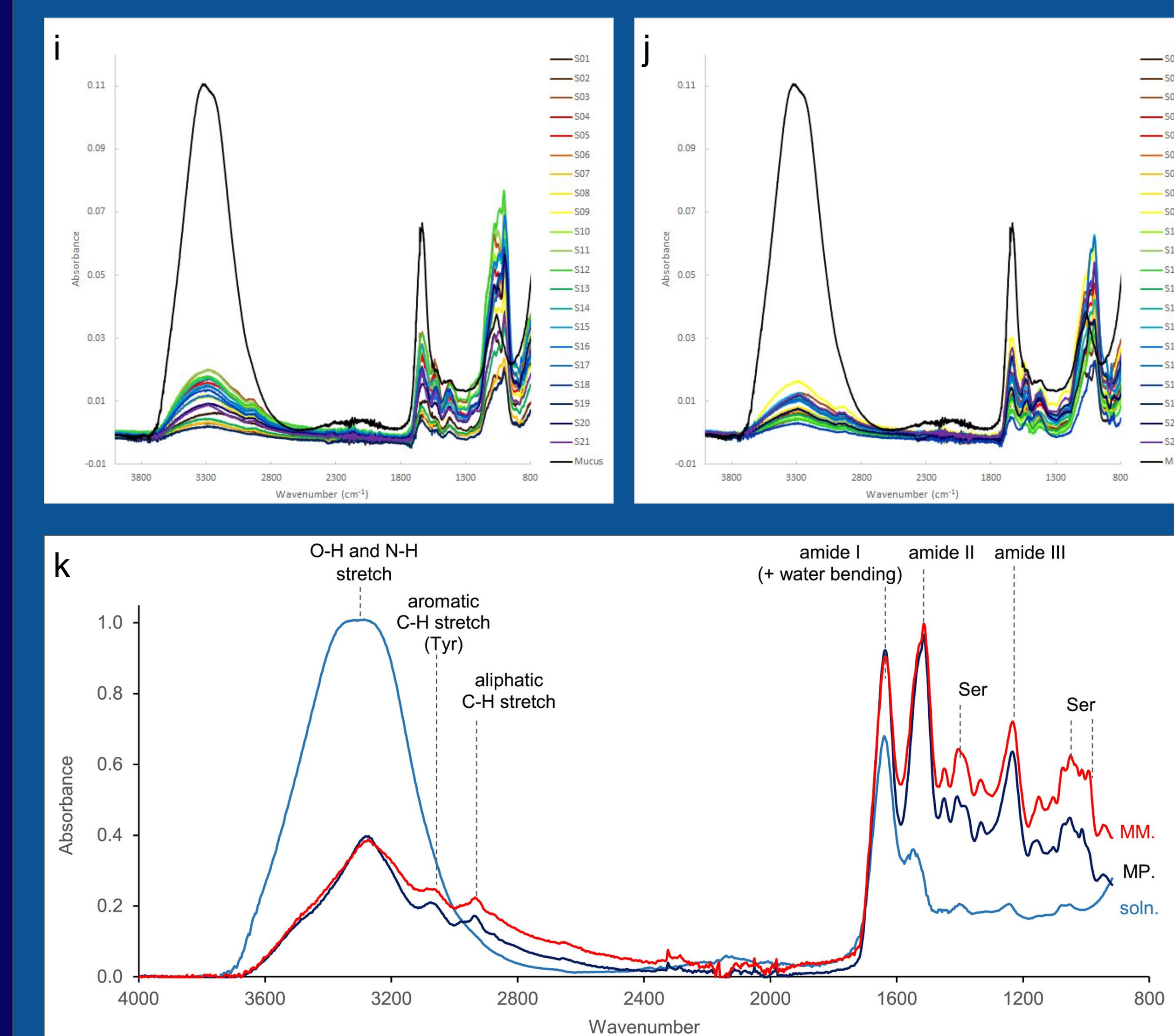
- Electron micrographs reveal the *Chaetopterus* tube is composed of layers of highly oriented nanofibrils;
- The morphology of the material varies significantly depending on its location (interior vs exterior) and age (proximity to tip);
- Potential nucleation sites of nanofibril growth identified in mucus samples.



(**e**) interior of tube material, revealing multiple layers of nanofibers. (**f**) interior of tube material at a location farther from the tip, covered extensively by amorphous material. (**g**) exterior of the tube material, covered by both amorphous material and environmental substrate such as diatoms. (**h**) electron micrograph of mucus sample, possible nucleation site at which fiber growth initiates.

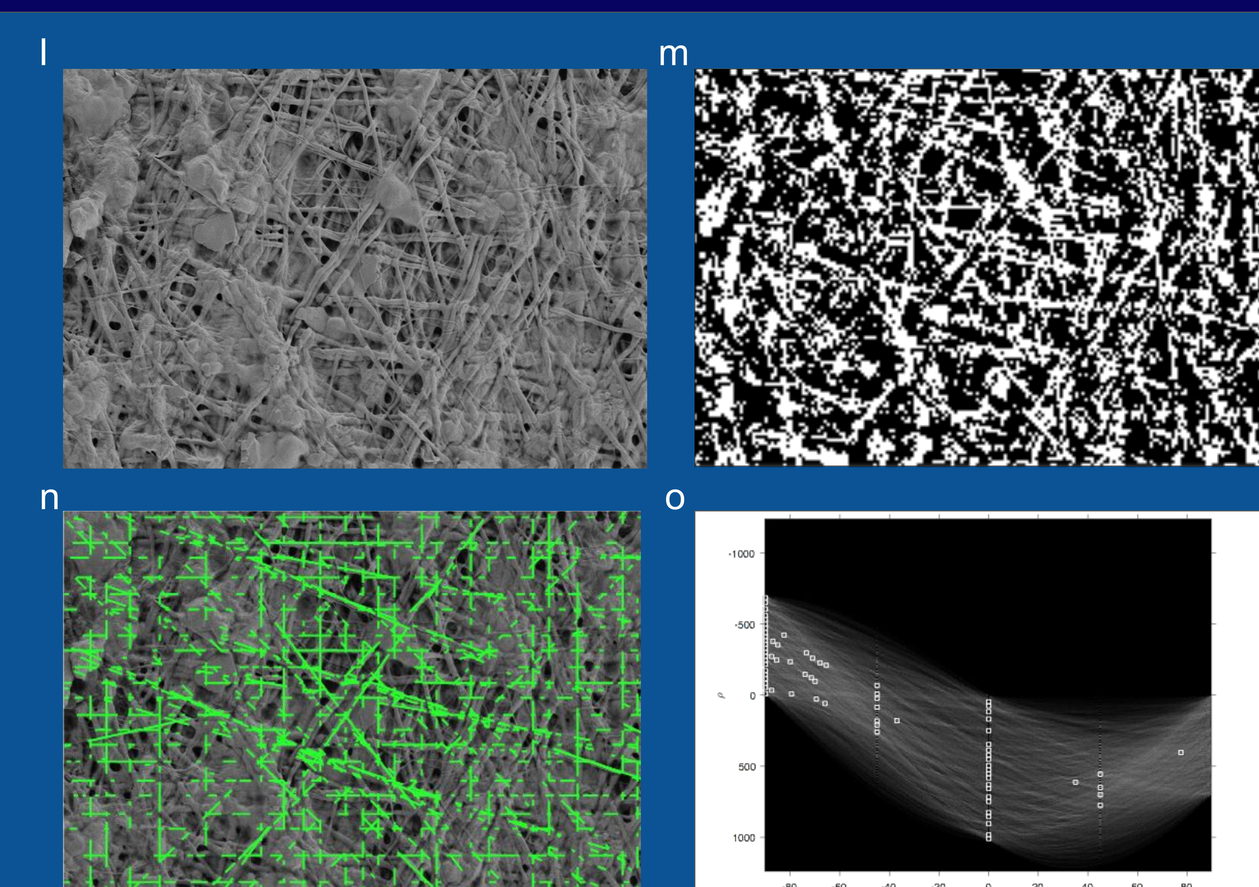
## Resilience Unaffected by Age

- FTIR spectra of both interior and exterior sides of tube segments exhibit high consistency along longitudinal growth axis
- Peaks of mucus spectra are consistent with tube material peaks, suggesting the former is a main constituent of the latter.
- Spectra of both tube and mucus appear similar to that of silkworm silk

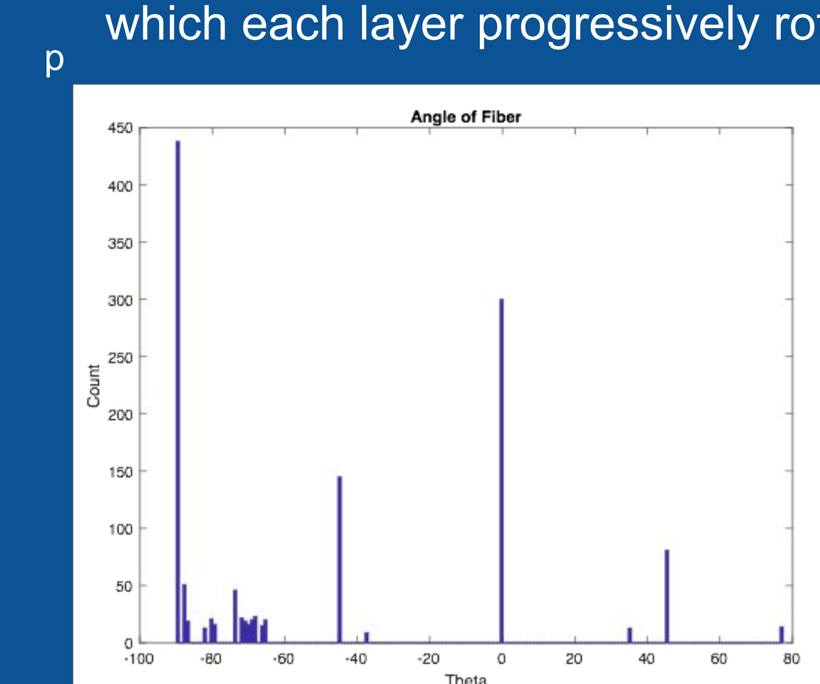



FTIR spectra of the interior side (**i**) and exterior side (**j**) of segment samples. The black line represents the spectrum of the mucous. (**k**) FTIR spectra of various Mulberry silkworm silk protein solutions and dried films.[2]

## MATLAB Image Processing



- Angles +45º, -45º and -90º are shown to recur with high frequency.
- Aggregates of same angle suggests bouligand structure, in which each layer progressively rotates a fixed angle.




(**l**) original electron micrograph image of the interior face of a tube segment. (**m**) image converted to black and white conversion for edge recognition. (**n**) recognized fibrils overlayed on original image in green. (**o**) parametric representation of lines. (**p**) Cumulative distribution of angles in original electron micrograph.

## Conclusions

- The *Chaetopterus variopedatus* housing tube was revealed to be constructed of highly oriented layers of nanofibrils;
- Electron micrographs demonstrate that each layer is composed of fibers aligned in a single direction;
- Hough transform based image processing algorithm reveals each layer is progressively rotated 45º with respect to the previous layer;
- FTIR spectra demonstrated little compositional variance along the longitudinal axis, suggesting resilience of material over time;
- Similarity between FTIR spectra of mucous and tube samples support hypothesis that the mucous is the main constituent material of the tube.

## Future Directions

- Generate an atomic compositional profile of the tube along the longitudinal axis using Energy Dispersive X-Ray (EDX) spectroscopy;
- 3D reconstruction of the tube material by using volume electron microscopy and Z-stacking;
- Raise *Chaetopterus sp.* in environments in which factors such as pH, substrate type, temperature, diet and water chemistry (including the presence/absence of elements such as iron) can be controlled;
- Dissolve tube material and analyze constituent molecules using high performance liquid chromatography.

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## References

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