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Preparation and Performance of Red Fluorescent Dye Printed Fabrics

Hao Shijie[1], Liu Xueying[1], Liu Xinyu[1], Zhang Chunyan[1], Jiang Yuele[1], Diao Wenlian[1]

[1]*Beihai University of Art and Design, Beihai, Guangxi, 536000, China*

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Abstract: The red fluorescent material was used to print the cotton fabric. Printing fabrics with high red fluorescence and UV absorbability were prepared. The effects of the amount of bonding agent, curing temperature and curing time on the friction resistance, soaping, scrubbing color fastness and UV transmittance, fluorescence spectrum and fluorescence quantum yield of printed fabric were studied by orthogonal method. The optimization process is the amount of 30% binder, the curing temperature at 130℃ and the baking time of 4min.

1. Introduction

Intelligent luminescent textile material is the focus of textile material development in recent years, in the fields of transportation, fire protection, ultraviolet protection, anti-counterfeiting of clothing, stage performances and other urgent needs. The luminescent material with electrogenic and photoexcitation characteristics is added to the fabric, and the color and brightness of the fabric can be controlled by excitation light source or intelligent electronic device. The unique properties of intelligent photoelectric and electroluminescent fabrics have great potential in driving the realization and development of intelligent wearable display devices[1][2][3].

A new functional fabric made of cotton, polyester, or polyester that is coated with a coating that combines luminescent materials with adhesives. $SrO_2Al_2O_3$ $(MSiO_2)$:Eu^{2+}, a commonly used ultra-long afterglow powder, is chemically stable, non-toxic, non-radioactive, and safe for humans. Eu^{2+} excites and emits wavelengths of around 510nm to everyday light sources.

Rare earth luminescent materials are specially treated and added to dyeing bath and printing paste as additives. The dyeing depth and brightness of dyeing and printing fabrics can be obviously improved, especially for ultrafine polyester fiber and ramie fabric. Fluorescent powder printing paste is produced by low temperature adhesive and fluorescent powder, as well as fluorescent powder foaming paste. Dry friction fastness after paint printing reaches]4-5, wet friction fastness generally reaches 4, feels softer, and improves the luminescence effect of the fabric. Adding rare earth luminescent material to deepen and brighten is due to its long-term absorption and storage properties, repeated absorption of light energy and release of long wave.

In this paper, red fluorescence material is selected. It has good luminescence performance, shows 615nm characteristic emission peak and emits strong red fluorescence under UV excitation. It is added to cotton fabric by means of printing, so that it has the characteristics of UV excitation emitting red fluorescence[4][5]. In this paper, friction resistance, soap resistance, perspiration resistance, brush-resistant color fastness, UV penetration and fluorescence intensity were tested during the experiment, and the effect of the amount of adhesive and baking temperature on printing effect were investigated[6].

2. Experimental Section

2.1 Experimental material

Waterborne Polyurethane Adhesives (Kestron Polymers Co., Ltd.), PTF Water-soluble Thickeners (Lijing Printing Materials Co., Ltd., Dongguan City), Polyacrylate Crosslinking Agents (Rudolph Chemical Co., Ltd.), Ultraviolet Red Fluorescent Powder (Beijing Saictron Chemical Co., Ltd.), Pure Cotton White Cloth.

2.2 Experimental instruments

Ultraviolet spectrophotometer (Thermo Fisher Scientific), thermostatic drum dryer (Shanghai Hualian Medical Devices Co., Ltd.), dye friction fastness tester (Zhejiang Wenzhou Textile Instrument Factory), analytical balance (AY220 SHIMADZU), brush-resistant fastness tester (Wenzhou Dawing Textile Instruments Co., Ltd.), FS5 integrated steady state transient fluorescence spectrometer (Edinburgh Instruments, UK), baking machine (Xiamen Rapid Textile Products Co., Ltd., Ltd.), polyurethane scrubbers.

2.3 Experimental methods

Fabric measures 50cm x 25cm and has a mass of 15g. Printing paste is made from 5% luminescent material, 1.5% thickening agent, 1% crosslinking agent, 20% -40% adhesive. According to L9 (3^4) orthogonal table 3 factors 3 horizontal orthogonal test, the test mainly considered the amount of adhesive, baking temperature and time, orthogonal test factors are shown in Table 1.

Table 1: Orthogonal experimental plan

number	A adhesive/%	B temperature/°C	C time/min
1	20	120	2
2	20	130	3
3	20	140	4
4	30	120	3
5	30	130	4
6	30	140	2
7	40	120	4
8	40	130	2
9	40	140	3

2.4 Methods of detection

The fastness of chintz in all colours. Friction fastness test, according to GB/T3920-2008 Textile Color fastness test Friction fastness test. Soap fastness test according to GB/T3921-2008 Textile fastness test Soap fastness test. Sweat stain fastness test according to GB/T3922-2013 Textile stain fastness test method. Brush colour fastness test, based on GB/T420-90 Textile colour fastness test method.

UV Passing Test the fastness of chintz in all colours. With reference to GB/T18830-2009 Assessment of UV Resistance of Textiles, UV UV-R (280-400nm) light source and corresponding UV reception sensors were used to test the UV blocking ability of the fabric samples by placing them between the devices. UPF values were calculated according to the formula [7].

$$\text{UPF} = \frac{\sum_{\lambda=290}^{\lambda=400} E(\lambda)\times\varepsilon(\lambda)\times\Delta\lambda}{\sum_{\lambda=290}^{\lambda=400} E(\lambda)\times T(\lambda)\times\varepsilon(\lambda)\times\Delta\lambda} \quad (1)$$

E (λ) is the spectral radiative energy of the sun. ε(λ) is the UV spectral efficiency of relative erythema the fastness of chintz in all colours.; UV transmittance of the sample when T (λ) is at that wavelength; Δλ is wavelength interval.

Fluorescence intensity test the fastness of chintz in all colours. Fluorescence spectroscopy was performed by Edinburgh Instruments' FS5 Steady Transient Fluorescence Spectrometer with a 450W high voltage long arc xenon lamp. By reflection detection, the incidence, acceptance slit is set at 1.5 nm and 2.0 nm, and the emitting light scan step is 1 nm. Because of the red fluorescence material, the detector received wavelength set to 615nm, sweep excitation spectrum, scan range of 330 nm ~ 420 nm. Based on the excitation spectrum, the maximum UV absorption peak of 381nm was obtained, and the wavelength of the light source was set to 381nm. The maximum emission peak was determined to be 616nm based on the detected emission spectra.

The fluorescence quantum yield formula is as follows:

$$\varphi_u = \varphi_s \times (F_e/F_s) \times (A_S/A) \quad (2)$$

In formula: φ_u and φ_s are the fluorescence quantum yield of sample and reference respectively, φ_u and φ_s are the emission quantum number of sample and reference respectively, φ_u and φ_s are the absorbance of sample and reference respectively. FS5 Steady Transient Fluorescence Spectrometer can detect the UV absorption spectra of samples without reference testing. The following formula is used to calculate the fluorescence quantum yield:

$$\varphi_u = \frac{F_e}{F_a} \quad (3)$$

φ_u and φ_s are the emission and absorption quantum numbers of the sample respectively, so the ratio of fluorescence emission area to UV absorption area of the sample.

3. Results and Discussion

3.1 The colour fastness of printed fabrics

Table 2: Color fastness performance data table

number	Rubbing fastness/level		Soaping fastness/level		Brushing fastness/level
	dry	wet	Staining	Discoloration	
1	4	4	4-5	4	3-4
2	4-5	4	4-5	4	4
3	4-5	4-5	4	4	4
4	4-5	4-5	4-5	4-5	4-5
5	4-5	4-5	4-5	4-5	4
6	4-5	4-5	4-5	4	4
7	4-5	4-5	4-5	4	4
8	4-5	4-5	4	4	4
9	4-5	4	4-5	4	4

The color fastness of nine samples was tested by three factors and three levels orthogonal test. The results are shown in table 2. After analyzing the mean and extreme difference of baking temperature, time and amount of binder, the orthogonal test analysis table of 3 color fastness was obtained.

Table 3: Color fastness test analysis calculation table

factor	standardl	Rubbing fastness/level		Soaping fastness/level		Brushing fastness/level
		dry	wet	Staining	Discoloration	
A	T1	4.250	4.083	4.333	4.000	3.833
	T2	4.417	4.333	4.500	4.333	4.167
	T3	4.500	4.167	4.333	4.000	4.000
	R	0.250	0.250	0.167	0.333	0.334
B	T1	4.250	4.167	4.500	4.167	4.000
	T2	4.417	4.250	4.333	4.167	4.000
	T3	4.500	4.167	4.333	4.000	4.000
	R	0.250	0.083	0.167	0.167	0
C	T1	4.333	4.167	4.333	4.000	4.000
	T2	4.333	4.083	4.500	4.167	4.333
	T3	4.500	4.333	4.333	4.167	4.000
	R	0.167	0.250	0.167	0.167	0.333

According to the average and extreme difference analysis in Table 3, the effects of various factors on the color fastness of printed fabrics are as follows. The fastness of chintz in all colours.

As the amount of adhesive increased, dry friction fastness increased, wet friction fastness, brush fastness and soap fastness increased first and then decreased, but the increase and decrease of the magnitude, very little change. When the amount of binder than 30% has been saturated, all color fastness has reached more than level 4, continue to increase the amount of binder, color fastness does not change significantly, so the amount of binder than or equal to 30% of the fabric color fastness is the best.

The effects of baking temperature were summarized as 140 °C, 130 °C, 120 °C, dry friction fastness, dry friction fastness, dry friction fastness and dry friction fastness respectively. When it comes to baking time, the difference between 3min and 4min results is small, so 3min is more appropriate for energy efficiency reasons. In summary, the relative optimization scheme of aqueous polyurethane binder is as follows: the amount of adhesive used is 30%, the baking temperature is 130 °C, and the baking time is 3 min.

3.2 UV transmittance

Ultraviolet transmittance curves were obtained by using sample 5 process with 30% binder, baking temperature 130 °C and baking time 3 min. The original curve is the UV transmittance of blank cotton fabric. According to Figure 1, the UV transmittance of cotton fabric itself varies at different wavelengths: at wavelength between 340nm and 400nm, the UV transmittance is stable at about 50%. At wavelength below 340nm, the transmittance decreases with the wavelength, and at wavelength 280nm, the UV transmittance is 27.42%. According to the comparison of three curves, the binder has partial UV absorption, while the penetration rate of fluorescent material printing decreased significantly, the lowest at 340nm ~ 38nm, and the UV resistance of the fabric sample was effectively increased by fluorescent material.

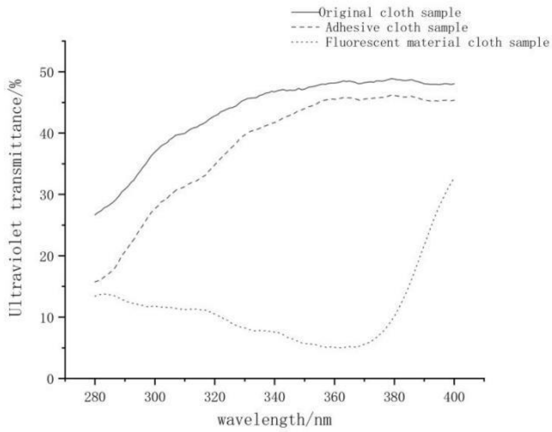

Figure 1: UV transmittance curve

Table 4: Each sample UPF numerical meter

number	UPF
Original cloth sample	2.253
Adhesive cloth sample	6.242
Fluorescent material cloth sample	10.441

The UPF values of each sample were obtained according to the UPF formula. (Table 4)

The UPF of the fluorescent material sample was 10.441, which was significantly higher than that of the original sample, mainly due to the strong UV absorption capacity of the fluorescent material. However, its UPF index still does not meet the UPF>30 condition of GB/T 18830-2009 standard anti-UV function product, so photoluminescent fabrics do not have anti-UV function and can only block less UV exposure.

3.3 Fluorescence intensity

The UV spectra of the sample printed with sample 5 process are shown in Figure 2, and the UV absorption characteristics are shown in Table 5. According to Table 6, the maximum absorption peak wavelength is 382nm, which corresponds to the excitation peak of the original fluorescent material, but due to the interaction between the binder and the fluorescent material, the maximum absorption peak changes blue and widens the half-peak width by 30nm, reducing the excitation sensitivity.

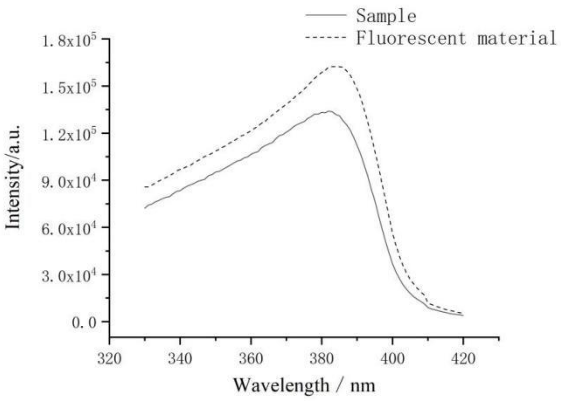

Figure 2: UV absorption spectrogram

Table 5: Characteristics of UV absorption spectroscopy

number	Characteristics of ultraviolet absorption spectrum			
	λ_{max}/nm	$\Delta\lambda$/nm	$F_{max}/10^5$	$S/10^6$
Fluorescent material	384	0	28.196	37.775
sample	382	-2	16.468	31.327

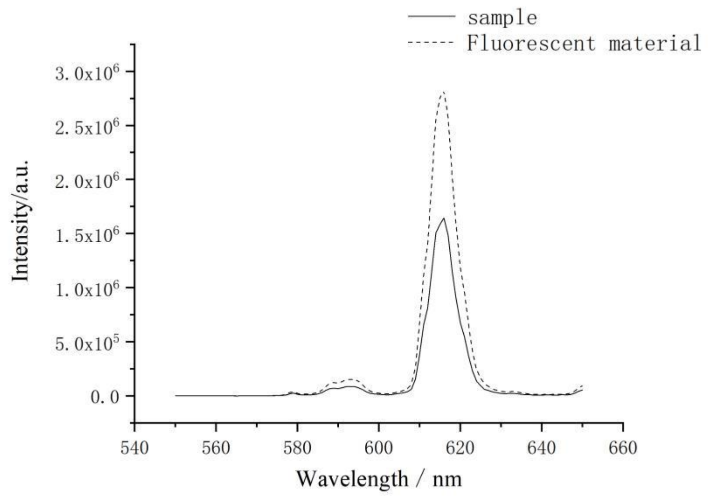

Figure 3: Fluorescence emission spectrogram

Table 6: Characteristics of fluorescence emission spectrum

number	Fluorescence emission spectral characteristics			
	λ_{max}/nm	$\Delta\lambda$/nm	$F_{max}/10^4$	$S/10^6$
Fluorescent material	616	0	16.253	26.438
sample	616	0	13.411	15.253

Figure 3 shows the $^5D_0 \rightarrow {}^7F_2$ (616nm) characteristic peak of the fluorescent material activator Eu^{3+}, indicating that cotton fabrics and adhesives do not affect the maximum emission peak and half-peak width of the fluorescent material, but have a decisive effect on fluorescence brightness. Based on the fluorescence quantum yield formula, the fluorescence quantum yield of samples and fluorescent materials was calculated to be 0.487 and 0.699, and the fluorescence quantum yield decreased by 30% under the influence of binder and cotton cloth.

4. Conclusions

Photoluminescent fabrics showed bright red fluorescence under UVA UV lamps, and based on various color fastness, UV transmittance and fluorescence spectroscopy, 30% binder dosage, baking temperature of 130 ° C and 4min baking time were determined to be the best processes. Photoluminescent fabric has only partial UV absorption function, so it cannot be used as an anti-UV product, but its high luminescent efficiency makes it have broad luminescent development prospect.

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