The Effects of Antibacterial and Flame Resistance Finishing to the Properties of Cotton/Bamboo Pulp Interwoven Fabric

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Abstract: In order to better study the effects of antibacterial and flame resistance finishing to the properties of cotton/bamboo pulp interwoven fabric, a kind of cotton/bamboo pulp interwoven fabric was designed and woven. Fabric properties before and after antibacterial and flame resistance finishing like tensile strength at break, tearing strength, anti-bending stiffness, drapability coefficient, wrinkle recovery angle, air permeability, water vapor permeability, water absorption, dimensional stability to washing, vertical burn damaged length and bacterial inhibition rate etc. were tested. The results show that tensile strength at break, tearing strength, wrinkle recovery angle, air permeability, water vapor permeability, water absorption after antibacterial and flame resistance finishing are worse than those of before finishing. anti-bending stiffness, dynamic drapability coefficient, dimensional stability to washing, vertical burn damaged length, bacterial inhibition rate after antibacterial and flame resistance finishing are better than those of before finishing. Static basically remains the same. It is considered that fabric antibacterial and flame resistance property are better after finishing.
Keywords: interwoven fabric; antibacterial finishing; flame resistance finishing; bamboo pulp fiber; bacterial inhibition rate; vertical burn damaged length.

1. Introduction

Functional textiles are extending continuously in actual life with the development of economy and living standard [1,2]. Antibacterial fabric, flame resistance fabric, anion fabric, heat accumulation and warmth retention fabric, far-infrared fabric and other functional fabrics are favored by consumers [3,4,5]. Study the properties before and after antibacterial and flame resistance finishing of cotton/bamboo pulp interwoven fabric has important economic and practical value [6]. A kind of cotton/bamboo pulp interwoven fabric was designed and woven. Fabric properties before and after antibacterial and flame resistance finishing like tensile strength at break, tearing strength, anti-bending stiffness, drapability coefficient, wrinkle recovery angle, air permeability, water vapor permeability, water absorption, dimensional stability to washing, vertical burn damaged length and bacterial inhibition rate etc. were tested and analyzed.

2 Identification and properties analysis of bamboo pulp fiber

2.1 Burning method

Burning method identified fibers according to the different combustion states and melting, the burning smell and the color, shape, hardness of burning residue near the flame, in the flame and leave the flame[7]. Combustion characteristics of bamboo pulp fiber was shown in Table 1.

Table 1 Combustion characteristics of bamboo pulp fiber

near the flame	in the flame	leave the flame	shape of burning residue	smell
no shrinking, no melting	burning quickly	burning sequentially	a little soft gray ashes	burning paper smell

2.2 Microscopic method

Microscopic method identified fibers by observing morphological structure of fibers by using ordinary biology microscope. Morphological structure of bamboo pulp fiber was shown in Table 2 and Fig. 1.

Table 2 Morphological structure of bamboo pulp fiber

longitudinal form	transversal form
with irregular grooves and uneven surface	The edge has irregular zigzag, but has not skin-core structure

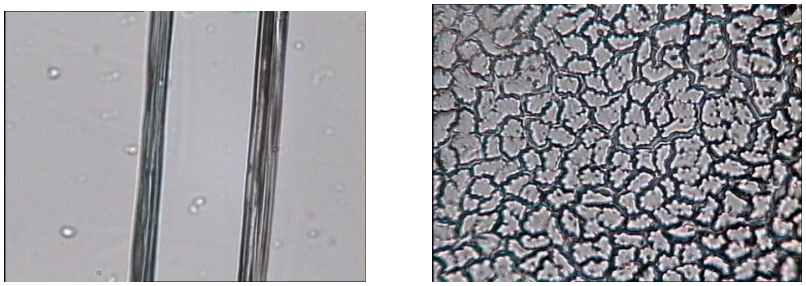

Fig. 1 Morphological structure of bamboo pulp fiber（x1000）

2.3 Chemical dissolution method

Chemical dissolution method identified fibers according to different dissolubility of fibers by using different chemical solvent under different temperature. In order to obtain more accurate test results, it is necessary to strictly control the chemical reagent concentration, processing temperature and time [8,9]. The dissolubility of bamboo pulp fiber was shown in Table 3.

Table 3 the dissolubility of bamboo pulp fiber

Hydrochloric acid（37 %）	normal temperature	S
	boiling	S_0
Sodium hydroxide （5 %）	normal temperature	I
	boiling	I
Formic acid （88 %）	normal temperature	I
	boiling	I
99% N—Dimethyl formamide	normal temperature	I
	boiling	I
Nitric acid（65 %）	normal temperature	I
	boiling	I
Sulfuric acid （75%）	normal temperature	S_0
	boiling	P

Remarks: S_0-solution immediately; S-solution; P-solution partly; I-no solution

3 The properties of bamboo pulp yarn

Single-strong CV, linear density weight CV, single yarn breaking strength, linear density deviations, coefficient of variation unevenness, nep, thick place, thin place were tested according to 《GB/T3916-2013 Textiles-Yarns from packages-Determination of single-end breaking force and elongation at break using constant rate of extension (CRE) tester》[10],《GB/T4743-2009 Textiles-Yarn from packages-Determination of linear density(mass per unit length) by the skein method》 [11]，《GB/T3292.1-2008 Textiles-Unevenness of textile strands-Part 1:Capacitance method》[12]. The properties of bamboo pulp yarn was shown in Table 4.

Table 4 the properties of bamboo pulp yarn

Indexes	Value
Single-strong CV/%	4.9
linear density weight CV/%	1.5
single yarn breaking strength/cN.tex^{-1}	12.1
linear density deviations/%	+0.7
coefficient of variation unevenness/%	12.1
nep/a.km^{-1}	3
thick place/a.km^{-1}	28
thin place/a.km^{-1}	60

4 Fabric structure and specification parameters

The fabric was used 14.5tex cotton warp yarns and 14.5tex bamboo pulp weft yarns woven on JAT710 air jet looms, density of warp yarn was 433 roots/10cm, density of weft yarn was 315 roots/10cm, width was 146.5cm. In order to accurately measure the properties before and after antibacterial and flame resistance finishing like tensile strength at break, tearing strength, anti-bending stiffness, drapability coefficient, wrinkle recovery angle, air permeability, water vapor permeability, water absorption, dimensional stability to washing, vertical burn damaged length and bacterial inhibition rate etc, and avoid error introduced by the size and impurities, the fabric was desized using amylase and then rinsed with cold water 2-3 times, dry in the air, placed in standard atmospheric conditions over 48h, made the fabric got equilibrium under absorption state[13].

5 Antibacterial and Flame Resistance Finishing

Using ATB9800 antibacterial/odor-resistant finishing agent and FPK8002 flame retardant [14]. ATB9800 antibacterial/odor-resistant finishing agent was a non-dissolution-type durable antibacterial finishing agent. ATB9800 had good security, it could effectively remove the bacterial, fungi and mildew of fabric, keep the fabric clean, and prevent the regeneration and reproduction of bacterial. ATB9800 antibacterial/odor-resistant finishing agent was fixed to the fibers because active groups of ATB9800 could form covalent bonds with Hydroxyl group or amine group of fibers, it had a reliable washable broad-spectrum antibacterial effect. The antibacterial principle was that it destroyed the cell wall of bacteria, the intracellular osmotic pressure was higher than extracellular osmotic pressure, so the cell membrane ruptured, cytoplasm disclosed. This would terminate the metabolic processes of microorganism, so that micro-organisms could not grow and reproduce. FPK8002 flame retardant could be applied to the padding process.

Antibacterial finishing: fabric → padding antibacterial solution (padding temperature 30℃, ATB9800 40g/L; pick up ratio 60 ~ 90%, the working fluid volume is small) → drying (110℃) → tentering (140℃×30s) → remove fabric

Flame resistance finishing: fabric → padding (FPK8002 350g/L; two dip two rolling, pick up ratio 60 ~ 80%) → drying (90 ℃) → baking (120℃× 4min) → remove fabric.

6 Test equipment, test parameters and Executive standards

The Test equipment, test parameters and executive standards were shown in Table 5. The test data such as tensile strength at break, tearing strength, anti-bending stiffness, drapability coefficient, wrinkle recovery angle, air permeability, water vapor permeability, water absorption, dimensional stability to washing and vertical burn damaged length were shown in Table 6. Bacterial inhibition rate was shown in Table 7.

Air permeability, water vapor permeability, water absorption, dimensional stability to washing were tested by Nantong Textile Quality Testing Institution Co., Ltd, Report NO: 16157431. Bacterial inhibition rate was tested by Guangdong Detection Center of Microbiology. Report NO: 2016FM7324R01.

Table 5 Test equipment, test parameters and implementation of standards

Test items	Test equipment	Executive standards	Test parameters
Pulling property	YG065 fabric Strength Tester	GB/T 3923.1-2013 Textiles—Tensile properties of fabrics—Part 1:Determination of maximum force and elongation at maximum force using the strip method	Width:50mm±0.2mm （excluding flash）; Length should be able to meet the gauge length; Gauge length:200mm; Stretching speed:100mm/min; Pretension:2N.
Tearing property	YG033A fabric tearing tester	GB/T 3917.1-2009 Textiles--Tear properties of fabrics--Part 1:Determination of tear force using ballistic pendulum method (Elmendorf)	Cutting length:20±0.5mm; Tearing length:43±0.5mm
Rigidity and elasticity	LLY-01B electronic stiffness tester	GB/T 18318.1-2009 Textiles—Determination of bending behavior—Part 1:Incline method	Size:（25±1）mm×（250±1）mm;
Drapability	LLY-351 draping style apparatus	GB/T 23329-2009 Textiles - Determination of drapability of fabrics	Diameter: 24cm

Wrinkle recoverability	YG541D automatic digital fabric wrinkles elasticity tester	GB/T 3819-1997 Textile fabrics--Determination of the recovery from creasing of a folded specimen by measuring the angle of recovery	Pressure overload:10N; the area under pressure overload: 18mm◊15mm;the time under pressure overload:5min±5s
Air permeability	YG461D digital fabric permeability meter	GB/T 5453-1997 Textiles--Determination of the permeability of fabrics to air	Area:20cm^2 ;Pressure drop:100Pa
Water vapor permeability	YG601 moisture permeability box	GB/T 12704.1-2009 Textiles--Test method for water-vapour transmission of fabrics--Part 1:Desiccant method	Diameter: 70mm
Flame resistance	HD815A flame resistance tester	GB/T 5456-2009 Textiles - Burning behaviour - Flame spread properties of vertically oriented specimens	Size: 560mm X 170mm
Antibacterial property	HACH spectrophotometer	GB/T20944.2-2007 Textiles-Evaluation for antibacterial activity-Part 2:Absorption method	Weight:0.40g±0.05g
Water absorption	YG871L capillary effect testing instrument	GB/T21655.1-2008 Textiles—Evaluation of absorption and quick-drying—Part 1:Method for combination tests	Size:10cm◊10cm
Washing resistance	YG701 automatic testing machine of shrinkage rate	GB/T8629-2001 Textiles-Domestic washing and drying procedures for textile testing; GB/T 8630-2013 Determination of textile dimensional change in washing and drying	Size:500mm◊500mm, washing time :15min

Table 6 Fabric properties before and after antibacterial and flame resistance finishing

Indexes		Before finishing		After finishing	
		Warp	Weft	Warp	Weft
tensile strength at break /N		620.8	281.6	422.6	250.0
tearing strength /N		12.60	7.73	9.02	5.06
anti-bending stiffness /mN.cm		0.77	0.37	1.37	0.70
dimensional stability to washing /%		-4.1	-2.1	-3.1	-1.6
wrinkle recovery angle /°	urgent	83.48	86.92	64.93	82.17
	Slow	73.91	81.33	69.62	75.74
drapability coefficient/%		66.09		69.97	
air permeability/mm.s^{-1}		328		161	
water vapor permeability /g.(m^2*24h)		9660		9380	
vertical burn damaged length /mm		207		85	
water absorption /%		127		103	

Table 7 Bacterial inhibition rate

Microorganisms	The total number of colonies detected after inoculation of control sample "0" （cfu/piece）	The total number of colonies detected after 18h inoculation of control sample （cfu/ piece）	The total number of colonies detected after 18h inoculation of sample（cfu/ piece）	Antibacterial value	Bacterial inhibition rate（%）
Escherichia coli ATCC 8739	4.7×10^4	1.6×10^7	< 20	＞5.9	> 99
Staphylococcus aureus ATCC 6538	3.6×10^4	5.3×10^7	< 20	＞6.4	> 99
Candida albicans ATCC 10231	6.0×10^4	2.3×10^5	80	3.5	> 99

7 Analysis of test results

7.1 Analysis of tensile strength at break

According to Table 6, the warp tensile strength of the fabric decreased 31.9%, weft tensile strength decreased 11.2%, this was due to the antibacterial and flame resistance finishing, after finishing the fibers were not easy to produce slip, part of the fibers was damaged, the warp and weft tensile strength of the fabric decreased significantly [15].

7.2 Analysis of tearing strength

The breaking strength and breaking elongation of the yarn were closely related to the tearing strength of the fabric, and the tearing was a step in which the yarns in the fabric were broken one by one in turn, if the yarn was strong, the tearing strength of the fabric was large, the greater the force triangle would be pulled, the triangle had the more number of yarns at the same time, the tearing strength was larger [16]. According to Table 6, the warp tearing strength of the fabric decreased 28.4%, weft tearing strength decreased 34.5%. This was mainly due to the breaking strength and breaking elongation of the yarn decreased after antibacterial and flame resistance finishing, the fragility of fabric increased, tearing strength decreased.

7.3 Analysis of anti-bending stiffness

According to Table 6, the warp anti-bending stiffness of the fabric increased 77.9%, weft anti-bending stiffness increased 89.2%. After antibacterial and flame resistance finishing, antibacterial agents and flame retardants filled in the fabric gap, this made yarn slippage reduction; at the same time, the movement of cellulose molecules and internal rotation were limited, the mobility between the cells was limited too, so the anti-bending stiffness increased.

7.4 Analysis of drapability

Drapability reflects the forming effect, the greater drapability coefficient indicated fabric was more rigid, drapability was worse. According to Table 6, drapability coefficient increased, from 66.09% to 69.97%.Antibacterial agents and flame retardants filled in the fabric gap, the tightness of the fabric increased, the degree of freedom between the yarn became small, this hindered the drapability of fabric.

7.5 Analysis of wrinkle recoverability

The larger wrinkle recovery angle, wrinkle recoverability of fabric was better, the wrinkle resistance of fabric was better too [17]. According to Table 6, the total urgent wrinkle recovery angle before finishing was 170.4°（warp+weft), the total slow wrinkle recovery angle before finishing was 155.24°（warp+weft). the total urgent wrinkle recovery angle after finishing was147.1°（warp+weft), the total slow wrinkle recovery angle after finishing was145.36°（warp+weft). the total urgent wrinkle recovery angle decreased 15.8%, the total slow wrinkle recovery angle decreased 6.8%, wrinkle resistance of fabric became worse, the whole fabric becomes stiff after finishing, this resulted wrinkle resistance of fabric became worse by external pressure [15].

7.6 Analysis of air permeability

The air permeability of fabrics depended on the number and size of warp and weft yarns in the fabric, such as the warp and weft density, the warp and weft count, fiber properties, yarn structure, thickness of fabric and

weight per unit area and so on. the air permeability was greater; the air permeability of the fabric was better [18]. According to Table 6, after finishing, the air permeability of fabric decreased a lot, up to 50.9%.The antibacterial agents and flame retardants adhered to the fabric, the gap of the fabric decreased, this caused the air permeability of fabric decreased.

7.7 Analysis of water vapor permeability

Water vapor permeability of fabric was an important comfort, health performance, it was directly related to the ability to discharge sweat steam [19]. No matter what the season, the body would continue to distribute sweat steam, if the sweat steam quickly distributed out through the fabric, the body would feel comfortable. Water vapor permeability was a measure of moisture permeability of the fabric index, the amount of moisture was larger, sweat steam emitted faster [20]. According to Table 6, water vapor permeability decreased2.9% after finishing. The antibacterial agents and flame retardants adhered to the fabric, the gap of the fabric decreased, this caused the water vapor permeability of fabric decreased.

7.8 Analysis of flame resistance

For the same kind of woven fabric, the flame resistance finishing of the fabric could reduce vertical burn damaged length significantly. After flame resistance finishing, the flame retardants fixed on the surface of fabric, and the flame retardants also penetrated into the internal of fibers, the gap between the yarn reduced, so that the fabric permeability decreased Then the oxygen saturation would drop. At the same time, the flame retardants accelerated the dehydration and carbonization of the fibers and reduced the generation of flammable gases when they were heated, the purpose of fire- resistance achieved [2]. According to Table 6, vertical burn damaged length reduced from 207mm to 85mm.

7.9 Analysis of dimensional stability to washing

Dimensional stability to washing of fabrics or other textile products had a great impact on the specifications. According to Table 6, before finishing, warp dimensional stability to washing was -4.1%，weft dimensional stability to washing was -2.1%;after finishing, warp dimensional stability to washing was -3.1%， weft dimensional stability to washing was -1.6%.

7.10 Analysis of water absorption

Water absorption refered to the percentage of the moisture absorbed by the fabric to the original quality of the fabric when the fabric was completely wetted out of the water and no water was dripped. According to Table 6, water absorption before finishing was 127%，water absorption after finishing was 103%. After finishing, a small number of hydrophilic groups of cotton and bamboo pulp fiber were closed, moisture regain decreased, thus the water absorption of fabric was affected.

7.11 Analysis of antibacterial property

Escherichia coli ATCC 8739, Staphylococcus aureus ATCC 6538, Candida albicans ATCC 10231were tested by Guangdong Detection Center of Microbiology. According to Table 7, bacterial inhibition rate was higher than 99%.

8 Conclusions

（1）After finishing, the warp and weft tensile strength of the fabric decreased significantly.
（2）After finishing, the warp and weft tearing strength of the fabric decreased.
（3）After finishing, the anti-bending stiffness increased.
（4）After finishing, drapability coefficient increased.
（5）Wrinkle resistance of fabric became worse, the whole fabric becomes stiff after finishing.
（6）After finishing, the air permeability and water vapor permeability of fabric decreased.
（7）After finishing, vertical burn damaged length reduced, the flame resistance of fabric became better.
（8）After finishing, dimensional stability to washing increased.
（9）After finishing, water absorption of fabric decreased.
（10）After finishing, bacterial inhibition rate was higher than 99%.

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