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Antibacterial and Comfort Properties of Untreated Bamboo Fabric Related to Cotton Fabrics Treated with Zinc Oxide

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Article

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ABSTRACT

The current study aims to evaluate and categorize bamboo fabric's functional and comfort properties. The study includes the selection of 100% bamboo fabrics of 127 g/m^2 and 112 g/m^2 and cotton fabrics of 104 g/m^2. The cotton fabric was chemically processed and then treated with ZnO (1%, 2%, and 3%) using a padding machine. The antibacterial action of bamboo and ZnO-coated cotton samples was assessed and analysed against E. coli and S. aureus. The moisture properties of the chosen samples were tested. Further, the chosen samples are tested for properties like bending, drapeability, specific handle force, and air permeability. It was found that bamboo samples exhibit extensive microbial activity, and the same was proven through the 3% ZnO treatment of cotton samples. Both cotton and bamboo samples demonstrated enhanced moisture management properties. The comfort properties of bamboo samples are observed to be exceptional compared to cotton samples, making them more suitable for functions in situ than cotton.

KEYWORDS

bamboo, cotton, zinc oxide, antimicrobial activity, comfort properties

INTRODUCTION

Bamboo fibre has been used in medicine since the 6th century. It is an abundant and renewable resource, and gaining popularity over synthetic fibres because of its biodegradability [1–5]. Several studies have shown that bamboo is a multifunctional fibre and is recognized as a natural green composite, in which cellulose fibrils are ingrained in the matrix of lignin and hemicellulose [6-10]. Bamboo plants are the fastest-growing grasses, which have woody stems, and generally, they do not require pesticides or fertilizers [11-13]. Further, it does not occupy the cultivated land [14]. According to the manufacturing methods, bamboo fibre for textiles is categorized as natural bamboo fibre and regenerated bamboo fibre [15]. The extracted fibres contain a rounded cross-section, and the composition is 73% cellulose, 10% lignin, and about 12% hemicellulose [16]. Bamboo fibre offers unique properties such as anti-UV radiation, antibacterial, breathable, a cold and soft handle, good tensile strength, and flexibility, and is also used in erosion control, environmental greening, and medicinal applications [17-20]. Bamboo fabrics are 2–3 °C cooler than the surrounding temperature. Further, they absorb and evaporate moisture quickly, hence producing a more comfortable feel and are more absorbent, able to keep three times its weight of water than cotton fabric due to micro-gaps in the structure [21]. Bamboo material can be used in the areas of hygiene materials and food packaging, bamboo shoes, and apparel [22]. The origin of bamboo's antibacterial characteristics is "Kun", representing a –O H functional group in a direct translation. It fails to explain the particular compound and its area in bamboo; the crushed bamboo powder is extracted with water, 20% aqueous DMSO, and dioxane. *Escherichia coli was* used as a test organism. They found that water extracts and dioxane separately did not appear to have any antibacterial activity, whereas the extracts of bamboo in a 20% dimethyl sulfoxide solution indicate inhibition of microbial growth. Because DMSO was used to extract hemicellulose, it is clear that the hemicellulose could not exhibit significant antibacterial action. Therefore, it was concluded that lignin contains strong antibacterial compounds [7]. In addition to cellulose and lignin, bamboo contains various organic compounds. It has a starch content of 2–6%, a deoxidized saccharide content of 2%, a fat content of 2–4%, and a protein content of 0.8–6%. Bamboo's carbohydrate content plays an important role in its durability and service life; bamboo's resistance to fungal assault is linked to its chemical composition [23]. Tayyar et al. worked on the evaluation of antibacterial, mechanical, and comfort properties of woven fabrics consisting of cotton, bamboo, and silver fibres cotton-bamboo and cotton-silver blended fabrics were created for the study, mechanical qualities were explored, antibacterial activities were determined, and thermal comfort properties were measured [24]. They reported that by varying the weft yarn type and density, the mechanical and comfort qualities of shirting and bedding fabrics can be improved, as well as the antibacterial activities. Antibacterial compounds from the shoot skins of moso bamboo (*Phyllostachys pubescens*) were evaluated by Tanaka et al. [25]. They found the dichloromethane-soluble methanol extract from the bamboo shoot skin (*Phyllostachys pubescens*) prevented the growth of *Staphylococcus aureus*. Nuclear magnetic resonance and mass spectrometry were used to identify the active components as stigmasterol and dihydrobrassicasterol. These chemicals slowed the growth of *S. aureus and E. coli*. Furthermore, in terms of structure-activity connections, the activities of these phytosterols are determined by their side chain structures. These findings suggest that extracts of bamboo shoot skins, as well as the active chemicals found in the skins, could be beneficial as antibacterial materials. Rocky and Thompson studied the production of natural bamboo fibre: assessment and comparison of antibacterial activity [26]. Natural bamboo fibres treated under mild conditions outperformed the raw red margin bamboo plant (*Phyllostachys rubromarginata*) in antibacterial activity against *Staphylococcus aureus*. Bamboo contains chemicals that encourage bacterial growth as well as antibiotic properties. Even though there is a substantial quantity of literature accessible on bamboo fibre, production, and bacterial characteristics, there is very little information available on the content of antibacterial agents in terms of percentage found in bamboo. A thrust was felt to evaluate the presence of antibacterial agents in bamboo in terms of percentage relative to antibacterial chemical-treated cotton, as both materials are composed of cellulose. Hence, the present study evaluates the antibacterial agent present in the bamboo-weaved fabric as far as the rate of contrast and ZnO-treated cotton texture are concerned. Further, bamboo fabrics are also characterized for their moisture management, comfort, and handling properties.

EXPERIMENTAL

Materials and methods

100% bamboo (natural) fabrics of 127 and 112 gsm and 100% unprocessed cotton fabrics were used for the study. An LR-grade zinc oxide chemical was selected as an antibacterial finish for cotton fabric for a comparative study. The bamboo and cotton (plain weave) fabric was manufactured on the rapier loom at Kumaraguru College of Technology, Coimbatore. Table 1 shows fabric characteristics.

Table 1. Physical characteristics of the fabrics

Sample code	Warp x weft (density per cm)	Linear density (tex)		Crimp (%)		Mass /area (GSM)	Thickness (mm)
		Warp	Weft	Warp	Weft		
C-104	35 x 28	15	14	10	11	104	0.256
B-127	30 x 20	20	30	11	5	127	0.290
B-112	30 x 17	20	30	9	7	112	0.285

The selected fabrics were characterized for thread density according to ISO 1963–1969. The normal of 10 perceptions chosen haphazardly is reported as the final value. The yarn crimp (warp and weft) is measured as per IS: 3442-1966. The crimp percentage is evaluated with the following formula:

$$\text{Crimp (\%)} = \frac{L_2 - L_1}{L_1} \times 100 \quad (1)$$

where L_1=Initial yarn length, L_2= stretched yarn length.

Mass per area, tearing strength, and air permeability of specimens are measured as per IS: 1964-1970, IS: 6489-1971, and ASTM- D 737. Further, the compressibility of the samples was evaluated as test procedure IS 7702-1975. The compressibility of grey and processed samples are determined using the:

$$\text{Compressibility (\%)} = \frac{(T_o - T_m) \times 100}{T_o} \quad (2)$$

where T_o is the thickness at 0.5 gf/cm^2, T_m is the thickness at the maximum load

Moreover, the selected fabric samples were also characterized by drapability and bending length according to the standard ASTM –D3691, and ASTM-D1388 respectively.

Grover *et.al* [27] model handle force tester used. In this test, the force required to pull the fabric out was recorded. Handle force is divided by fabric weight per unit area (g/m^2) to get a specific handle force.

The manufactured bamboo fabric of 127 and 112 GSM is desized to remove the size. Further, the selected 100 % cotton fabric is also processed. The significance testing and correlation coefficient approach is used to statistically examine the test outcomes.

Application of ZnO on a cotton fabric

The prepared ZnO solution was applied by pad dry cure process. The bleached cotton samples were immersed in the solution containing ZnO, Lissapol N (0.5%), and acrylic binder (1%) for 5 min. The concentrations of ZnO used are 1%, 2%, and 3% referring to earlier literature [28]. Then they are gone through a padding mangle at a speed of 15 m/min with a pressure of 15 kg/cm^2 to the abundant solution. Each sample is allowed to pass through the solution twice for better distribution of the solution. After padding, the fabric is dried in an oven for 4 minutes at 80 °C and cured for 3 minutes at 140 °C.

Antibacterial activity

The parallel streak technique is utilized to assess the antibacterial ability of bamboo and processed cotton fabric specimens against *E. coli* and *S. aureus* using the AATCC test method 147. A 4 cm diameter cloth specimen was placed in close contact with agar that had previously been streaked with *E. coli* and *S. aureus* inoculum. For 24 hours, the plate was incubated at 37 °C [29].

Absorbency

AATCC TS -018 standard test procedures are used to estimate absorbency. A drop of water was permitted to tumble from fixed tallness onto the test example. The time required for the specular impression of the water drop to vanish is estimated and recorded as wetting time. The ISO 11092 test strategy is used to gauge the water vapour penetrability of chosen textures. It comprises estimating the dynamic heat flow brought about by the dissipation of water going through the tried example. The wickability of the material was measured according to the DIN 53925 test method.

RESULTS AND DISCUSSION

The cotton fabric is processed (desized, scoured, and bleached) and ZnO antimicrobial finish is applied at different add-on levels, i.e., 1%, 2%, and 3% by the pad dry cure method. The treated texture tests were analysed for physical and functional properties. 100% bamboo fabric is also desized and tested for physical and functional properties.

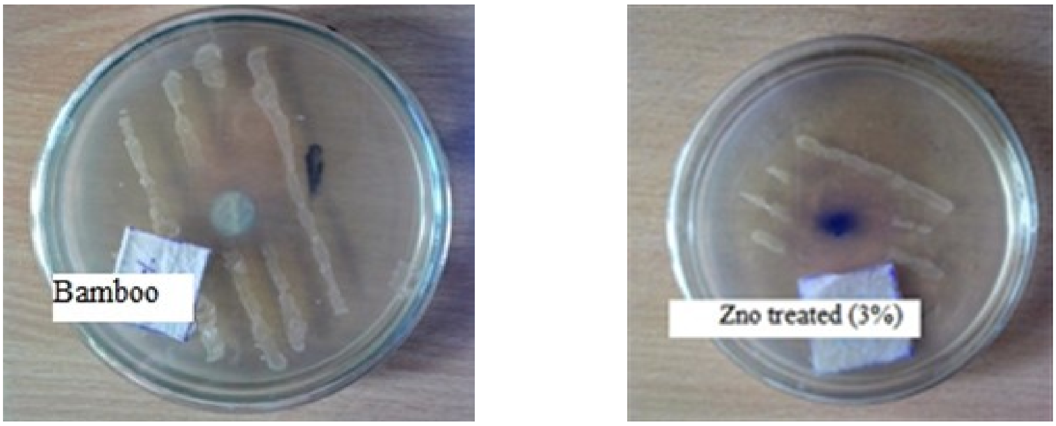
Table 2. Antibacterial activity of bamboo and cotton fabric treated with ZnO

Sample	Zone of inhibition (mm)		Zone of inhibition (mm) after 10 washes		Zone of inhibition (mm) after 20washes	
	E-coli	S. aureus	*E-coli*	S. aureus	*E-coli*	S. aureus
C-104- 1%	0	0	0	0	0	0
C-104- 2%	13	11	10	7	6	5
C-104- 3%	29	28	27	25	18	17
B-127	31	30	31	29	24	22
B-112	30	29	29	26	21	21

Note: C-104-1% - refers that the cotton fabric of 104 gsm treated with 1% ZnO; Zone of Inhibition – 0 refers to the clear interruption of bacterial growth below the sample

Antibacterial activity

Table 2 shows the results of the antibacterial activity of the treated cotton and bamboo fabrics. Cotton samples treated with 2% and 3% are effectively reducing the bacterial growth against the selected microorganism. Further, the bamboo fabrics also show an apparent interruption of bacteria's growth beneath and around the fabrics treated with 1% of ZnO, making it inherently Anti bacteriostatic. The reason for the natural antibacterial action might be the presence of bamboo Kun in its structure. Figure 1 shows that the bamboo fabrics are effectively inhibiting bacterial growth, which is more or less equal to the cotton samples treated with 3% ZnO for both gram-positive and gram-negative bacteria. Further, the bacterial inhibition zone does not change significantly after ten washing cycles, but there is a decrease in the area of inhibition after 20 washing cycles for both cotton and bamboo fabrics. However, Bamboo fabric shows a higher zone of inhibition even after 20 washing cycles.



a) b)

Figure 1. Antibacterial activity samples (a) Bamboo fabric; (b) ZnO-treated fabric

Moisture vapour permeability

Vertical wicking height

The vertical wicking height of the selected samples is shown in Table 3, and it was observed that the bamboo fabrics show a rapid increase in wicking height of 2.2 cm, and the cotton (C-104) sample shows a lower wicking height of 0.2 after one minute.

Table 3. Wicking height of selected samples

Time (min)	Wicking height (cm)		
	B-127	B-112	C-104 (Bleached)
1	1.6	2.2	0.2
3	2.3	2.6	0.4
6	2.9	3.2	0.9
9	3.3	5.0	1.6
12	3.5	5.4	2.2
15	3.8	5.7	2.8
18	4.0	6.0	3.0

Wicking height continuously increases concerning time. This is due to the pores between the fibres, and yarns creating capillary action. The speed and amount of liquid that wicks into a fabric depends on the capillary space distribution and size. Bamboo fabric (B-112) shows a higher wicking height than B-127 due to low mass per unit area and thickness. The average wetting time for bleached cotton fabric is higher than for bamboo fabrics.

Table 4. Relative water vapour permeability, absolute water vapour resistance and wetting time

Sample	Relative vapour permeability (%)	Avg. absolute water vapour resistance (Pa m^2/W)	Wetting time (s)
C-104	53.43	2.62	2.82
B-127	57.17	3.31	1.06
B-112	57.86	3.37	1.09

Table 4 shows the relative water vapour permeability and absolute water vapour resistance of the selected fabrics. Bamboo fabrics offer higher average relative water vapour permeability than cotton fabric samples; B-112 shows higher vapour permeability than B-127 due to their lower mass and thickness. High thread density and microchannels or micropores along the bamboo fibres and yarns transmit faster than cotton fabric. Further, it also shows better water vapour resistance and wetting time over cotton specimens due to higher thickness

Bending length

Table 5 shows that the bending length decreased from grey cotton to bleached cotton fabric in both warp and weft directions due to weight reduction. During chemical processing, the added size waste and added natural impurities are removed, resulting in improved softness and reduced thickness (Table 5). However, the warp bending length is more than the weft, due to the taut condition of the warp threads in the fabric during weaving, and also more threads in warp offer higher bending length than weft. Further, there is a marginal increase in bending length after ZnO treatment (Table 5) because ZnO antimicrobial finish forms a complex layer on the face of the fabric forming hydrogen bonds. It is also observed that the bending length increases with an increase in add-on level in both directions. The bamboo desized sample (B-112) showed lower bending length in warp and weft direction than other samples (Table 5), due to weight loss and improved softness. The results are statistically significant p-value is less than 0.5 (Table 6).

Air permeability

Table 5 shows that the air permeability of cotton fabric samples decreased in wet processing, due to the increased thread density due to the shrinkage of the fabric. Further, protruding fibres ejecting from the fabric after processing will restrict the passage of air leading to a decrease in air permeability. The effect further increased in the samples treated with ZnO (Table 5). The bamboo desized sample (B-112) showed more air permeability on comparing with other samples (Table 5). The reason may be due to lower thread density resulting in more pores, allowing more comfortable airflow. The results were subjected to statistical analysis, and Table 6 shows that the result is significant ($p<0.5$).

Table 5. Effect of chemical processing and antibacterial finish on comfort properties

Treatment type	Compressibility (%)	Drape coefficient	Specific handle (force (gm))	Air permeability ($cm^3/cm^2/sec$)	Bending length (cm)		Tearing strength (gm)		Weight loss (%)	Shrinkage (%)	
					Warp	Weft	Warp	Weft		Warp	Weft
Grey	10.15	0.78	5.58	119.37	2.55	2.02	1012.1	868.3			
Desized	9.15	0.71	5.1	107.82	2.39	1.88	956.1	798.7	5.0	8	6
	(-9.5)	(-9.0)	(-8.5)	(-10.7)	(-6.2)	(-5.5)	(-5.5)	(-8.0)			
Scoured	9.12	0.66	4.96	104.32	2.29	1.74	936.2	775.2	1.6	5	3
	(-10.1)	(-15.3)	(-11.5)	(-14.4)	(-10.2)	(-11.0)	(-7.5)	(-10.7)			
Bleached	8.8	0.65	4.71	102.12	2.18	1.68	927.3	760.1	1.2	3	2
	(-13.3)	(-16.6)	(-15.5)	(-16.9)	(-14.5)	(-13.3)	(-8.3)	(-12.5)			
C-104 -1%	8.80	0.65	4.71	101.6	2.18	1.68	930.3	762.8			
	(-13.3)	(-16.6)	(-15.5)	(-14.8)	(-14.5)	(-13.3)	(-8.1)	(-12.1)			
C-104 -2%	8.81	0.65	4.71	100.30	2.19	1.70	933.10	764.70			
	(-13.3)	(-16.6)	(-15.5)	(-15.9)	(-14.1)	(-15.8)	(-7.8)	(-11.9)			
C-104 -3%	8.81	0.65	4.72	100.30	2.19	1.70	934.20	765.70			
	(-13.3)	(-16.6)	(-15.5)	(-15.9)	(-14.9)	(-15.8)	(-7.7)	(11.8)			
B-127	5.17	0.59	4.25	152.80	3.52	1.73	3040.00	2256.00			
B-127- A.D	4.65	0.50	3.91	139.20	3.21	1.56	3288.00	2425.00	8.0	20	10
	(-10.1)	(-11.9)	(-8.2)	(-8.9)	(-8.8)	(-9.8)	(8.1)	(7.4)			
B-112	4.77	0.57	4.46	223.80	3.46	1.65	2624.00	2272.00			
B-112-A. D	4.21	0.50	4.12	202.5	3.11	1.48	2910.00	2521.00	8.0	23	14
	(-11.7)	(-12.2)	(-7.71)	(-9.5)	(-10.1)	(-10.3)	(11.0)	(11.0)			

Note: Parenthesis shows the percentage shift; A.D refers- After desizing;

Table 6. Statistical inference – P value

Property	Compressibility	Drape coefficient	Specific handle force	Air permeability	Bending length		Tearing strength	
					Warp	Weft	Warp	Weft
P Value (significance at $p<0.5$)	0.0001	0.0011	0.0012	0.0014	0.00012	0.00011	0.00011	0.0021

Drape coefficient

Drape coefficient values decrease in the chemical process (Table 5) because of the chemical process that makes the sample softer in removing impurities. Further, there is no significant change in the drape coefficient even after ZnO treatment at different concentrations. The samples B-112 and B-127 show equal drape co-efficient after desizing. It might be due to equal weight loss and shrinkage values. The results were subjected to Statistical analysis, and Table 6 shows that the result is significant ($p<0.5$)

Specific handle force

Chemical processing results in reduced specific handle force for cotton samples, and this is due to the reduced thickness and fabric softening, the results are in line with drape and bending length (Table 5). The antimicrobial finish did not affect specific handle force for various concentrations (Table 5). Specific handle force for samples B-127 and B-112 was reduced after desizing due to the removal of size (Table 5). The results were subjected to Statistical analysis, and Table 6 shows that the result is significant ($p<0.5$).

Tearing strength

The tear strength of cotton is reduced by chemical processing (Table 5). The fabric treated with caustic soda and hydrogen peroxide, which degrades the fabric to an extent, results in reduced tearing strength. Whereas a small improvement in increased tearing strength contributed by the addition of a complex layer of ZnO on the surface of the fabric, and the bonding between cotton and ZnO, which forms hydrogen bonds, results in improved tearing strength (Table 5). From Table 5, the B-127 sample offers high tear strength than other samples after desizing; this is due to higher shrinkage, yarn linear density and thread density.

Correlation coefficient

All the tested properties show a good correlation between the properties (Table 7). There is a linear relationship between bending length and drape coefficient. The bending length is a measure of the interaction between fabric weight and fabric stiffness in which a fabric bends under its weight. It is one component of a drape and indicates the stiffness of a cloth when bent in one plane under the influence of gravity.

Table 7. Statistical inference – correlation

Property	Compressibility vs. drape coefficient	Bending length vs. drape coefficient	Specific handle force Vs. bending length	Air permeability vs. compressibility
Correlation coefficient	0.68	0.89	0.79	0.88

CONCLUSION

The cotton fabric was pre-treated and finished with ZnO. 100% bamboo fabric was desized and tested for antimicrobial, and functional properties. The selected bamboo fabrics are effectively inhibiting bacterial growth with a zone of inhibition of 31 mm, and 30 mm. The inhibition zone range is similar to the cotton fabric treated with 3% zinc oxide. Hence, the selected bamboo fabrics offer a 3% level of antimicrobial agent. Further, bamboo fabrics offer better vertical wicking, relative vapour permeability, and wetting time over cotton fabric. The bamboo fabric offers better drape, tear, bending, and handle properties than cotton fabric. Further, the chemical treatment of cotton fabric improved the comfort properties.

Author Contributions

Conceptualization – Dakuri A; methodology – Dakuri A and Lolla RT; formal analysis – Dakuri A and Lolla RT; investigation – Dakuri A; resources –Lolla RT; writing-original draft preparation – Dakuri A and Lolla RT; writing-review and editing – Dakuri A and Lolla RT; visualization –Lolla RT; supervision – Dakuri A. All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

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