Synthesis and Property Testing of Na-AMPS/CMC Hydrogel with Various PANI Concentration

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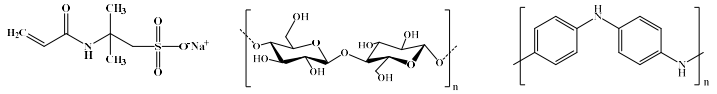
Abstract

This study aimed to develop and study the properties of a conductive composite hydrogel composed of sodium 2-acrylamido-2-methylpropanesulfonate (Na-AMPS), carboxymethyl cellulose (CMC), and polyaniline (PANI) for use as a wound dressing material. The hydrogel was prepared via photo-initiated free radical polymerization. PANI was added at different concentrations (0, 0.125, 0.25, 0.5, and 1 %w/w relative to Na-AMPS) to enhance electrical conductivity and render the material responsive to electrical stimulation. The synthesized hydrogels were transparent, sheet-like materials with PANI well dispersed throughout the structure. The formation of the polymer network was confirmed by Fourier Transform Infrared Spectroscopy. Mechanical testing showed that adding PANI increased the storage modulus and complex viscosity, indicating that the hydrogel became stiffer as the PANI concentration increased. Regarding water transport properties, the addition of PANI increased the water vapor transmission rate to a range of 65–73 $g \cdot h^{-1} \cdot m^{-2}$, which is suitable for wound dressing applications. The equilibrium swelling capacity slightly increased with the addition of PANI; however, it decreased at higher PANI concentrations. In addition, electrical conductivity measurements showed that conductivity increased with increasing PANI concentration. In conclusion, the Na-AMPS/CMC/PANI composite hydrogel exhibits appropriate mechanical strength, good moisture management, and enhanced electrical conductivity. Therefore, it has potential for use as a conductive wound dressing and may support the future development of electrically stimulated wound-healing systems.

Introduction

Hydrogels have attracted significant attention as wound dressing materials due to their ability to absorb wound exudate, maintain a moist wound environment, and allow gas permeability. These properties help support tissue regeneration and promote the wound healing process. Conductive hydrogels have gained increasing interest, as incorporating electrically conductive components into the hydrogel network allows the material to respond to external electrical stimulation and enables electrically controlled drug release. This capability may help enhance and accelerate the wound healing process. Conductive polymers such as polyaniline (PANI) are commonly used to improve the electrical conductivity of hydrogel systems.

Therefore, this study aims to prepare and characterize a conductive composite hydrogel composed sodium 2-acrylamido-2-methylpropanesulfonate (Na-AMPS), carboxymethyl cellulose (CMC) incorporated with polyaniline (PANI). The developed hydrogel is expected to function as an effective wound dressing material by maintaining an appropriate wound environment, reducing irritation, and enabling electrically controlled release of active agents. This approach may provide a promising strategy for the development of advanced wound dressing materials that can better meet clinical needs.



Na-AMPS **CMC** **PANI**

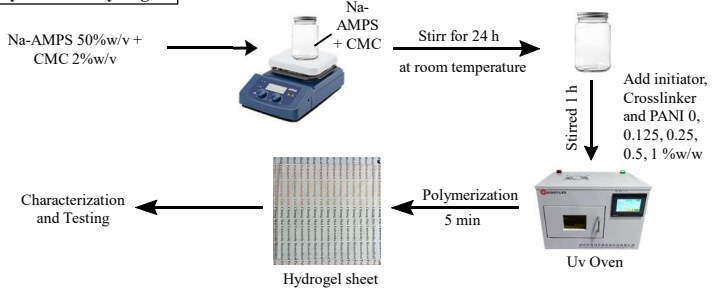
Experiment

1. Synthesis of PANI

Aniline ($C_6H_5NH_2$) + Ammonium persulfate (APS) + HCl → Oxidative polymerization, 3 h → PANI

Samples	PANI content (w/w)
ACP-0	0
ACP-0.125	0.125
ACP-0.25	0.25
ACP-0.5	0.5
ACP-1	1

2. Synthesis of Hydrogel



Conclusions

The Na-AMPS/CMC/PANI composite hydrogel was successfully synthesized by photo-initiated free radical polymerization using different concentrations of PANI. FTIR analysis confirmed the formation of the polymer network and the successful incorporation of PANI within the hydrogel structure. The results showed that increasing the PANI concentration enhanced the mechanical properties of the hydrogel, as indicated by higher storage modulus, complex viscosity, suggesting that the hydrogel network became stiffer.

In terms of water transport properties, the hydrogel exhibited an appropriate water vapor transmission rate for application as a wound dressing material. The swelling ratio slightly increased with the addition of PANI but tended to decrease at higher PANI concentrations. In addition, the electrical conductivity of the hydrogel increased with increasing PANI content. In conclusion, the Na-AMPS/CMC/PANI composite hydrogel demonstrates suitable mechanical strength, moisture management ability, and electrical conductivity. Therefore, it has potential for use as a conductive wound dressing material and may support the future development of electrically stimulated wound healing systems.

Acknowledgement

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Results and discussion

Physical appearances

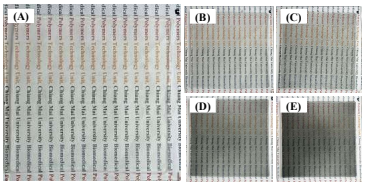


Fig.1 Comparison of the physical appearances of hydrogel in different PANI concentration (w/w) : (A) ACP-0, (B) ACP-0.125, (C) ACP-0.25, (D) ACP-0.5 and ACP-1.

The synthesized hydrogels appeared as transparent sheet-like materials,andthecolorbecamedarkerasthePANIconcentrationincreased.

Structural Analysis by FTIR

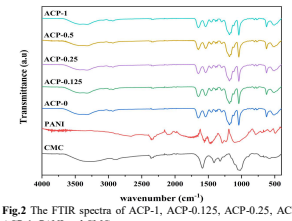
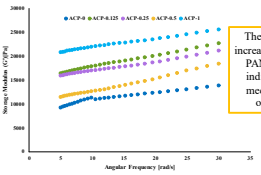


Fig.2 The FTIR spectra of ACP-1, ACP-0.125, ACP-0.25, ACP-0.5, ACP-1, PANI and CMC.

The FTIR spectra showed characteristic peaks of the functional groups in the hydrogel structure. A broad peak at 3200–3500 cm^{-1} corresponds to –OH stretching, the peak at 2920 cm^{-1} is attributed to C–H stretching, and peaks at 1030–1150 cm^{-1} correspond to S=O stretching from Na-AMPS. In addition, characteristic peaks of PANI were observed at 1500–1600 cm^{-1}, confirming the successful incorporation of PANI into the hydrogel network.

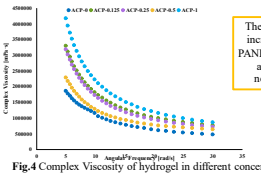
Mechanical Properties

Dynamic Shear Rheometer



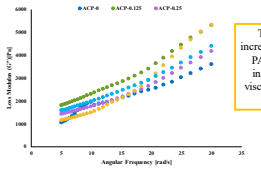
The storage modulus increased with increasing PANI concentration, indicating improved mechanical strength of the hydrogel.

Fig.3 The Storage Modulus (G') of hydrogel in different concentrations of PANI.



The complex viscosity increased with higher PANI content, suggesting a denser polymer network structure.

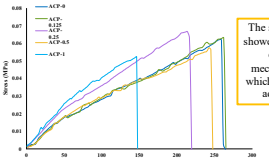
Fig.4 Complex Viscosity of hydrogel in different concentrations of PANI.



The loss modulus increased with increasing PANI concentration, indicating enhanced viscoelastic behavior of the hydrogel.

Fig.5 The Loss Modulus (G'') of hydrogel in different concentrations of PANI.

Tensile Testing



The stress–strain curves showed that the hydrogels exhibited good mechanical properties, which improved with the addition of PANI.

Fig.6 The stress-strain curves in different concentrations of PANI.

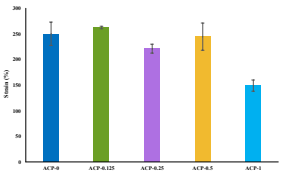


Fig.7 The Percent Strain of hydrogel in different concentrations of PANI.

The percent strain varied among the samples. ACP-0.125 showed the highest strain value, indicating better deformation ability, while ACP-1 exhibited the lowest strain, suggesting a reduced flexibility at higher ACP concentration.

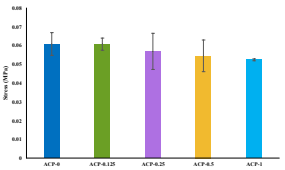


Fig.8 The Stress of hydrogel in different concentrations of PANI.

The stress values of the hydrogels slightly decreased as the PANI concentration increased. This result suggests that the addition of PANI affected the mechanical strength of the hydrogel network, possibly due to changes in the internal polymer structure.

Conductivity Test

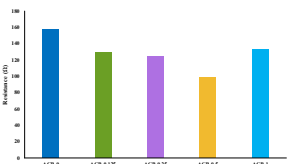


Fig.10 The Resistance of hydrogel in different concentrations of PANI.

Electrical resistance decreased with increasing PANI concentration, indicating improved electrical conductivity.

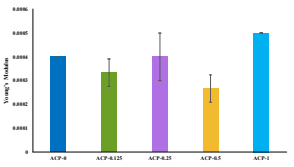
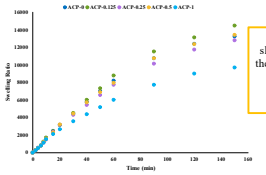


Fig.9 The Young's modulus of hydrogel in different concentrations of PANI.

Young's modulus varied among the samples, indicating differences in stiffness. ACP-1 showed the highest modulus, suggesting the strongest and stiffest structure, while ACP-0.5 exhibited the lowest modulus, indicating lower stiffness compared to the other samples.

Water Swelling



The swelling ratio slightly increased with the addition of PANI but tended to decrease at higher PANI concentrations.

Fig.11 The swelling ratio of hydrogel in different concentrations of PANI.

Water Vapor Transmission Rate

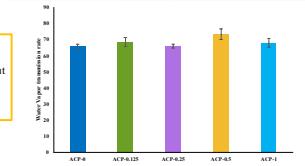


Fig.12 The water vapor transmission rate of hydrogels with different concentrations of PANI over 8 hours.

The WVTR values were within a suitable range for wound dressing applications, indicating good moisture management ability of the hydrogel.