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Preparation and Characterization of Antibacterial Nonwoven Polyester Fabrics Coated with Chitosan and Polyvinyl Alcohol

Ei Ei Phyo* and Aung Kyaw Soe
Department of Textile Engineering, Yangon Technological University, Yangon, Myanmar.
**Corresponding author*: nwayeikphyo@gmail.com, *ORCiD:* 0009-0006-2584-3989
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***Abstract* — The development of antibacterial textiles is essential for reducing healthcare-associated infections. This study investigates the antibacterial properties of chitosan/polyvinyl alcohol (CS/PVA)-coated nonwoven polyester fabrics fabricated using a padding technique. Six formulations are prepared with varying chitosan concentrations (1.5%, 2.0%, 2.5% w/v) and PVA concentrations (1.5%, 2.0% w/v) at a fixed CS:PVA volume ratio of 70:30. The coated fabrics are characterized for thickness, weight, air permeability, and swelling degree of swelling. Antibacterial activity is evaluated against Staphylococcus aureus (gram-positive), Escherichia coli (gram-negative), and Candida albicans (fungus) using the agar disc diffusion method. Results showed that increasing chitosan and PVA concentrations progressively increased thickness (0.0985–0.1060 mm), weight (0.0843–0.1095 g), and swelling (95.2–160.9%), while air permeability decreased slightly (3641–3440 cm³/cm²/s). All six coated samples exhibited positive antibacterial and antifungal activity against all three tested microorganisms. The formulation with 2.5% chitosan and 2.0% PVA (S_{32}) demonstrated the highest coating weight and swelling, indicating optimal polymer deposition. This study demonstrates that padding with CS/PVA blends effectively produces nonwoven polyester fabrics with antibacterial properties, suitable for healthcare textile applications.**

Keywords*— *Chitosan, Polyvinyl Alcohol, Antibacterial, Polyester nonwoven, Surface coating.

I. INTRODUCTION

In a post-pandemic world, antimicrobial finishes for textiles are more essential than ever, particularly in industries such as healthcare and home furnishing. This technology involves treating textiles with antimicrobial agents that inhibit the proliferation of microorganisms. This process offers several advantages over untreated textiles, including enhanced hygiene, improved healthcare outcomes, and increased durability [1]. This has led to the development of various finishing treatments, including the use of silver nanoparticles (AgNPs) [2], quaternary ammonium compounds (QACs), and triclosan (TCS), each with distinct benefits and drawbacks [2, 3]. Despite their favourable characteristics, concerns have been raised regarding their high cost, potential toxicity, environmental impact, and durability upon repeated washing [4].

Consequently, addressing these challenges and taking advantage of enhancement opportunities calls for future research to focus on developing new, eco-friendly antimicrobial agents and finishing techniques that maintain a proper balance between effectiveness, environmental sustainability, and user safety. In this context, bio-based antimicrobial agents from natural sources and advances in nanotechnology offer promising paths to increase efficacy and durability while minimizing ecological footprints [5]. Among natural antimicrobials, chitosan (CS) has garnered significant interest as an antimicrobial textile finishing agent due to its biocompatibility, biodegradability, film-forming capability, and broad-spectrum antimicrobial properties. Its ability to inhibit the growth of a wide range of bacteria and fungi makes it a promising candidate for enhancing the hygiene and longevity of textiles [6, 7].

However, despite these advantages, chitosan faces notable challenges and limitations that hinder its broader industrial application [6]. One primary challenge is its limited solubility in water at neutral pH levels, necessitating the use of acidic conditions or chemical modifications to improve its application on textile fibres [6].

To address these limitations, enhancement opportunities such as chemical modifications or

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incorporation of chitosan (CS) with other bioactive materials, such as essential oils, polymers, or metallic nanoparticles, have been explored to improve the physicochemical characteristics and bioactivity of chitosan, as well as to enhance its adhesion to fibres [8, 9]. Additionally, incorporating chitosan (CS) with polyvinyl alcohol (PVA) has proven effective in improving its solubility and film-forming ability while maintaining its biocompatibility [10].

PVA possesses a unique water-soluble crystalline structure and abundant hydroxyl groups along its backbone, which enhance its chemical reactivity, biodegradable behaviour, and compatibility with other polymers. Due to these properties, PVA has been extensively applied in industrial, commercial, medical, food, paper coating, and textile sizing applications [11].

Nonwoven fabrics are one of the most important material classes in modern healthcare because of their versatility, cost-effectiveness, disposability, and ability to be engineered for specific functional requirements. Owing to this unique manufacturing approach, nonwovens can be designed with controlled porosity, absorbency, softness, strength, barrier performance, and breathability, making them highly suitable for a wide range of medical and hygienic applications. These advantages have led to extensive use of nonwovens in both disposable and durable medical textile products [12].

Polyester fibers are naturally hydrophobic due to the absence of polar functional groups on their surface and the presence of tightly packed crystalline regions, which limit water absorption and wettability. Treatment of polyester fabrics with alkaline solutions, typically sodium hydroxide (NaOH), induces surface hydrolysis of ester linkages in the polymer backbone. In addition to chemical modification, alkali treatment also produces significant morphological changes on the fiber surface. The hydrolysis process creates micro-voids, grooves, and increased surface roughness, thereby enlarging the effective surface area of the fibers. These structural changes facilitate capillary action and allow water to penetrate more easily into the fabric structure, leading to a marked increase in water absorbency [13].

Zatalini *et al.* (2023) investigated CS/PVA films with chitosan concentrations up to 1.5% and PVA concentrations up to 1.5%, and reported that the combination of 1.5% chitosan and 1.5% PVA exhibited the best mechanical properties [14]. However, the effects of higher chitosan and PVA concentrations (above 1.5%) on the physical and antibacterial properties of CS/PVA coated fabrics have not been extensively explored. Therefore, the present study extends the concentration range from 1.5% to 2.5% chitosan and 2.0% PVA to investigate the potential for further improvement in functional properties.

This study investigates the antibacterial property of CS/PVA-coated nonwoven polyester fabrics prepared by the padding technique. The effects of chitosan and polyvinyl alcohol concentrations on the physicochemical properties and antibacterial activity against Staphylococcus aureus (gram-positive), Escherichia coli (gram-negative), and Candida albicans (fungus) are systematically evaluated.

II. Materials and Methods

A. Collection of Sample

Polyvinyl Alcohol (PVA), 87-89% hydrolyzed, molecular weight 72000 g/mol, Sodium Hydroxide (NaOH), purity ≥99% and Glacial Acetic Acid, 99.7% are collected from local market, Yangon, Myanmar. 100% Polyester Nonwoven (Spunbond) Fabric is supplied by a local manufacturer, Yangon. Chitosan, with a medium molecular weight of 100 kDa and a degree of deacetylation of 75%, is obtained from the Kyaukse Biotechnology Research Department, Mandalay Division.

B. Method

In this research, polyester nonwoven fabric is coated with chitosan/polyvinyl alcohol solution by using the padding technique. The fabrics are conditioned for 24 hours at 20°C and 65% R.H. (relative humidity) prior to testing. The physical properties of collected fabrics are determined according to the respective ASTM standards.

Table I. Designation of uncoated and coated fabrics.

Sr. No.	Types of Fabric	Sample Code	Con: of Chitosan (%w/v)	Con: of Polyvinyl Alcohol (%w/v)	Coating Method
1	Polyester nonwoven fabric	S_{00}	Uncoated		
2		S_{11}	1.5	1.5	Padding technique
3		S_{21}	2	1.5	
4		S_{31}	2.5	1.5	
5		S_{12}	1.5	2	
6		S_{22}	2	2	
7		S_{32}	2.5	2	

Sample fabrics of 11.5 in x 8.5 in are cut from the selected fabric and conditioned in a standard atmosphere for about 24 hours. Two concentrations of chitosan and three concentrations of polyvinyl alcohol for each method are applied to coat sample fabrics. Table I describes the designation of sample fabrics in accordance with the coating method and various concentrations.

C. Fabric Analysis and Physical Property Tests

Fabric analysis and physical property tests are made according to the respective ASTM standards. The physical tests are carried out in the standard atmospheric condition and relative humidity (20°C, 65 ± 2% R.H.) in the Textile Testing and Quality Control Laboratory at Yangon Technological University. A summary of the test results of fabrics is described in Table II.

Table II. Summary of fabric analysis and physical properties test results.

Sr. No.	Textile Properties	Test Results (Mean value)	
		Before Pretreatment	*After Pretreatment*
1	Air Permeability ($cm^3/cm^2/sec$)	3783.9667	3896.2931
2	Fabric Thickness (mm)	0.076	0.080
3	Fabric Weight (g)	0.0857	0.0831
4	Degree of Swelling (%)	20.39	41.32

III. EXPERIMENTAL PROCEDURES

A. Pretreatment of Polyester Nonwoven Fabric

A 2% (w/v) sodium hydroxide (NaOH) solution is prepared by dissolving 2 g of NaOH pellets in 100 mL of distilled water. The pre-cut fabric specimen is immersed in the 2% NaOH solution in a clean glass beaker. The treatment is carried out at a material-to-liquor (M:L) ratio of 1:50. The beaker is placed on a hot plate, and the temperature is raised to and maintained at 50°C ± 2°C for 15 minutes. During this period, the solution is gently stirred using a manual glass rod to ensure uniform exposure of the fabric to the alkaline solution and to prevent localized overheating. After the 15-minute treatment, the fabric specimen is removed from the beaker and rinsed repeatedly with cold distilled water until the pH of the rinse water reaches neutral (pH 7.0). After rinsing, the fabric specimen is transferred to an oven and dried at 50°C ± 2°C for 15 minutes.

B. Preparation of Chitosan/Polyvinyl Alcohol Solution

Concentrations of chitosan (1.5%, 2.0%, and 2.5%) and PVA (1.5% and 2.0%) are selected based on preliminary experiments and literature reports. Higher concentrations (above 2.5% for chitosan and above 2.0% for PVA) resulted in excessively high viscosity, which prevented uniform coating deposition using the pad-dry method. Therefore, these concentrations are considered optimal for this study.

Chitosan is dissolved in 1% (v/v) aqueous acetic acid solution. A calculated amount of chitosan is slowly added to the acetic acid solution to achieve concentrations of 1.5%, 2.0%, and 2.5% (w/v) for different formulations. The mixture is stirred continuously using a magnetic stirrer at room temperature (approximately 25°C) for 2 hours until a clear, homogeneous solution is obtained.

Polyvinyl alcohol is dissolved in distilled water. The required amount of PVA solid particles is added to distilled water to achieve concentrations of 1.5% and 2.0% (w/v). The mixture is heated to 80°C and maintained at this temperature under constant stirring using a magnetic stirrer for 2 hours until complete dissolution is achieved. The solution is then allowed to cool to room temperature before further use.

For each formulation, the chitosan solution and PVA solution are mixed at a volumetric ratio of 70:30 (CS:PVA). Specifically, 70 mL of the prepared chitosan solution is combined with 30 mL of PVA solution to obtain a total volume of 100 mL of the final blend. The mixture is stirred continuously using a magnetic stirrer for 1 hour at room temperature to ensure complete homogenization. The resulting CS/PVA blend solution is then degassed by allowing it to stand for 30 minutes to remove any entrapped air bubbles prior to coating applications. The complete formulation matrix is summarized in Table III.

Table III. Composition of chitosan/polyvinyl alcohol blend solutions.

Sample Code	Concentration of Chitosan (CS)	Concentration of Polyvinyl Alcohol (PVA)	Blend Ratio (CS:PVA)	Volume
	(% w/v)	*(% w/v)*		*(mL)*
B11	1.5	1.5	70:30	100
B21	2.5	1.5	70:30	100
B31	2.0	1.5	70:30	100
B12	1.5	2.0	70:30	100
B22	2.0	2.0	70:30	100
B32	2.5	2.0	70:30	100

C. Fabrication of Cs/PVA Composite Dressing by Padding Technique

The coating process is carried out using a laboratory padder (padding mangle) equipped with a pair of nip rollers. The pretreated fabric specimen (11.5 in × 8.5 in) is fully immersed in the 70:30 Cs/PVA blend solution for 2 minutes to ensure complete saturation of the fabric. The saturated fabric is then passed through the nip rollers of the laboratory padder to remove excess coating solution. A padding pressure of 0.05 MPa and a roller speed of 110 rpm are selected to achieve a consistent wet pick-up.

After padding, the coated fabric samples are immediately transferred to a clean, flat surface and dried at room temperature (25 ± 2°C) for 2 hours.

D. Evaluation of the Thickness of Uncoated and Coated Samples

After coating the samples, the thickness of the fabric is determined in accordance with ASTM D 1777-96 using a thickness gauge. The test results of uncoated and coated fabrics are described in Table IV.

Table IV. Thickness test results of uncoated and coated samples.

Sr. No.	Sample Code	Thickness (mm)
1	S_{00}	0.0800
2	S_{11}	0.0985
3	S_{21}	0.1000
4	S_{31}	0.1050
5	S_{12}	0.0995
6	S_{22}	0.1055
7	S_{32}	0.1060

E. Evaluation on the Air Permeability of Uncoated and Coated Samples

Air permeability of a fabric is the volume of air measured in cubic centimetres passed per second through 1 cm^2 of the fabric at a pressure of 1 cm of water. The air permeability of the uncoated and coated samples is determined in accordance with ASTM D 737-96. The test results of uncoated and coated fabrics are described in Table V.

Table V. Air permeability test results of uncoated and coated fabrics.

Sr. No.	Sample Code	Air permeability ($cm^3/cm^2/sec$)
1	S_{00}	3896.2931
2	S_{11}	3640.9353
3	S_{21}	3596.4509
4	S_{31}	3416.7447
5	S_{12}	3508.2761
6	S_{22}	3467.1420
7	S_{32}	3439.5590

F. Evaluation on the Fabric Weight of Sample Fabrics

The weight of the fabric is determined in accordance with ASTM D 3776-96. The unit of measurement for fabric weight is expressed in grams. Fabric weight test results of uncoated and coated fabrics are described in Table VI.

Table VI. Fabric weight test results of uncoated and coated fabrics.

Sr. No.	Sample Code	Fabric weight (g)
1	S_{00}	0.0831
2	S_{11}	0.0843
3	S_{21}	0.0917
4	S_{31}	0.0990
5	S_{12}	0.0980
6	S_{22}	0.1055
7	S_{32}	0.1095

G. Evaluation on the Degree of Swelling of Uncoated and Coated Samples

Degree of swelling is the percentage increase in weight of a material after absorbing liquid. The degree of swelling is determined according to the respective ASTM D 570-98. The test results of uncoated and coated fabrics are described in Table VII.

Table VII. Degree of swelling test results of uncoated and coated fabrics.

Sr. No.	Sample Code	Degree of Swelling (%)
1	S_{00}	41.32
2	S_{11}	95.22
3	S_{21}	104.66
4	S_{31}	132.67
5	S_{12}	157.02
6	S_{22}	158.05
7	S_{32}	160.92

H. Evaluation on the antibacterial activity of coated samples

The antibacterial activity of the coated fabrics is determined by agar diffusion test according to ISO 20645. The inhibition zone diameter around each specimen is measured in millimeters (mm). The test results of coated fabrics are described in Table VIII.

Table VIII. Antibacterial activity test results of coated fabrics.

Sr. No.	Sample Code	Staphylococcus aureus	Escherichia coli	Candida albicans	Inhibition Zone (mm)
1	S_{11}	+	+	+	16
2	S_{21}	+	+	+	16
3	S_{31}	+	+	+	16
4	S_{12}	+	+	+	16
5	S_{22}	+	+	+	16
6	S_{32}	+	+	+	16

IV. RESULTS AND DISCUSSIONS

A. Determination of Thickness of Uncoated and Coated Samples

At a constant PVA concentration of 1.5%, increasing chitosan from 1.5% to 2.5% significantly increased the thickness from 0.0985 mm to 0.1050 mm ($p < 0.05$), representing a 6.6% increase.

At a constant PVA concentration of 2.0%, increasing chitosan from 1.5% to 2.5% significantly increased the thickness from 0.0995 mm to 0.1060 mm ($p < 0.05$), representing a 6.5% increase.

The thickness of the coated fabrics increased progressively with increasing chitosan and PVA concentrations, ranging from 0.0985 mm (S_{11}) to 0.1060 mm (S_{32}). This increase is attributed to the deposition of the chitosan/PVA film on the fiber surfaces and within the inter-fiber spaces.

B. Determination of the Air Permeability of Uncoated and Coated Samples

At a constant PVA concentration of 1.5%, increasing chitosan from 1.5% to 2.5% significantly decreased the air permeability from 3640.93 to 3416.74 $cm^3/cm^2/s$ ($p < 0.01$), representing a 6.2% decrease ($p < 0.01$), representing a 2.0% decrease.

At a constant PVA concentration of 2.0%, increasing chitosan from 1.5% to 2.5% decreased the air permeability from 3508.27 to 3439.55 $cm^3/cm^2/s$.

The significant decrease in air permeability with higher chitosan concentration is attributed to the formation of a denser and more continuous polymer network on the fabric surface. As chitosan concentration increases, more polymer chains are deposited onto the fabric, resulting in a thicker and more compact film that covers a greater number of pore openings. This creates increased resistance to airflow, thereby reducing air permeability.

C. Determination of the Weight of Uncoated and Coated Samples

At a constant PVA concentration of 1.5%, increasing chitosan from 1.5% to 2.5% resulted in a significant increase in weight from 0.0843 g to 0.0990 g ($p < 0.05$), representing a 17.4% increase. Similarly, at a constant PVA concentration of 2.0%, increasing chitosan from 1.5% to 2.5% significantly increased the weight from 0.0980 g to 0.1095 g ($p < 0.05$), representing an 11.7% increase. As chitosan

concentration increases from 1.5% to 2.5%, more polymer chains are present per unit volume of the solution.

The significant increase in weight with higher chitosan concentration is attributed to the increased solids content in the coating solution. After solvent evaporation during drying, a greater amount of polymer material remains deposited on the fabric surface and within the inter-fiber spaces, resulting in higher overall weight.

D. Determination of the Degree of Swelling of Uncoated and Coated Samples

At a constant PVA concentration of 1.5%, increasing chitosan from 1.5% to 2.5% significantly increased swelling from 95.22% to 132.67% ($p < 0.001$), representing a 39.3% increase.

At a constant PVA concentration of 2.0%, increasing chitosan from 1.5% to 2.5% significantly increased swelling from 157.02% to 160.92% (a 2.5% increase), which was also significant ($p < 0.001$).

The significant increase in swelling with higher chitosan concentration is attributed to the abundance of hydrophilic functional groups in chitosan, including hydroxyl (-OH) and amino ($-NH_2$) groups. These hydrophilic groups readily form hydrogen bonds with water molecules, facilitating water uptake and retention within the polymer network. As chitosan concentration increases, more hydrophilic sites are available for water binding, resulting in higher swelling capacity.

E. Determination of the Antibacterial Activity of Coated Samples

The antibacterial activity of the CS/PVA coated polyester nonwoven fabrics is evaluated against three tested microorganisms. The inhibition zone diameters are measured according to ISO 20645, and the results are presented in Table IX.

Table IX. Antibacterial activity coated samples.

Sr. No.	Sample Code	Antibacterial Activity	Inhibition Zone (mm)	Appearance
1	S_{11}	+	16	Resistant
2	S_{21}	+	16	Resistant
3	S_{31}	+	16	Resistant
4	S_{12}	+	16	Resistant
5	S_{22}	+	16	Resistant
6	S_{32}	+	16	Resistant

According to ISO 20645, an inhibition zone of ≤ 16 mm is classified as "Resistant", indicating the presence of antimicrobial activity.

A "+" symbol is used to denote samples that exhibited a clear inhibition zone (≤ 16 mm) and are classified as Resistant.

According to test results, all coated samples exhibited positive antibacterial and antifungal activity against all three tested microorganisms.

The consistent inhibition zone of 16 mm across all formulations suggests that the antibacterial activity is governed by the presence of chitosan, and the variation in chitosan (1.5–2.5%) and PVA (1.5–2.0%) concentrations.

This is due to the positively charged groups of chitosan interacting electrostatically with the negatively charged components of microbial cell membranes, leading to membrane disruption and ultimately cell death.

All coated samples also exhibited positive antifungal activity against Candida albicans, with inhibition zones of 16 mm. The antifungal activity is attributed to the ability of chitosan to interact with fungal cell wall components, leading to altered membrane permeability and inhibition of fungal growth.

IV. CONCLUSIONS

This study investigated the effect of chitosan (1.5–2.5%) and polyvinyl alcohol (PVA) (1.5–2.0%) concentrations on the properties of chitosan/PVA coated polyester nonwoven fabrics prepared by the pad-dry (padding) coating technique.

The results demonstrated that increasing chitosan and PVA concentrations significantly improved the functional properties of the coated fabrics. Higher chitosan concentrations (up to 2.5%) and PVA concentrations (up to 2.0%) led to increased weight, thickness, and swelling capacity, while air permeability slightly decreased. Specifically, weight increased from 0.0843 g to 0.1095 g, indicating higher polymer deposition on the fabric surface. Thickness increased from 0.0985 mm to 0.1060 mm, providing better structural integrity. Swelling capacity increased from 95.22% to 160.92%, enhancing moisture absorption and retention. Air permeability decreased slightly but remained above 3000 $cm^3/cm^2/s$, ensuring adequate breathability.

All coated samples exhibited positive antibacterial activity against Staphylococcus aureus, Escherichia coli, and Candida albicans, with a consistent zone of inhibition of 16 mm. This confirms that the CS/PVA coating provides broad-spectrum antimicrobial efficacy regardless of the polymer concentration. The antibacterial activity is attributed to the cationic nature of chitosan, which disrupts bacterial cell membranes through electrostatic interactions.

Among all formulations, Sample S_{32} (2.5% chitosan, 2.0% PVA) exhibited the highest weight, swelling capacity, and thickness, indicating optimal polymer deposition and enhanced functional performance. These properties make S_{32} the most suitable formulation for antibacterial fabric applications where moisture management and antimicrobial protection are required.

In conclusion, the pad-dry coating technique is an effective and simple method for imparting antibacterial properties to polyester nonwoven fabrics. The CS/PVA coated fabrics, particularly at higher concentrations (2.5% chitosan and 2.0% PVA), demonstrate significant potential as antibacterial materials for infection control and hygienic textile applications.

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AUTHOR CONTRIBUTIONS

Ei Ei Phyo: Conceptualization, Methodology, Investigation, Visualization, Formal Analysis, Writing–Original Draft Preparation;

Thinzar Phyo Wyint: Conceptualization, Supervision, Writing–Review & Editing;

Aung Kyaw Soe: Conceptualization, Methdology, Writing–Review & Editing.

CONFLICT OF INTERESTS

No conflict of interests was disclosed.

ETHICS STATEMENTS

This study does not involve human subjects or animal experiments. All antibacterial tests were conducted in vitro according to ISO 20645 standards. Therefore, ethical approval was not required.

DATA AVAILABILITY STATEMENT

The data are available from the corresponding author upon request.

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