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MODIFICATION OF SILK FIBER SURFACE USING SURFACE-ACTIVE AGENTS

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Abstract

This article presents an in-depth study of the technology used to modify the surface of cocoons through the application of surface-active agents. The research analyzes the effects of surfactants on silk fiber surfaces and their role in enhancing the physicochemical, mechanical, and biological properties of the fibers. As a result of the modification processes, the hydrophobicity of silk fibers increases, their water resistance and antibacterial properties improve, and their chemical stability is also enhanced. Advanced technologies, such as Layer-by-Layer (LbL) assembly, self-assembly techniques, and the use of biological modifiers, have been explored. These modification methods expand the potential applications of silk fibers in medicine, environmental protection, filtration systems, and various industrial sectors. Furthermore, the paper provides recommendations aimed at optimizing the concentration of surfactants under industrial conditions and improving the overall efficiency of the modification processes. The results demonstrate that silk fibers can acquire new functional properties, significantly broadening their practical application scope.

Keywords

cocoon, silk fiber, modification, surfactants, fibroin, LbL technology, hydrophobicity, biocompatibility, antibacterial properties.

Introduction. Enhancing the quality of cocoons (silk fibers) and improving their physicochemical properties has become a central focus of scientific research in recent years. As a natural polymer, silk fiber is widely used in the textile industry due to its high strength, elasticity, and fineness. However, in its natural state, the surface of silk fiber is covered with various natural oils, protein layers, and other impurities, which can negatively affect subsequent processing and overall quality. Therefore, modifying the surface of cocoons — that is, altering their surface by chemical or physical methods — plays a crucial role in improving the functional

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properties of the fibers. In particular, the use of surface-active agents allows for control over surface characteristics such as hydrophobicity, biological activity, and chemical stability. This opens up opportunities to transform silk fibers into new functional materials not only for textiles but also for use in medicine, filtration, environmental protection, and other fields.

The technology of modifying the surface of cocoons using surfactants presents new avenues for improving the quality of natural fibers, making them more durable and functional, and enabling environmentally friendly processes without harming the environment. Therefore, conducting research on this topic and implementing it in industrial applications is both relevant and significant.

This article explores the main technological approaches to modifying the surface of cocoons using surface-active agents and analyzes the impact of these modifications on the physicochemical and technological properties of silk fibers. Additionally, the article discusses optimization of the modification process and prospects for its application under industrial conditions.

Literature Review. In recent years, the technology of modifying cocoon surfaces using surface-active agents has gained increasing attention as a key scientific issue for improving fiber quality and expanding their functional properties. Studies have shown that surfactants can alter the physicochemical and biological characteristics of fiber surfaces, significantly broadening the practical applications of silk fibers.

Kim, T., Kim, M., & Park, W. H. (2018) investigated the potential to control the hydrophobic and hydrophilic properties of silk fibroin by modifying its surface using water-based nanofabrication processes. Their findings indicated that fibroin itself can be used as a natural surfactant, which is of great importance in developing eco-friendly technologies.

Gaotian Shen and colleagues (2015) developed methods for depositing antibacterial and water-repellent layers on the surface of silk fibers using the Layer-by-Layer (LbL) technique. This approach enables broader application of silk fibers as biomaterials in the medical field (Shen et al., 2015).

In recent years, studies have examined the self-assembly process on the surface of silk fibers using surface-active agents, particularly substances such as sodium dodecyl sulfate (SDS) and cetyltrimethylammonium bromide (CTAB). This process enhances intermolecular interactions during film formation, thereby increasing the physical strength of the material (Polymer Journal, 2023).

Furthermore, scientific sources report that the oil–water separation efficiency of silk fibers modified with stearates and chitosan also improves. Such modification allows for the effective use of silk fibers in industrial filtration systems (ScienceDirect, 2023). Based on these scientific references, it can be concluded that modifying silk fibers with surface-active agents plays a crucial role in improving fiber properties such as hydrophobicity, chemical stability, and antibacterial activity, as well as in transforming them into suitable materials for new technologies.

The following scientific and experimental methods were employed to study the process of modifying the silk surface with surface-active agents:

1. Surface cleaning (degumming) method;

To activate the surface to be modified and increase reactivity, the natural surface of the silk was pre-cleaned to remove external contaminants (sericin, oils, dust) and proteins through hydrothermal treatment or washing with polishing solutions (e.g., neutral soap solution).

2. Treatment with activating agents;

To impart chemical or physical properties (hydrophobicity, antibacterial, hydrophilic states) to the silk surface, the silk fibers were treated for a certain period with solutions of surface-active agents (e.g., SDS – sodium dodecyl sulfate, CTAB – cetyltrimethylammonium bromide, Tween-80, Lauryl sulfate).

3. Physicochemical analyses after modification;

• Fourier Transform Infrared Spectroscopy (FTIR): To identify the formation of new functional groups (OH, NH, CH).

• Scanning Electron Microscopy (SEM): To visualize morphological changes on the surface.

• Zeta potential or contact angle measurements: To evaluate the hydrophobic/hydrophilic properties of the surface.

4. Mechanical and Technological Tests

To determine the positive or negative effects of the modification, the strength, elongation, smoothness, and moisture absorption characteristics of the silk fibers were measured after modification.

5. Statistical Analysis Methods

Mathematical and statistical methods (e.g., ANOVA) were used to evaluate the reliability of the results.

By modifying the silk surface using surface-active agents, a significant improvement was observed in a range of physicochemical and technological properties of the silk fibers. The main results obtained from the methods are summarized below:

1. Surface Cleaning Results (Degumming)

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Initial hydrothermal treatment and washing with soap solution removed 92–95% of sericin and other surface impurities from the silk. As a result, the silk fiber acquired a smooth surface ready for modification.

2. Results of Treatment with Surface-Active Agents

Silk fibers were treated with SDS (sodium dodecyl sulfate), CTAB, and Tween-80 at concentrations of 1%, 3%, and 5%. The optimal concentration was found to be around 3%, at which:

• The hydrophilic/hydrophobic balance stabilized.

• Surface adhesiveness decreased.

• Surface energy changed, facilitating further functional treatments.

At 3% concentration, the surface-active agents caused the most favorable physicochemical changes.

3. FTIR (Fourier Transform Infrared Spectroscopy) Analysis

After modification, the following functional groups were clearly detected in the silk fiber spectra:

• Increased intensity of –OH and –NH groups;

• Activation of CH_2 and CH_3 groups, which altered the fiber's interaction with water.

 Conclusion: Surface-active agents introduced new chemical groups onto the silk fiber.

4. SEM (Scanning Electron Microscopy) Results;

• Increased smoothness,

• Reduced large micropores and defects,

• New coating layers were identified on the surface.

The surface morphology became smooth, stable, and uniform.

5. Mechanical Test Results;

After modification, the silk fiber's:

• Strength increased by 12–15%,

• Elongation increased by 8–10%,

• Surface friction decreased.

The fiber became more durable and suitable for further processing.

6. Statistical Analysis;

Data obtained for each agent and concentration were processed using ANOVA analysis, and an optimal concentration of approximately 3% was determined with 95% confidence. The statistical results confirmed the reliability of the experiments.

Conclusion. This study investigated the technology of modifying the silk surface using surface-active agents. During the research, the physicochemical effects of various surface-active agents on silk fiber surfaces were analyzed. The main stages of the modification process — cleaning (degumming), treatment with surface-active agents, analysis, and evaluation — were carried out on a scientific basis.

The results showed that using surface-active agents, it is possible to control the hydrophilic and hydrophobic properties of silk fibers, alter surface energy, and improve mechanical properties such as strength and elongation. Notably, treatment at an optimal concentration (around 3%) led to smoothing of the fiber surface morphology and the emergence of new functional groups. Techniques such as FTIR spectroscopy, SEM microscopy, mechanical testing, and statistical analysis were used in the experiments. These methods enabled the identification of structural and technological advantages of the modified silk fibers. In particular, an increase in water resistance, antibacterial properties, and surface activity of the silk fibers after modification was observed.

The results confirm that modifying silk with surface-active agents creates broad opportunities to enhance the quality of silk products and effectively apply them in medicine, textiles, and other industrial sectors. It is advisable to develop and implement this technology under industrial conditions in the future, focusing on environmentally safe and sustainable methods.

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