Anti-ultraviolet Treatment for Cotton Fabrics by Dyeing and Finishing in one Bath and Two Steps

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Abstract: In this study, a new approach to a UV-blocking treatment for cotton fabrics was developed by dyeing and finishing in one bath and two steps. In this approach, nano-TiO_2 was used as inorganic anti-ultraviolet agent, adhesives poly (vinyl pyrrolidone) PVP was used to improve the wet fastness. Ultraviolet Spectrometer was used for testing and analysis the anti-ultraviolet ability of the cotton fabric before and after the nano-TiO_2 finishing. The effect of the anti-ultraviolet performance and wet fastness of cotton fabrics with different content of nano-TiO_2 or adhesives were investigated. The results show that the nano-TiO_2 UV finishing can effectively improve the UV blocking ability of cotton fabric. With the increase usage of nano-TiO_2, the UV blocking ability of the treated cotton fabrics was increasing. Wet fastness was decreasing when there was no PVP adhesive while it was increasing when there was PVP adhesive and the ability of UV blocking was also increasing. But the content should be controlled in a moderate range; the ability of UV blocking would decrease if the content was exceeding the appropriate range. The electronic fabric strong-tensile machine was used for testing the tearing and breaking tenacity of the treated fabric and the computer-permeability tester was used for testing its air permeability. The results show that the treatment of nano-TiO_2 in this approach for UV-blocking treatment had little effect on the wear ability of the cotton fabric.

Keywords: anti-ultraviolet, cotton fabrics, Nano -TiO_2, PVP adhesive, finishing

1. Introduction

Since the 20th century , due to the increasingly use of Freon solutions, the ozonosphere on the earth aerosphere has been severely destroyed, the amount of ultraviolet radiation that reaches the surface of the earth has been increasing, which is more and more seriously affecting the health of human beings [1, 3]. Although people have taken universal education and use of sunscreen extensively, the incidence of skin cancer is rising. There are many factors of getting skin cancer, but now the factor of long-term radiation by ultraviolet ray has been recognized as an important one [4, 5]. So it is very urgent to research and empolder anti-ultraviolet radiation products, in order to protect from excessive UV radiation. And now, nano materials are used for producing UV-protective textile and enjoys by academic circles and business enterprise field, because of its excellent characteristics [6, 8]. There are many opportunities and challenges on the development of UV-protection clothing, because we should know how it can successfully applied to textiles, including having last characteristics of UV-production, having no effect on textile (such as hand, permeability) and also should consider the feasibility of techniques and cost-effectiveness of products [9].

At present, the nanotechnology worldwide-used in the fabric UV-proof finishing can be mainly divided into three different ways, including implanting, spinning, printing and dyeing.

In the implanting method [10], the anti-ultraviolet nanoparticles are firmly absorbed into the micro-pores on the surface of natural fibers or natural fiber fabrics by special treatment way, endowing the treated fibers or fabrics with anti-ultraviolet function. This method has solved two world-famous problems about the dispersion and fixation of nanoparticles in the natural or chemical fibers. But this technique is very difficult, and it cannot be widely used.

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In the spinning method [11], the anti-ultraviolet nanoparticles are dispersed and melted into the polymer solution and spun into fibers. This method can ensure the firmly combination of the UV- proof agents with the fabrics, but it has complex technique, low production rate, high costs. Moreover, it can be only used for the treatment of chemical fibers. While in the printing or dyeing method [12] the UV-proof agents are mixed into the color paste, dispersed and combined with the textile product in the printing or dyeing process. This can ensure the good dispersion of nanoparticles. Although the products treated by this method have low wet fastness and the functions cannot be maintained long time, but it is simple and quite workable.

In this study, we improved on the printing or dyeing method. The dyeing and finishing are carried out in one bath and two steps to avoid the degradation of dye caused by TiO_2 and save the water. Nano-TiO_2 is used as inorganic anti-ultraviolet agent, poly (vinyl pyrrolidone) PVP is used as an adhesive to increase the wet fastness of treated fabric and maintain its longstanding functions to overcome the disadvantage of the printing or dyeing method. Polyethylene glycol 400 is used as softening and dispersion agent to improve the mechanical and physical properties of treated fabrics.

2. Experiments

2.1 Materials

Cotton fabric (100% bleached cotton plain fabric purchased from Taiwan), nano-TiO_2 (provided by the Institute of Polymer Composite [IPC] of Zhejiang University, about 50 nm), reactive orange K-G, dispersion NNO, ethanol (Wuxi Longjili Chemicals Co.Ltd), penetrating agent JNC, polyethylene glycol 400 (Shanghai Pudong Gaonan Chemicals Co.,Ltd), polyvinylpynolidone (PVP, China Medicine Group Shanghai Chemicals Reagent Co.,Ltd), all the other reagents were analytical grade, and were used without further purification.

2.2 The preparation of nano-TiO_2 dispersion solution

After weighing the needed TiO_2 powder into 4 middle-size beakers, add adequate ethanol to the beakers and then put them into the ultrasonic shaker to shake for 10 min, stirring with glass rod continuously.

2.3 Dyeing and nano-TiO_2 anti-ultraviolet treatment for cotton fabric

Table 1
Dyeing recipe

item	dosage
reactive dye /%	2
NNO/g/L	1
NaCl /g/L	20(used in two times)
Na_2CO_3/g/L	10
scour/g/L	1
dyeing time/min	30
dyeing temperature/℃	60
dye fixing time/min	60
dye fixing temperature/℃	70
soap-boiling time /min	15
soap-boiling temperature /℃	95-100
bath ratio	1：30
PH	10
penetrating agent (JNC)	adequate

Table 1 is the dyeing recipe, and the anti-ultraviolet treatment recipe is adding different nano-TiO_2 and PVP, as shown in table 2, into the remainder of dyeing solution.

The dyeing and treatment procedure is as following:

Preparation of the nano-TiO_2 dispersion solution → dyeing solution preparation → adjusting the PH to 10 → dyeing (60 ˚C, 30 min) → dye fixation (70 ˚C, 30 min) → adding the nano-TiO_2 dispersion solution → nano-TiO_2 anti-ultraviolet treatment (70 ˚C, 30 min) → washing (40 ˚C water) → soaping (100 ˚C, 10 min) → washing (normal temperature) → drying (105 ˚C)

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2.4 Characterization

According to the Chinese standard GB/T 18830-2002, Textiles—Evaluation for solar ultraviolet radiation protective properties, the UV-transmittance of the fabrics before and after finished was tested by UV-spectrophotometer (UV2550). The diameter of each circular sample is 2 cm. The Colorfastness was measured according to the Chinese standard GB/T 3920-1997, Textiles—Tests for color fastness-Color fastness to rubbing, by Rubbing Colorfastness Test Machine (Y571, specification: 60±3/min). The Electronic Fabrics Strength Tester (YG065HS-50/PC) was used to the test the fabric strength (gauge, 200mm; speed, 100mm/min; temperature and humidity 20˚C, 65%), according to the Chinese standard GB/T3923.1-1997, Textiles—Tensile properties of fabrics—Part 1: Determination of breaking force and elongation at breaking force—Strip method. The dimension of each quadrate sample is 35×5 cm. The Computerized Permeability Tester (YG461E) was used to test the permeability of the samples (took 5 points of every sample to get the average under the conditions of 20˚C, 65 % humidity), according to the Chinese standard GB/T5453-1997, Textiles—Determination of the permeability of fabrics to air.

3. Results and discussion

3.1 Influence of Nano-TiO_2 and its content on the UV-proof function of cotton fabric

It was reported that [13, 14] UV radiation, both UVA and UVB, falls into the regions of 315-400 and 280-315 nm, respectively, of solar spectrum. Skin needs to be protected from excessive UV radiation, primarily UVB, since it has the highest skin damage potential. So, we mainly analysed the spectrogram in the range of 280-400nm wavelength.

The content of nano-TiO_2 and PVP in each treatment solution is as given in Table 2.

Table 2
Content of TiO_2 and PVP in each treatment solution

No.	#1	#2	#3	#4	#5	#6	#7	#8
TiO_2 / %	0.0	0.2	0.5	0.8	1.5	1.5	1.5	1.5
PVP / %	0.0	0.0	0.0	0.0	0.0	0.2	0.8	1.5

Spectrogram of cotton fabrics treated with different content of nano-TiO_2 was shown in Figure 1 Table 3 was obtained from Figure 1 through calculating. Here, transmission decrease/% = [1– (transmission after treatment–transmission before treatment)/transmission before treatment] ×100 %. The adhesive content is 0.0 %. The wavelength of UVA is in the range of 315-400 nm and the UVB is in the range of 280- 315 nm.

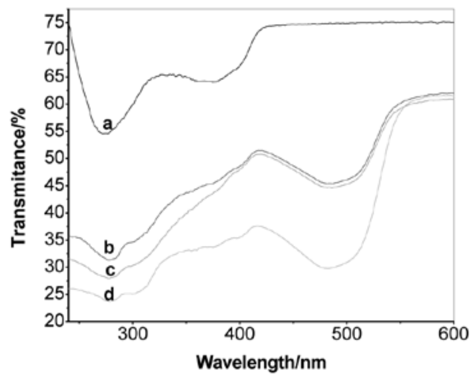

Figure 1 Spectrogram diagram of cotton fabrics treated with different content of nano-TiO_2 (a) grey cloth, (b) 0.2 % nano-TiO_2, (c) 0.5 % nano-TiO_2, (d) 1.5 % nano-TiO_2

From the Figure 1 and Table 3, it can be seen that both the UVA and UVB blocking rate increased sharply after the cotton fabric treated by nano-TiO_2. Moreover, the related UVA and UVB blocking rate increased gradually with the increase in the content of nano-TiO_2. The treated fabric has good UV blocking ability while the UV blocking ability of untreated fabric was not so. This indicates that the treatment of nano-TiO_2 has made the max transmission wavelength of cotton fabric move forward to the long wavelength; the UV-blocking ability of treated cotton fabric has increased largely. The UV-blocking ability of treated cotton fabric increased with the increase of the content of nano-TiO_2 due to the strong absorption and UV-reflection functions of nano-TiO_2.

TiO_2	blocking rate[%]		UPF		UPF grade	
[%]	UVA	UVB	UVA	UVB	UVA	UVB
0.0	30.7	35.5	14	16	-	16
0.2	55.2	66.6	25	31	25	30
0.5	59.3	69.9	27	32	25	30
1.5	67.5	74.9	30	35	30	35

3.2 Influence of the content of nano-TiO_2 on the wet fastness of treated fabric

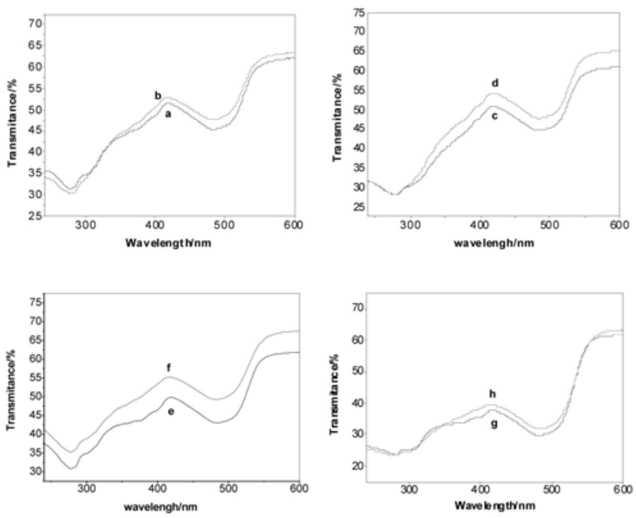

Figure 2 Spectrogram of the fabric after treated with different content of TiO_2 (a) 0.2%, (b) sample a after 50 washing circles, (c) 0.5%, (d) sample c after 50 washing circles, (e) 0.8%, (f) sample e after 50 washing circles, (g) 1.5%, (h) sample g after 50 washing circles

Figure 2 is the spectrogram of different content nano-TiO_2 treated cotton fabric after 50 washing circles. Table 4 was obtained from Figure 2 through calculation. Here, the washing procedure is as follows.

Soaping (room temperature, 10 min) → water washing (room temperature) → drying (105 ˚C), repeat this procedure 50 times.

From Figure 2 and Table 4, it can be seen that after 50 washing circles, all UVB blocking rate decreased slightly, UVA blocking rate fluctuated and the UV-proof function of treated fabric didn't changed (except the sample treated with 0.8 % TiO_2) with the increase of the content of the nano-TiO_2 from 0.2 % to 1.5 %. Moreover the decrease extent of UVB blocking rate was very low. But in the regions of 315-400 nm wavelengths, the UV-proof function of 0.8 % TiO_2 treated fabric dropped. These show that the wet fastness of nano-TiO_2 treated cotton fabric is also a problem.

Table 4
UV resistance performance of fabric treated with different content of nano-TiO_2 after 50 washing circles

TiO_2	blocking rate[%]		UPF		UPF grade	
[%]	UVA	UVB	UVA	UVB	UVA	UVB
0.2	55.2	66.6	25	31	25	30
0.2	56.2	65.8	26	30	25	30
0.5	59.3	69.9	27	32	25	30
0.5	56.0	69.2	26	32	25	30
0.8	57.1	65.7	26	32	25	30
0.8	52.1	61.6	24	30	20	30
1.5	67.5	74.9	30	35	30	35
1.5	66.7	75.4	31	35	30	35

3.3 The influence of PVP and its content on the UV-proof functions of cotton fabric

Figure 3 shows the Spectrogram of adding different content of adhesive in the treatment solution. Table 5

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and table 6 were calculated from Figure 3 Here, the content of nano-TiO_2 is 1.5 %.

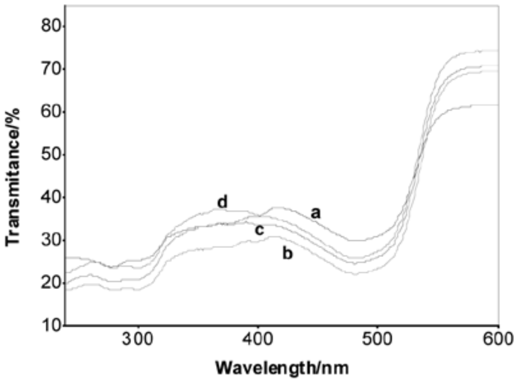

Figure 3 Spectrogram of adding different content of adhesive (a) 0% adhesive, (b) 0.2% adhesive, (c) 0.8% adhesive, (d) 1.5% adhesive

Table 5
UV resistance performance of fabric treated with different content of PVP

PVP [%]	blocking rate[%] UVA	UVB	UPF UVA	UVB	UPF grade UVA	UVB
0.0	67.5	74.9	30	35	30	35
0.2	72.8	81.2	34	37	30	35
0.8	68.2	78.9	31	36	30	35
1.5	65.4	76.3	30	35	30	35

From Figure 3 and Table 5, we can see that in the range of 280-400 nm wavelengths, curve a only has wave trough, curve b, c and d have both wave peak and wave troughs. But generally speaking, curve b, c and d is below curve a. Moreover, with the increase of the content of adhesive, the UV-proof function of treated fabric increased firstly and then decreased. When the content of adhesive is 0.2%, the fabric has the best UV-proof function. This shows that the adding of adhesive is helpful in improving the UV-proof function of cotton fabric. But it is not better to have the more content of the adhesive. When the content is more than a certain limit, it will has a screen effect on UV-proof function of nano-TiO_2, and then cause the decrease of the UV-proof function of treated fabric.

3.4 Influence of PVP and its content on the wet fastness of treated fabric

When nano-TiO_2 content was 1.5%, spectrogram of the fabric treated with different content adhesive and washed after 50 times were shown in Figure 4 Table 7 was calculated from Figure 4

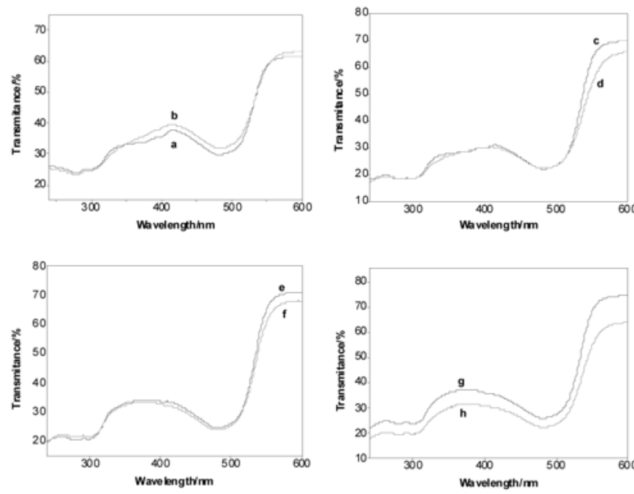

Figure 4 Spectrogram of the fabric treated with different content adhesive (a) 0.0 %; (b) sample a after 50 washing circles; (c) 0.2% adhesive; (d) sample c after 50 washing circles; (e) 0.8% adhesive; (f) sample e after 50 washing circles; (g) 1.5% adhesive; (h) sample g after 50 washing circles

Table 6
UV resistance performance of fabric treated with different content of PVP after 50 washing circles

PVP [%]	blocking rate[%] UVA	UVB	UPF UVA	UVB	UPF grade UVA	UVB
0.0	67.5	74.9	30	35	30	35
0.0	66.7	75.4	31	35	30	35
0.2	72.8	81.2	34	37	30	35
0.2	73.5	81.2	34	37	30	35
0.8	68.2	78.9	31	36	30	35
0.8	68.8	78.0	32	36	30	35
1.5	65.4	76.3	30	35	30	35
1.5	71.1	80.2	33	37	30	35

From the Figure 4, Table 6, it can be evident that the UV-proof function of treated fabric was invariable after 50 washing circles. Some of the UVA and UVB blocking rate didn't decrease but increased slightly. These may be due to the fact that the cotton fabric became more compact after 50 washing circles.

Comparing with Table 4, the adding of adhesive PVP in the treatment solution had greatly improved the wet fastness of treated fabric. Moreover, with the increase of adhesive content, the water-resistance ability of the fabric was enhanced.

3.5 The influence of adhesive on the rubbing color fastness of treated fabric

Table 8 is the relationship between dry rubbing color fastness and the content of adhesive. From Table 8, it can be found that the rubbing color fastness of treated fabric is high, and the adhesive is helpful to the rubbing color fastness of the treated fabric due to its connection among the fabric, dyestuff and nano-TiO_2 particles.

Table 8
Dry rubbing color fastness and the content of adhesive

NO.	dry rubbing[G] Warp	Weft	Warp wet rubbing[G] Warp	Weft
#1	4-5	4-5	3-4	3-4
#5	4-5	4-5	3-4	3-4
#6	5	5	4	4

3.6 Influence of Nano-TiO_2 treatment on the mechanical and physical properties of cotton fabric

Table 9
Mechanical properties of treated and untreated fabric

Sample	grey fabric Warp	Weft	treated fabric Warp	Weft
strength[N]	1106.5	491.3	907.0	409.7
extensibility[%]	28.3	35.0	37.4	33.5
decreased strength[N]			199.5	81.7
strength retaining rate[%]			82.0	83.4

The fracture strength of treated and untreated fabric is shown in Table 9. Here, strength retaining rate/%= {1−[(strength before treatment−strength after treatment)/strength before treatment]}×100%. We can find that the strength of nano-TiO_2 treated fabric dropped, but the strength retaining rate is above 80 %, as shown in Table 9.

Table10
Air permeability of treated and untreated fabrics

Sample	#1	# 5	# 8
air permeability [%]	83.8	8 2.3	7 9.3
air permeability decrease[%]		1.49	4 .48

Table 10 shows the air permeability of treated and untreated fabrics. It can be seen that the table 10 air permeability of treated fabric was decreased. When compared to sample #8 treated by the nano-TiO_2 treatment solution containing 1.5% adhesive, is lower than that of sample #5 finished by the nano-TiO_2 treatment solution without adhesive. This may be due to the existence of the adhesive on the surface of the fabric formed a soft film on the surface of the treated fabric. It would be no helpful to air infiltration.

4. Conclusions

We have demonstrated a new approach to nano-TiO_2 UV-blocking treatment for cotton fabrics. In this approach, the dyeing and treatment for cotton fabric were carried out in one bath and two steps. The anti-ultraviolet treatment in this way has greatly improved the UV blocking ability in the range of 280-400nm wavelength of cotton fabric and this ability increased with the increase of the content of nano-TiO_2. The adding of PVP could not only improve the wet fastness, but also increase the UV blocking ability of the treated fabric. But its content should be controlled into a certain range; otherwise, the UV blocking ability of treated fabric will decrease. There was a little effect on the mechanical and physical properties of cotton fabric via this treatment method.

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