



Structural, Chemical, and Multi-scale Mechanical Characterization of Waste Windmill Palm Fiber (*trachycarpus fortunei*)

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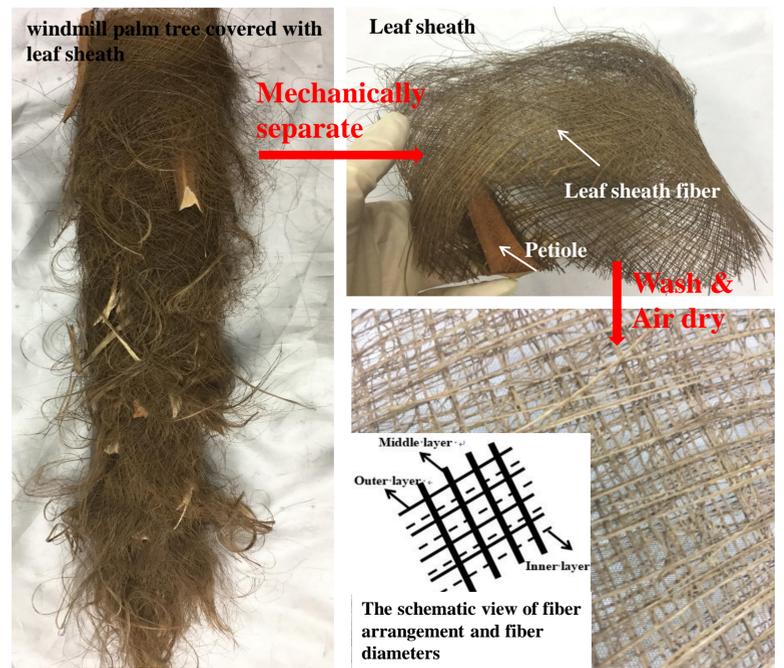
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1 Introduction

- Compared with traditional reinforcement materials used in composites, natural fibers offer advantages of biodegradability, good accessibility, fast renewability, high specific properties, and low cost¹.
- The majority of Windmill palm fiber (*Trachycarpus fortunei*) is discarded as waste and not used efficiently².
- A more comprehensive evaluation of palm fiber can promote its use as composite reinforcement material.



2 Materials



3 Methods

Morphological analysis

Digital biological microscope (XTS20G, Fukai LTD. China)

Diameter and length of each palm fiber and elementary fiber



Longitudinal and transverse surface morphology of the palm fiber

Chemical composition analysis

Technical association of Pulp and Paper industry (TAPPI) standards

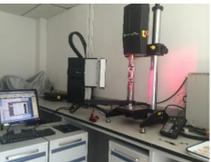
α -cellulose, hemicellulose, lignin and ash content

Structural analysis



MFA and relative crystallinity index (CrI)

Tensile tests



The tensile strength and modulus of palm fiber

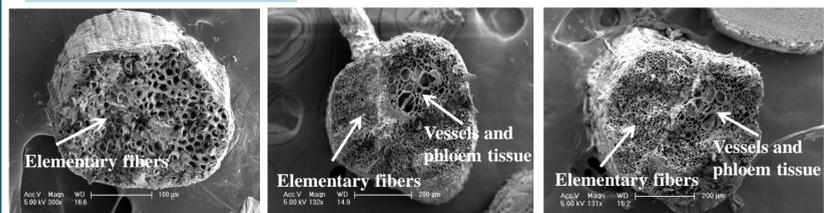
Nano-indentation tests



The elastic modulus and hardness of the cell wall of palm fiber

4 Results and discussion

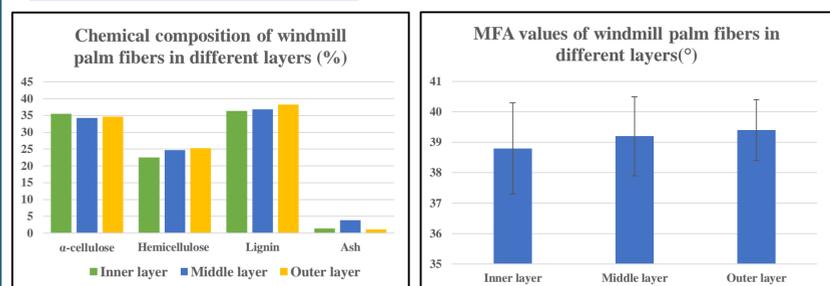
4.1 Fiber morphology Significant differences in various layers



| | Inner layer | Middle layer | Outer layer |
|----------------------------|-------------------------|---------------------------|---------------------------|
| Diameter (μm) | 230 \pm 57 (smallest) | 516 \pm 40 (largest) | 372 \pm 75 |
| Structural role | Elementary fibers | Elementary fibers | Elementary fibers |
| Conductive tissue | --- | Vessels and phloem tissue | Vessels and phloem tissue |

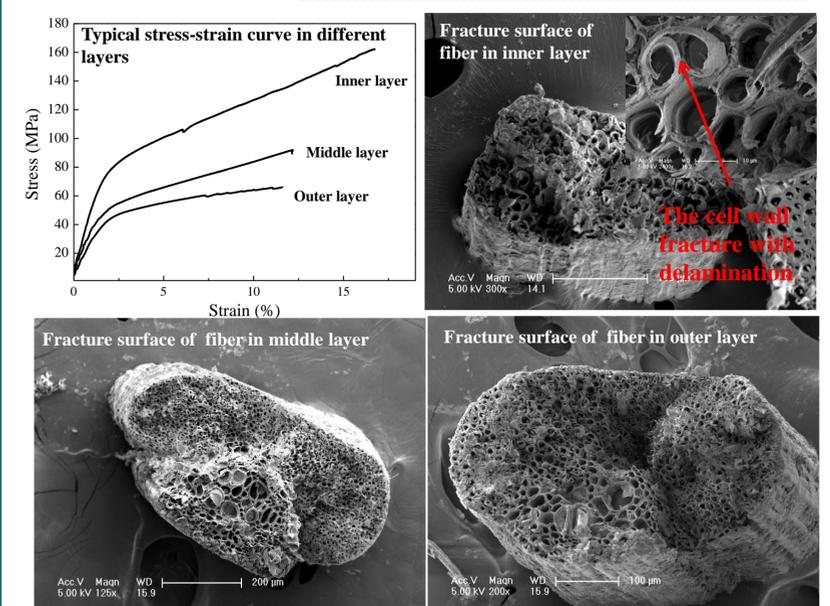
- The inner layers mainly play a structural role, and the outer and middle layers facilitate the transportation of nutrients through the conductive tissues.

4.2 Chemical composition and structural analysis Similar among the different layers



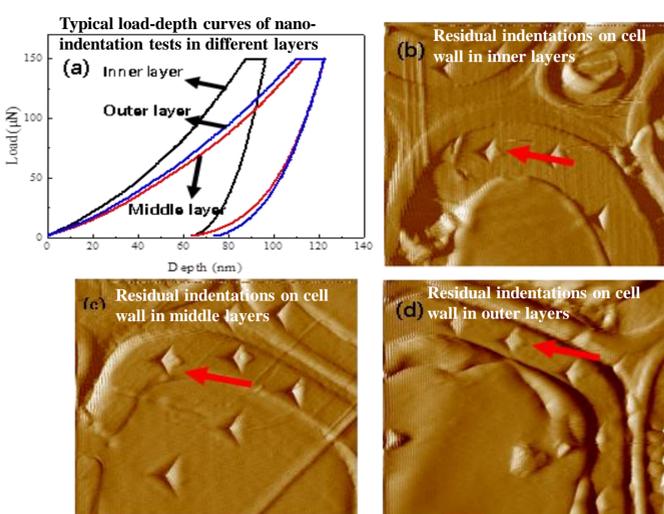
- The chemical composition and structural properties of windmill palm fibers among different layers are remarkable consistency.

4.3 Tensile properties Inner layer: the smallest diameter, superior mechanical properties among three layers



- The differences in mechanical properties between layers may be more associated with the morphological parameters, particularly fiber diameter.
- Windmill palm fibers showed ductile failure which was related to its fracture mode, as shown in figures.

4.4 Nano-indentation tests Testing elastic modulus and hardness: inner layers > outer layers > middle layers



- Fiber diameter could be important contributors to the difference in elastic modulus and hardness.

5 Conclusion

- The tensile and nano-indentation properties of fine fibers in the inner layer were highest among the three layers, which may reflect their mechanical role in leaf sheath.
- The palm fibers are not strong and stiff, but exhibit a high elongation at break.
- The nano-indentation results revealed that the modulus and hardness of windmill palm fiber were comparable to those of wood and crops fibers.
- These results will help promoting the use of windmill palm fiber as a material from renewable resources with more high-value applications.

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