Electrospun Cellulose Acetate-Based Composite Membrane for Enhanced Drug Delivery Performance

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ABSTRACT

Cellulose acetate (CA)-based wound dressings offer an eco-friendly alternative to petrochemical-based dressings, as CA is derived from natural cellulose. This study aims to add value to agricultural products such as sugarcane, corn, and cassava by utilizing CA, which can be extracted from these sources, to develop composite membranes for biodegradable wound dressings with antibacterial properties. To reinforce the CA membrane, carbon nanotubes (CNTs) were incorporated to enhance mechanical strength. Additionally, a nanosheet material (NM) was introduced to increase surface area, providing more sites for drug adsorption and release. Both CNTs and NM were used in minimal amounts to mitigate potential toxicity. The resulting fibrous composite membranes are expected to promote skin breathability, prevent excessive moisture buildup, and support wound healing while exhibiting antibacterial effects. This approach not only improves the performance of CA membranes for wound healing applications but also promotes sustainability by utilizing CA derived from domestic agricultural resources.

INTRODUCTION

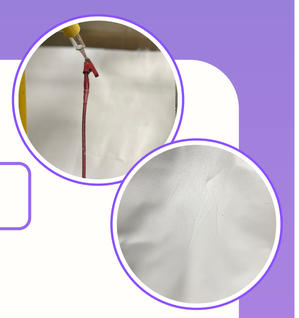
Most wound dressings are made from petrochemical-based polymers, which are resistant to degradation and lead to environmental risks. This study develops a biodegradable CA-based membrane reinforced with carbon nanotubes (CNTs) for increased strength and nanosheet material (NM) for enhanced drug adsorption and release. Using electrospinning, the membrane has a porous structure, ideal for wound healing. Minimal CNTs and NM loadings ensure biocompatibility while improving ventilation, preventing moisture buildup, and incorporating antibacterial and anti-inflammatory agents.

Fig. 1. Applications of drug-loaded CA composite membrane.

METHODOLOGY

- Preparation of CA membrane

Dissolve CA in acetone:DMAc ⟶ Stir at 30 °C for 24 h.



- Preparation of CA composite membrane

Disperse CNTs and NM in acetone:DMAc for 15 min. ⟶ Dissolve CA in the dispersion. ⟶ Stir at 30 °C for 24 h.

RESULTS AND DISCUSSION

- Structural characterization

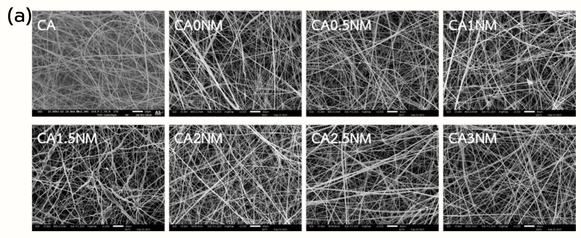


Fig. 2. (a) SEM images of CA composite membranes with different NM loading contents and (b) TEM image of CA composite membrane.

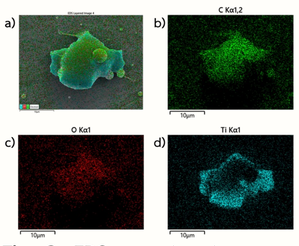


Fig. 3. EDS mapping images of CNTs/NM/drug membrane for (a) overall, (b) C, (c) O, and (c) Ti.

- The mechanical and thermal properties of the membranes using TGA, DTG and tensile test

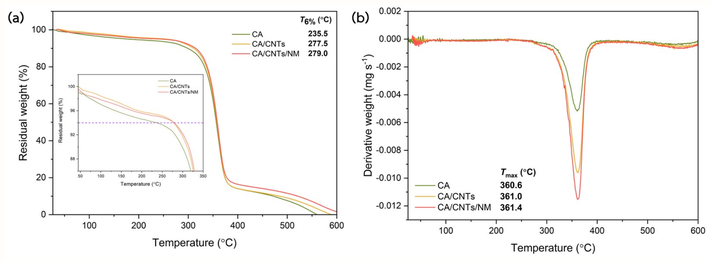


Fig. 4. Thermal characteristics of membranes: (a) TGA thermograms and (b) derivative weight curves.

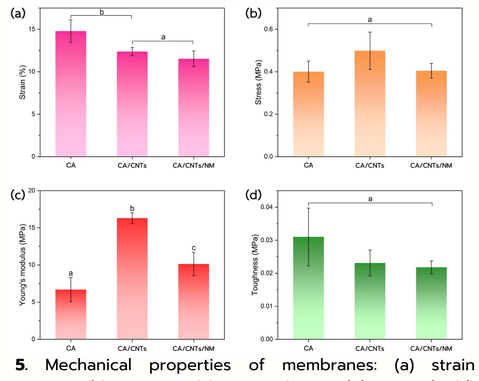


Fig. 5. Mechanical properties of membranes: (a) strain percentage, (b) stress, (c) Young's modulus, and (d) toughness.

- Characteristics of membranes using FT-IR spectroscopy, XRD, and Raman.

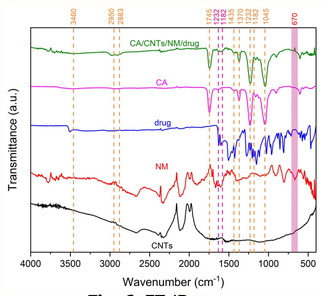


Fig. 6. FT-IR spectra.

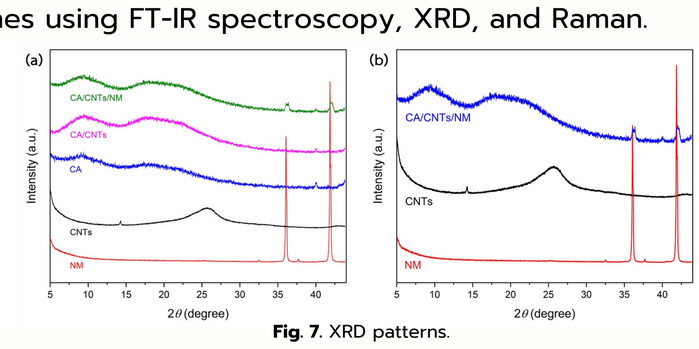


Fig. 7. XRD patterns.

RESULTS AND DISCUSSION

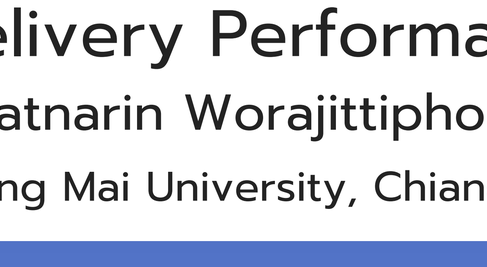


Fig. 8. Raman spectra of membranes.

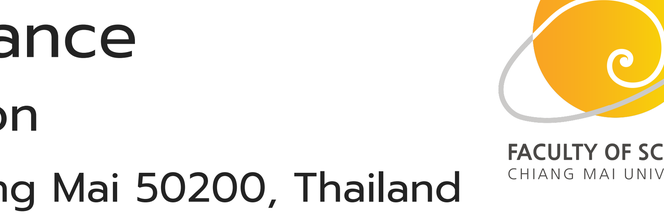


Fig. 9. Raman spectra of (a) CNTs and (b) NM.

- Water vapor transmission rate and water contact angle test of membranes.

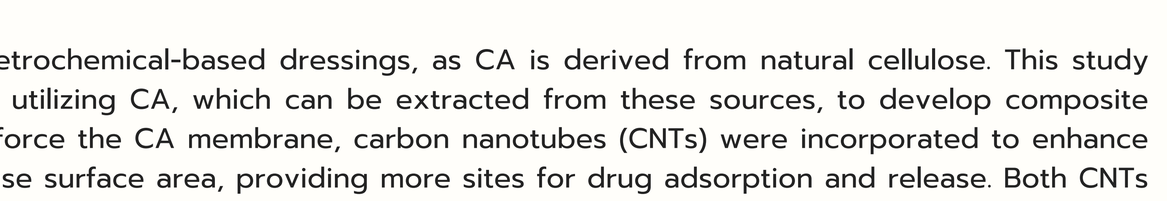


Fig. 10. Time-dependent water contact angles on membranes: (a) WVTRs, (b) water contact angles and (c) chronological digital images showing water drops on each membrane surface.

- Antibacterial activity of membranes at various incubation times and cell viability assessed by MTT assay.

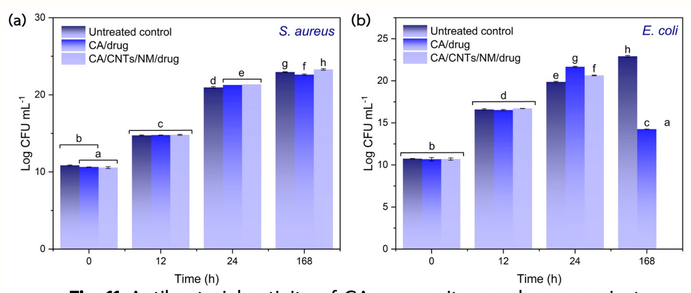


Fig. 11. Antibacterial activity of CA composite membrane against (a) *S. aureus* and (b) *E. coli*.

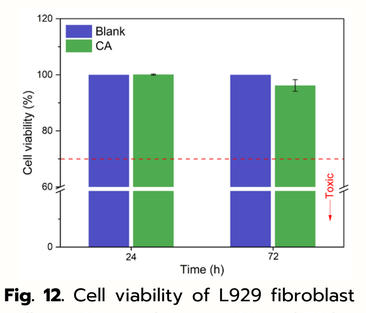


Fig. 12. Cell viability of L929 fibroblast cells on CA membrane at 24 and 72 h.

- Drug release study of CA composite membrane in simulated skin conditions.

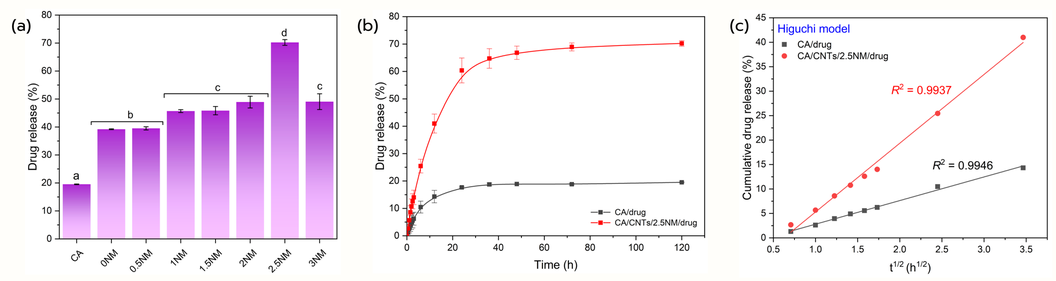


Fig. 13. (a) Drug release performance of CA composite membranes containing different NM contents at 120 h. (b) Cumulative drug release profiles of CA-based membranes over 120 h. (c) Drug release data fitted to Higuchi model.

Table 1. Correlation coefficient (R^2) and release exponent (n) of different release kinetic models of CA-based membranes.

Kinetic model	R^2		n	
	CA/drug	CA/CNTs/2.5NM/drug	CA/drug	CA/CNTs/2.5NM/drug
Zero order	0.9396	0.9838		
First order	0.6913	0.7452		
Hixson-Crowell	0.7991	0.8625		
Korsmeyer-Peppas	0.9771	0.9903	0.7520	0.8449
Higuchi	0.9946	0.9937		

Table 2. Comparison of drug release amounts from various drug carriers.

Material	Cumulative release	Reference
Cellulose acetate/Polyvinylpyrrolidone fibrous materials	68 %	[1]
Electrospun PEG-plasticized PLA/MAX phase membranes	66.52 %	[2]
Electrospun PVA-SA/GO membranes	20 %	[3]
Drug-loaded Dextran sulphate/Chitosan nanoparticles	74 %	[4]
Drug-loaded PLGA nanoparticles	80%	[5]
Electrospun CA/CNTs/NM membranes	**70 %**	**This work**

CONCLUSION

- The characteristics of CA composite membrane confirmed the presence of CNTs and NM within the CA membrane, effectively enhancing its mechanical properties.
- The thermal analysis showed that the melting temperature (T_m) was 279.0 °C and the composite decomposed at 361.4 °C.
- The drug release test showed that 70% of the drug was released over 120 h.
- The CA membrane was non-toxic to L929 fibroblast cells and inhibited *E. coli*.

ACKNOWLEDGEMENTS

Department of Chemistry, Faculty of Science, Chiang Mai University
Faculty of Science, Chiang Mai University
Polymer Research Laboratory, Faculty of Science, Chiang Mai University
Dr. Thanaphorn Rakkan and Dr. Tharnthip Krasian

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