Highly Anisotropic Wood-Based Composite with Layered Structure for Thermal Insulation and Electrical Conductivity

SOCIETY OF WOOD SCIENCE & TECHNOLOGY

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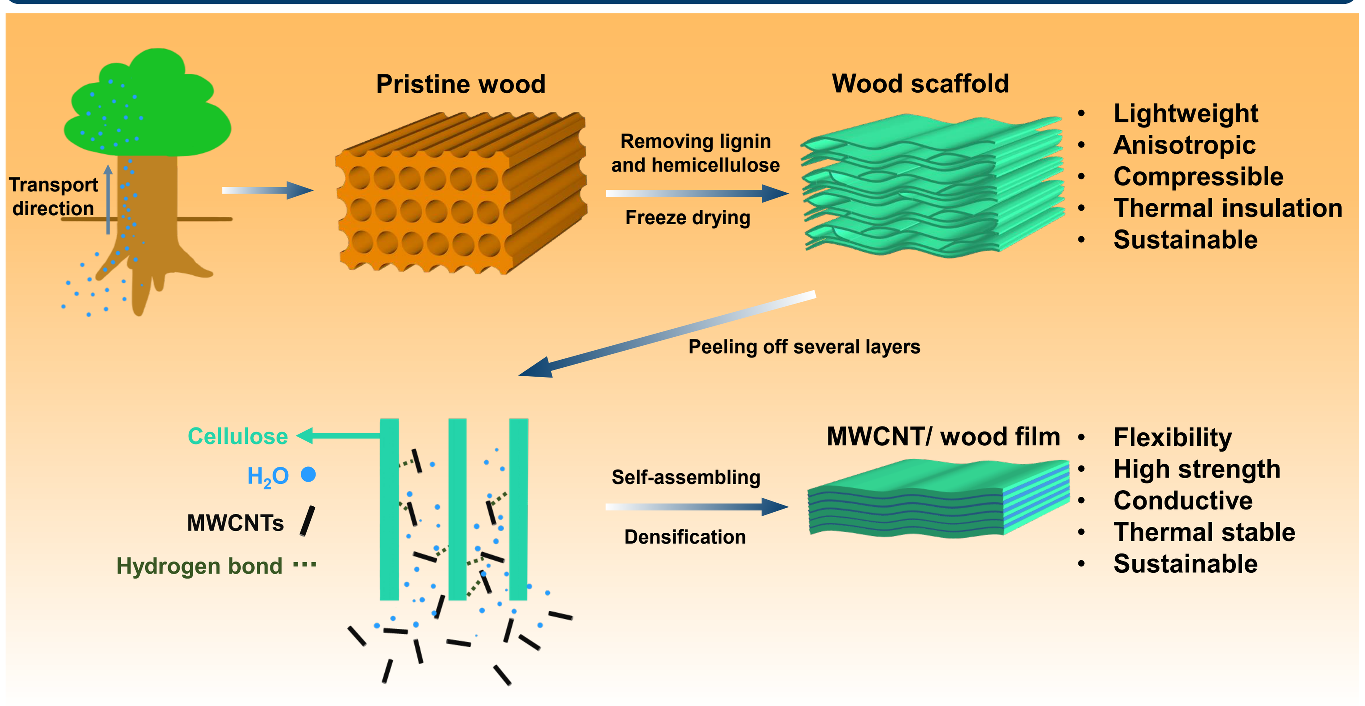
Introduction

Composite materials have attracted tremendous attention because of their excellent properties and unique functionalization. Generally, the conventional composites composed of substrate and functional fillers are fabricated by blending, which leads to a randomly oriented structure. To improve its performance, the high volume of the fillers is mixed into the substrate, which causes high cost and filler aggregation, even destroys the structure of composites, and then affects the mechanical strength. By designing an anisotropic and layered structure, the high performance of composites with high mechanical strength can be achieved.

Trees are one of the most abundant biomass resources on the planet. The highly aligned microchannels of trees transport water and nutrients and further organize to form a natural anisotropic hierarchical structure. Presently, the unique structure and characteristics of wood and its derivatives have drawn considerable interest in various applications, especially optics, acoustics, water treatment and purification, energy storage, electromagnetic interference shielding and thermal insulation materials.

In this study, we reported a strategy to fabricate wood-based composites for thermal insulation and electrical conductivity through a simple top-down wood nanotechnology. The wood nanotechnology further confers to the wood scaffold anisotropy, flexibility, and workability. The wood scaffold exhibits a low density of 32.18 mg/cm^3 and a high specific surface area of 31.68 m^2/g. Moreover, the wood scaffold presents mechanical compressibility and anisotropic thermal conductivity. The thermal conductivity perpendicular to the fiber direction and in the fiber direction were 0.033 W/mK and 0.11 W/mK, respectively. The wood-based electrically conductive film is prepared by directly impregnating Multi-Walled Carbon Nanotubes (MWCNTs) into wood, followed by densification. Driven by the capillary forces, the MWCNTs were uniformly deposited on the surface of cellulose along the aligned channels. The conductive film exhibited excellent flexibility and high mechanical performance with the tensile strength and a Young's modulus of 99.67 MPa and 4.06 GPa, respectively. Moreover, the conductive film presented an anisotropic resistivity with an anisotropy factor of 30.45. A low resistivity of 0.044 Ω/m along the fiber direction and a resistivity of 1.34 Ω/m perpendicular to the fiber direction. The environmental-friendly and sustainable wood-based composites shows huge potential in various applications.

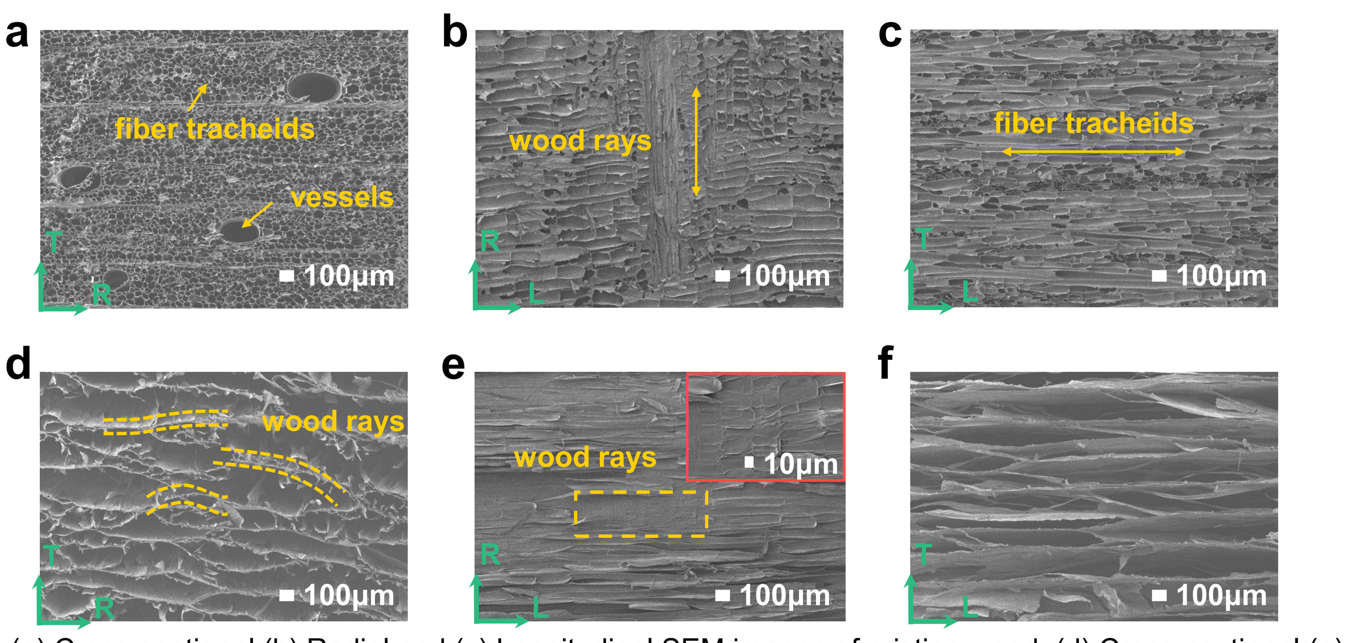
Methods



- The wood scaffold was prepared by the removal of lignin and partial hemicellulose of pristine wood in $NaClO_2$ and NaOH solution, respectively.
- The MWCNT/ wood film was prepared by introducing MWCNTs on the layered structure interface via capillary forces, followed by the freeze-dry processing and densification.

Results

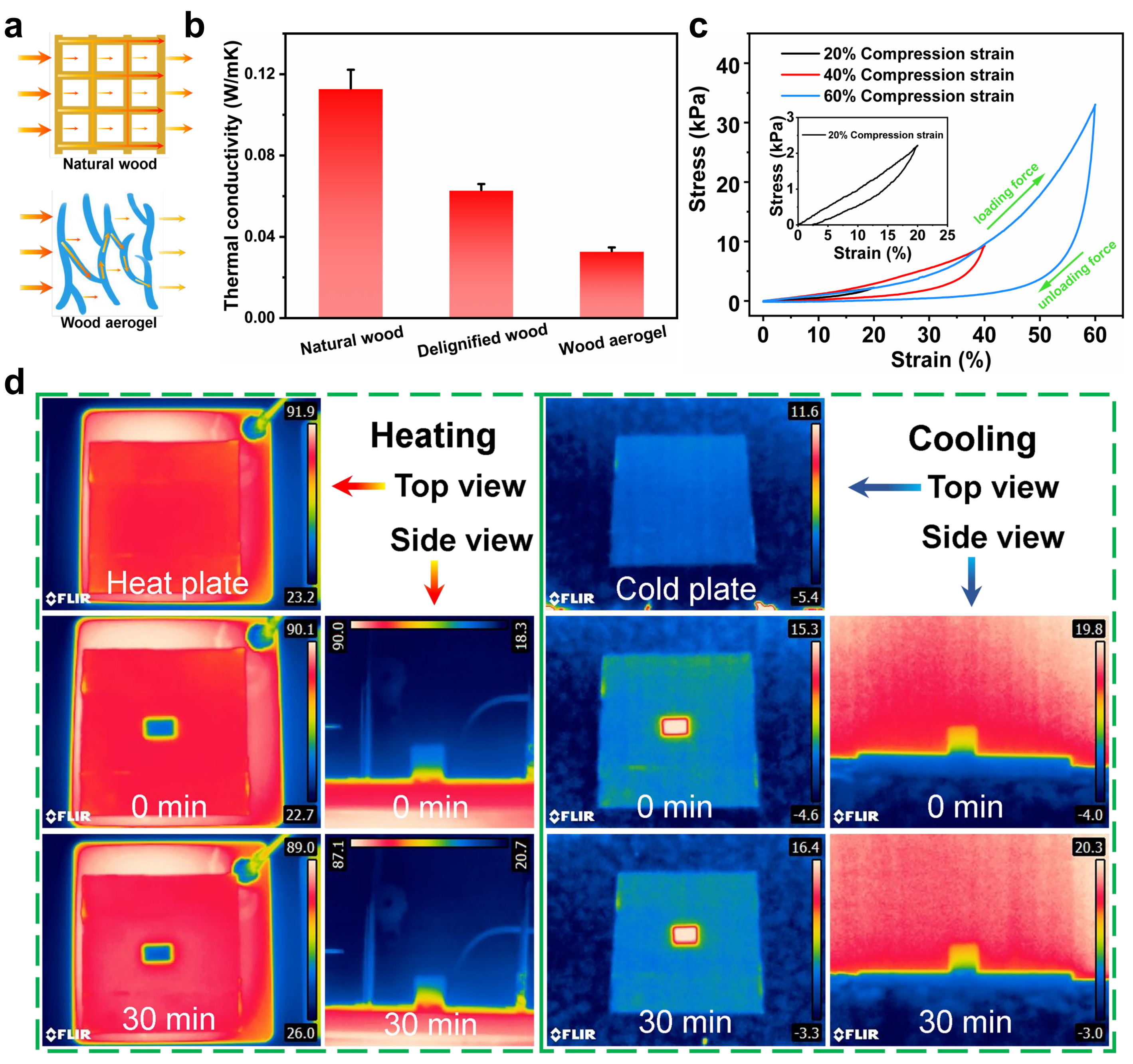
Significant evolution in structure



(a) Cross-sectional (b) Radial and (c) Longitudinal SEM images of pristine wood. (d) Cross-sectional (e) Radial and (f) Longitudinal SEM images of wood scaffold.

- Different transmission efficiency in different direction resulted in layered structure and aligned channels.
- The wood scaffold presented a low density of 32.18 mg/ cm^3 and high specific surface area of 31.68 m^2/g.

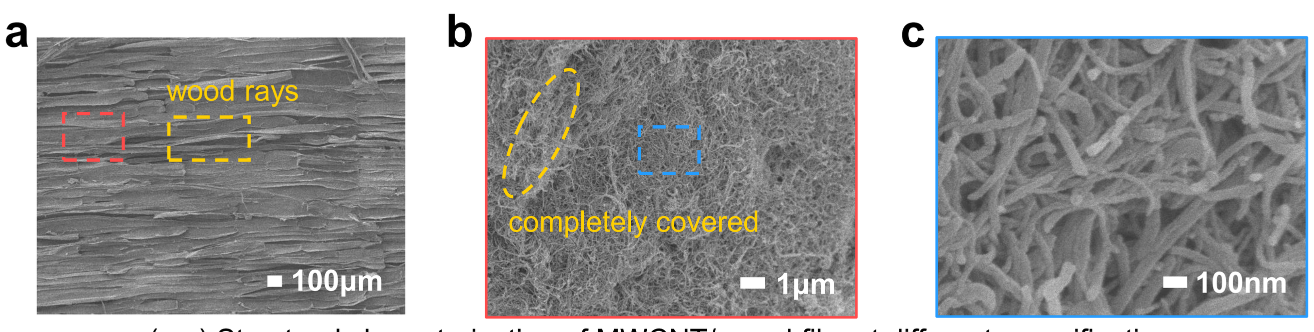
Compressibility and thermal insulation



(a) Schematic of thermal conduction. (b) Thermal conductivity of different specimens. (c) Stress-strain curves of wood aerogel under compression. (d) Infrared images of wood aerogel during the 30 min heating and cooling processes.

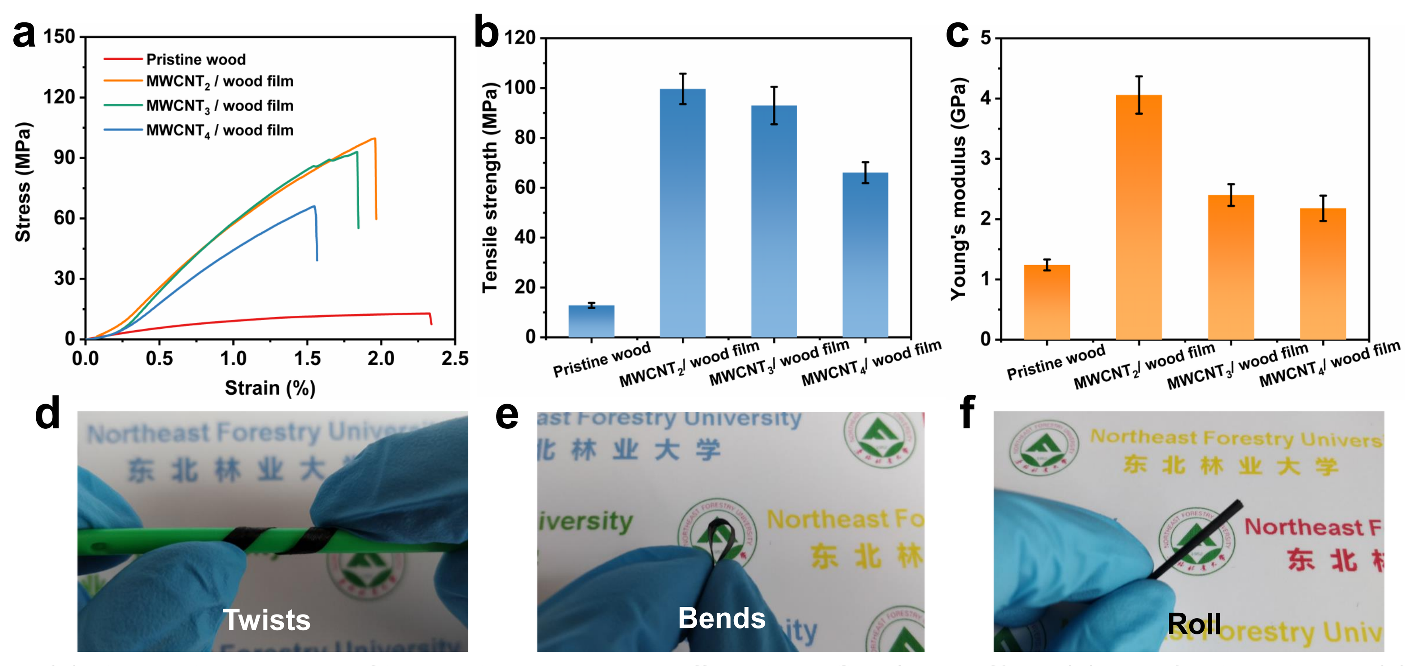
- The wood aerogel with layered structure exhibited excellent mechanical compressibility .
- The synergistic effect of the layered structure and the micropores reduced the thermal conductivity of wood aerogel from 0.113 W/mk to 0.033 W/mk.

Flexible, strong and conductive



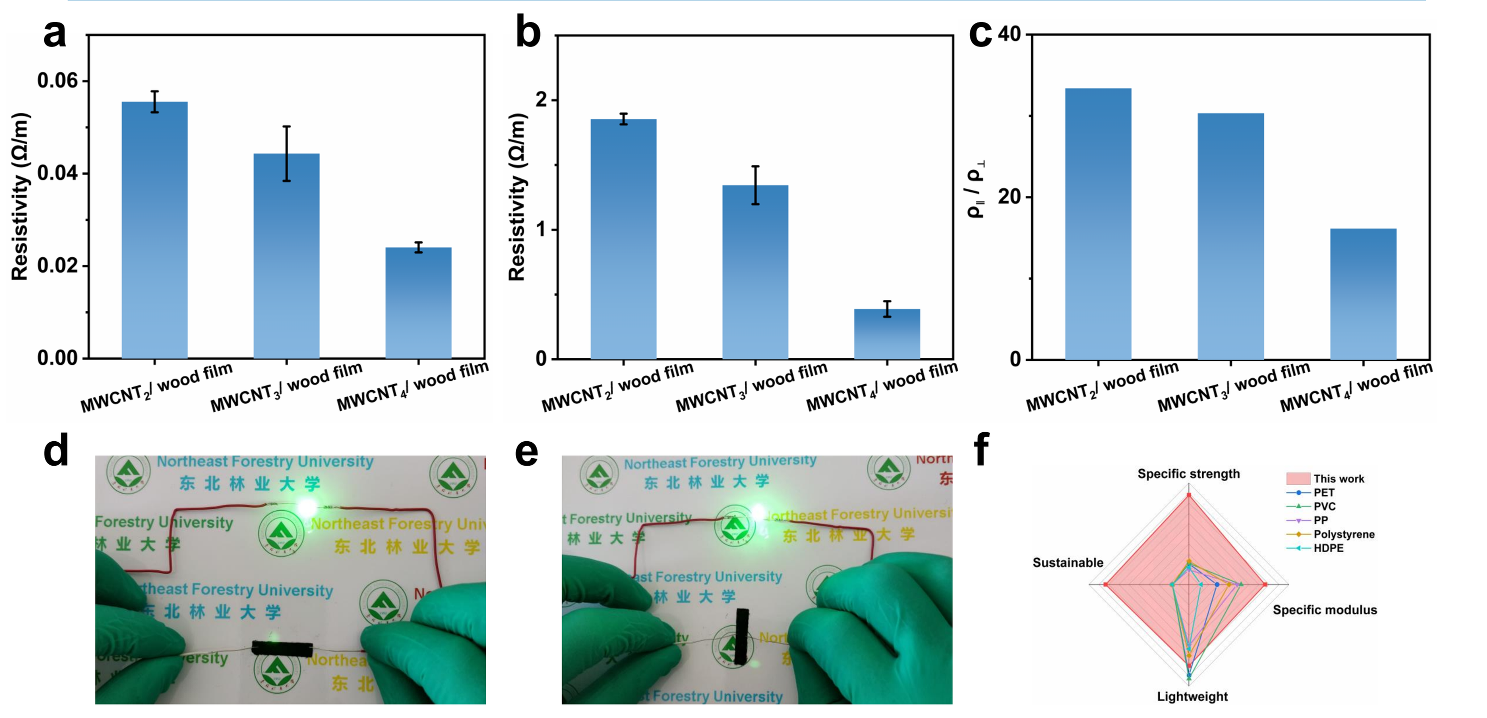
(a-c) Structural characterization of MWCNT/ wood film at different magnification.

- The MWCNTs were uniformly deposited on the surface of wood fibers.



(a) stress-strain curves of the pristine wood and different MWCNT/ wood films. (b) Tensile strength and (c) Young's modulus of the pristine wood and MWCNT/ wood films. (d-f) Photographs of the MWCNT/ wood film flexibility demonstrated by twisting, bending and rolling into a stick.

- Compared with the pristine wood, the MWCNT/ wood film exhibited approximately 5.15 - 7.77 times and 1.76 - 3.27 times higher tensile strength and Young's modulus, respectively.
- The MWCNT/ wood film possessed excellent flexibility.



The resistivity changes of different samples (a) along the fiber direction and (b) perpendicular to the fiber direction. (c) Comparison of anisotropic resistivity of different samples. Photographs of MWCNT/ wood film in an electrical circuit powering a LED. (d) along the fiber direction and (e) perpendicular to the fiber direction.

- The resistivity along the fiber direction was 0.044 Ω/m and the resistivity perpendicular to the fiber direction was 1.34 Ω/m.
- The MWCNT/ wood film presented an anisotropic resistivity with an anisotropy factor of 30.45.

Conclusions

- Wood scaffold as a great substrate possesses layered structure, aligned channels and abundant hydroxyl groups.
- MWCNT/ wood film with high mechanical strength and excellent flexibility has extensive application fields.

Acknowledgements

National Key R&D Program of China (2018YFD0600302)

Fundamental Research Funds for the Central University(2572018AB35)

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