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Cellulose Nanofiber–Microsphere Foams: A Facile Air-Drying Strategy for Scalable Fabrication

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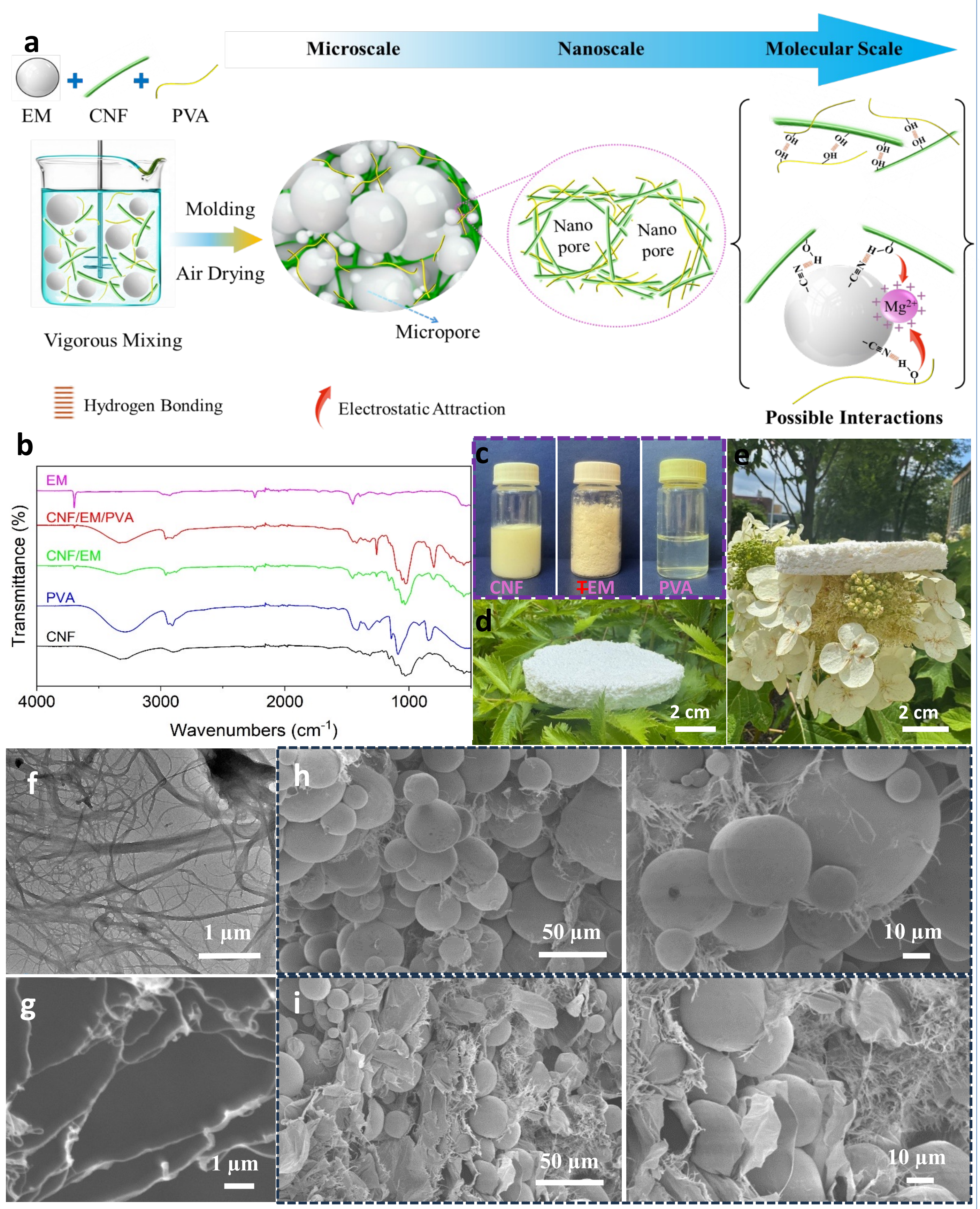
BACKGORUND

- Sustainable alternatives to petroleum-based foams are urgently needed for insulation and packaging.
- Cellulose nanofibers (CNFs) offer renewability, low density, and excellent mechanical properties.
- Conventional CNF foams rely on freeze-drying or supercritical drying, limiting scalability and increasing cost.
- Air-drying typically causes pore collapse due to capillary forces.
- Expanded microspheres (EMs) can stabilize porous structures and reduce density during drying.
- **Objective:** Develop a scalable, air-dried CNF-based foam with competitive mechanical and thermal performance

METHODOLOGY

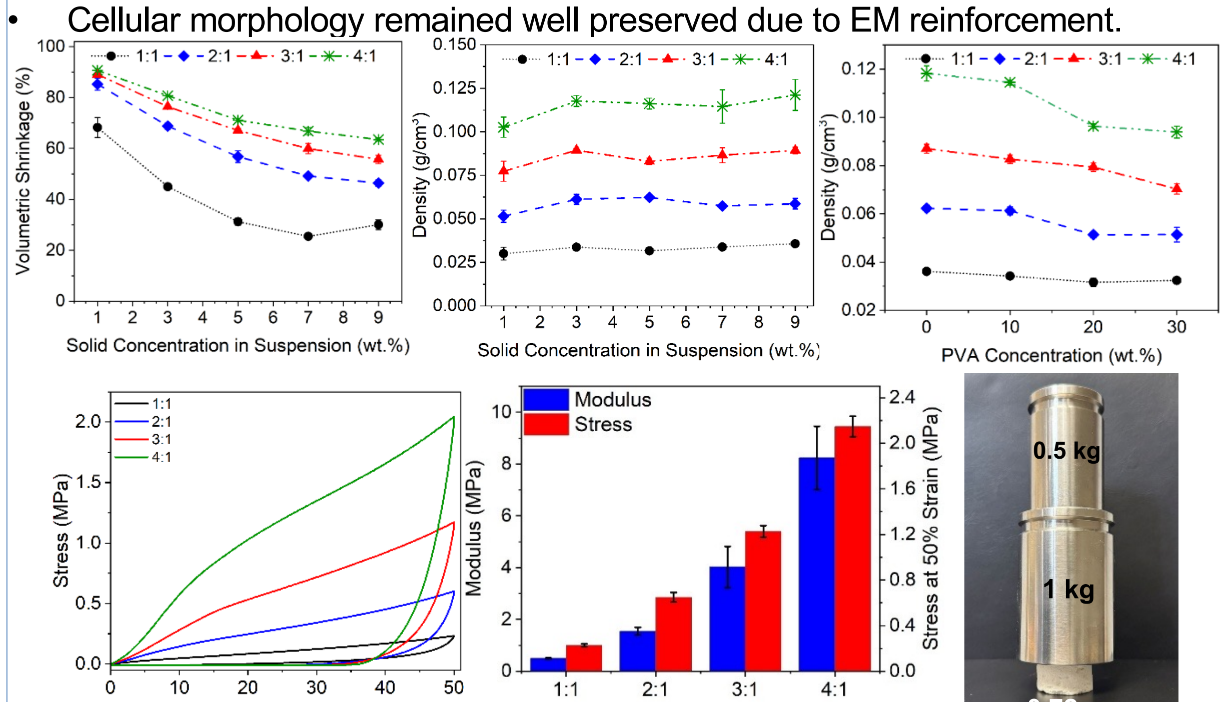


ABSTRACT: Scalable production of lightweight, thermally insulating bio-based foams remains challenging due to the high energy consumption and limited scalability of conventional drying techniques such as freeze-drying. In this work, we present a rapid and sustainable air-drying approach for fabricating cellulose nanofiber (CNF) foams with the aid of expanded microspheres (EMs) and polyvinyl alcohol (PVA). The resulting foams exhibit ultralow density, and enhanced mechanical and thermal performance without chemical modification or solvent exchange. Increasing the CNF/EM ratio significantly improves compressive modulus while maintaining low density. The foams demonstrate low thermal conductivity good thermal stability, and water-based recyclability, highlighting their potential for sustainable insulation and packaging applications.

RESULTS

Physical and Mechanical Properties

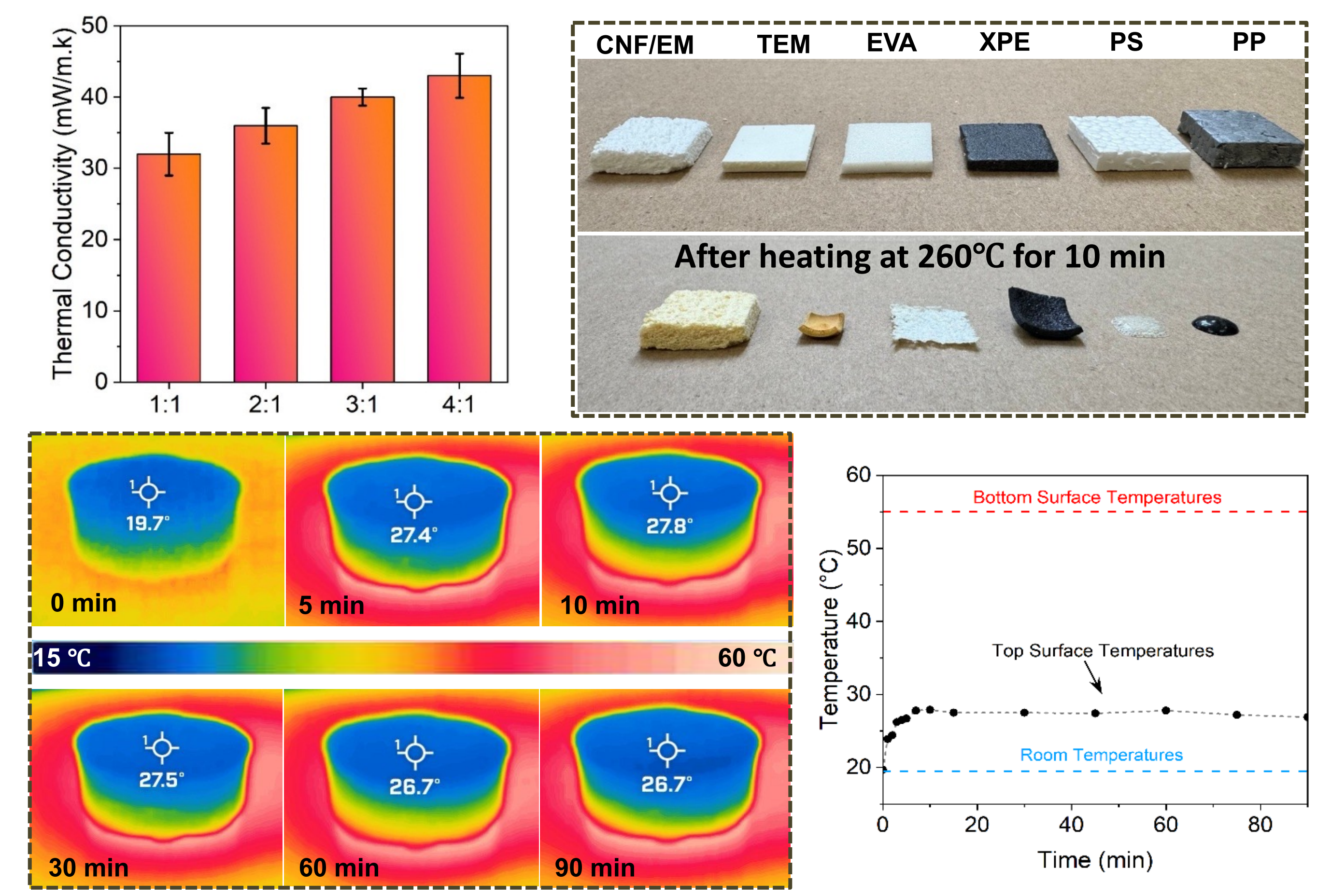
- Uniform, lightweight foams were successfully fabricated without freeze-drying.
- Increasing CNF/EM ratio enhanced structural integrity and stiffness.
- Compressive modulus increased from 0.49 MPa to 8.2 MPa with increasing CNF/EM ratio from 1:1 to 4:1 while density only increased 3.45 times.
- Cellular morphology remained well preserved due to EM reinforcement.



RESULTS

Thermal Properties

- Thermal conductivity ranged from 32 to 43 mW·m⁻¹·K⁻¹, comparable to commercial insulation materials.
- Foams exhibited good thermal stability and could be redispersed and remolded in water



CONCLUSION

- Air-dried CNF/EM foams were successfully fabricated without freeze-drying or solvent exchange.
- Density increased only 3.45× while compressive modulus improved from 0.49 to 8.2 MPa with increasing CNF/EM ratio.
- Foams achieved low thermal conductivity of 32–43 mW·m⁻¹·K⁻¹, comparable to commercial insulation materials.
- Cellular structure remained stable during air-drying due to EM reinforcement.
- Foams demonstrated water-based recyclability with retained structural integrity after reprocessing.
- The combination of low density, high stiffness, and scalable processing supports use in sustainable insulation and packaging applications.

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