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Creation of Biodegradable Wound Bandage Nonwoven Nanocomposites Based on Silk Fiber Waste and Study of Their Biophysical Properties

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Abstract: This article describes the creation of biodegradable wound dressings using silk fiber industrial waste and the testing of their physical and antibacterial properties. The silk fibroin nonwoven material was treated with chitosan and zinc oxide (ZnO) nanoparticles. Researchers measured moisture absorption, water vapor permeability, mechanical strength, and antimicrobial activity. The results show that these silk-based materials help maintain proper moisture in wounds and lower the risk of infection.

Keywords: Silk fibroin, nonwoven material, chitosan, ZnO nanoparticles, biodegradation, wound dressing.

Introduction: In recent years, the requirements for medical textile materials have been increasing significantly. In particular, wound dressings should be biocompatible, non-toxic, provide optimal gas exchange, and have antimicrobial activity. In this regard, natural polymers, particularly silk fibroin, are attracting significant attention as promising biomaterials.

Creating high-value-added medical materials from recycled silk fiber waste is not only economically important but also environmentally important. The β-layer structure of silk fibroin provides its mechanical stability, and the amino acid composition creates favorable conditions for cell adhesion. By combining it with chitosan and nanoparticles, it is possible to obtain a composite material with enhanced functional properties.

Research Aim and Objectives

This study aims to develop a biodegradable, antibacterial nonwoven wound dressing from silk fiber industrial waste and to test its key biophysical properties. The goal is to turn silk waste into a useful biomedical material with improved performance for regenerative medicine.

To reach this goal, the study set out these objectives:

- to fabricate a structurally stable nonwoven matrix derived from regenerated silk fibroin fibers;
- to enhance the surface functionality of the material through chitosan modification to improve hydrophilicity and biocompatibility;
- to incorporate zinc oxide (ZnO) nanoparticles as a bioactive component to impart antibacterial properties;
- to investigate the mechanical characteristics, moisture absorption capacity, and water vapor transmission rate (WVTR) of the developed composites;
- to assess the antibacterial efficacy of the fabricated materials against representative Gram-positive and Gram-negative bacterial strains.

These objectives aim to provide a scientific foundation for the use of silk-based nanocomposite nonwoven materials in today’s wound care systems.

METHODS

The main raw material was cleaned, dried silk fiber waste. A nonwoven structure was made using needle punching. After that, the material was treated with a 1% chitosan solution and dried. ZnO nanoparticles were made by ultrasonic dispersion and then sprayed onto the surface.

To study the structure and properties of the materials, we used scanning electron microscopy (SEM), Fourier-transform infrared spectroscopy (FTIR), mechanical testing, and microbiological analysis.

RESULTS

Biophysical Properties

Table 1. Biophysical characteristics of developed nonwoven materials

№	Sample	Moisture Absorption (%)	WVTR (g/m²·day)
1	Control	180	850
2	Chitosan-modified	210	920
3	ZnO-enriched	225	980

The results show that changing the material's surface made it much more hydrophilic. Moisture absorption rose from 180% in the control sample to 225% in the ZnO-enriched composite. The water vapor transmission rate (WVTR) also increased with each modification step.These values fall within the ideal range for keeping a wound moist, which helps tissue regenerate and prevents excess fluid from building up [2]. A higher WVTR indicates the material is more breathable while still maintaining the right moisture balance.

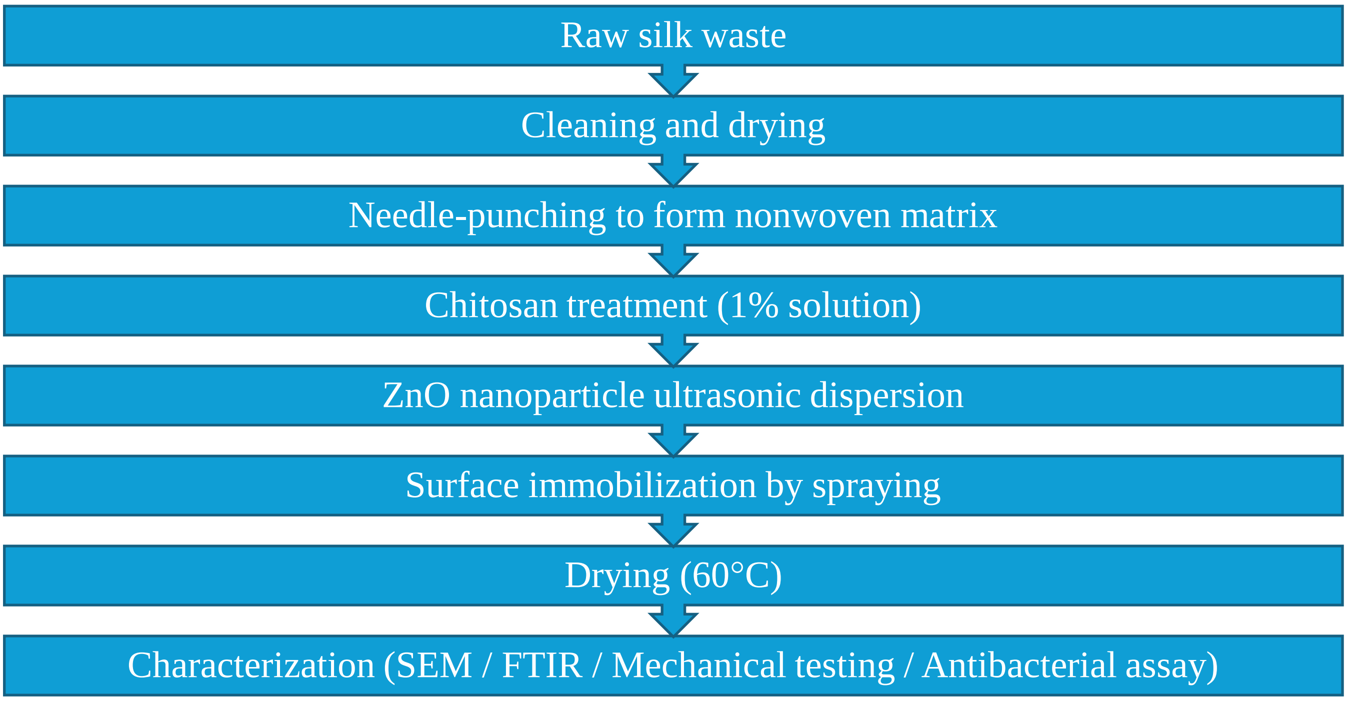

Figure 4 – Process Flow of Silk-Based Nanocomposite Nonwoven Fabrication

Mechanical Properties

Table 2. Mechanical performance of fabricated composites

№	Sample	Tensile Strength (MPa)	Elongation/at Break (%)
1	Control	4.5	34
2	Chitosan-modified	5.2	32
3	ZnO-enriched	5.6	30

The tensile strength increased from 4.5 MPa in the untreated sample to 5.6 MPa after ZnO addition. While there was a small drop in elongation at break, the composite still had enough flexibility for use in wound dressings. The increase in mechanical strength is likely due to better interactions between the silk fibers and the bioactive additives. ZnO nanoparticles are likely to act as reinforcing fillers, strengthening the fiber-to-fiber bonds in the nonwoven matrix [9].

Antibacterial Activity

Table 3. Antibacterial activity (inhibition zone diameter, mm)

№	Sample	S. aureus (mm)	E. coli (mm)
1	Control	0	0
2	Chitosan-modified	10	9
3	ZnO-enriched	16	14

The control sample showed no antibacterial effect. When chitosan was added, moderate zones of inhibition formed. The composite with added ZnO showed much stronger antibacterial activity against both Gram-positive and Gram-negative bacteria.

The stronger antibacterial effect is linked to the production of reactive oxygen species (ROS) and the release of Zn^{2+} ions. These factors damage the bacterial membrane and interfere with their metabolism [4,7].

DISCUSSION

The results show that adding biologically active components to silk-based nonwoven materials significantly improves their performance. Chitosan helps the material absorb water and endows it with natural antimicrobial properties, as its polycationic nature interacts with negatively charged bacterial cell membranes [3,5]. Adding ZnO nanoparticles makes the material even better at killing bacteria and also stronger. When silk fibroin, chitosan, and ZnO nanoparticles are combined, they form a multifunctional nanocomposite that is effective for wound care.

The material can absorb moisture and maintain WVTR values within the desired range, helping create a controlled environment for cell growth and tissue repair.

CONCLUSION

This study demonstrates that biodegradable nonwoven nanocomposites made from industrial waste silk fibers can be designed for wound dressings. The chitosan/ZnO-modified materials controlled moisture more effectively, were stronger, and showed better antibacterial properties than the untreated control.

The composite developed here is a promising option for advanced wound care. It offers biocompatibility, mechanical strength, and antimicrobial protection in one eco-friendly material.

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