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Influence of fluorescent pigments on the spectral characteristics of luminous coated fabrics

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Abstract

In recent years, luminous coated fabrics based on SrAl2O4; Eu2+, Dy3+ luminescent materials have attracted more attention. However, due to the single emission color of SrAl2O4; Eu2+, Dy3+ luminescent materials, the application of prepared coated fabrics has certain limitations. Therefore, at present, there is a need to develop a kind of luminous coated fabric which has the capability of emitting multiple colors of light. In this work, fluorescent pigments and SrAl2O4; Eu2+, Dy3+ luminescent materials were added to a coating slurry and uniformly coated over a woven fabric substrate. The effects of adding fluorescent pigments on the spectral characteristics of luminous coated fabrics were evaluated. The blue fluorescent pigment causes a significant blue shift in the emission spectrum of the blue light-emitting coated fabric, whereas the emission spectra of the orange and red light-emitting coated fabrics exhibit a significant red shift. The yellow-green fluorescent pigments significantly affect the coated fabric. The emission spectrum shows no evident change and is similar to the emission spectrum of white (without any fluorescent pigment) luminous coated fabric. The afterglow brightness of the colored luminous coated fabrics decreases exponentially with time. Adding blue fluorescent pigments has a greater impact on the brightness of the coated fabrics. The initial brightness is lower and the afterglow brightness loss is higher when using yellow-green fluorescence. The pigment has little effect on the brightness loss of coated fabrics, and the initial brightness of the coated fabric increases when adding yellow-green fluorescent pigments. Fluorescent pigments result in relatively low color purity for each colored coated fabric. However, the color rendering index is high, and the color rendering performance for the light source is excellent.

1. Introduction

Luminous coated fabrics are generally manufactured by illuminating materials and other finishing agents through coating process. The prepared products can continue glowing in the dark after absorbing ultraviolet light or visible light. The luminous coated fabrics have a uniqueness of day and night discoloration, and can meet modern people’s fashion pursuit and personalized aesthetics need [1–3]. This type of coating process is simple, short processes, and easy to operate, therefore received extensive note and research. Luminous coating fabric is not only widely used in home textiles products, fun clothing and decorative decoration, etc, but also it is developing into transportation, construction, national defense and other fields, and has a broad market prospect [4–6].

Luminous coated fabrics are a new type of fabric containing rare earth luminescent materials. Currently, SrAl2O4; Eu2+, Dy3+ luminescent materials are widely used materials featuring night luminescence, these can also absorb visible and ultraviolet light and exhibit excellent long-lasting luminescence performance in the dark [7–11]. The rare earth luminescent materials are added to the coating matrix, so that the coating not only has the properties of ordinary coated fabrics, but also can emit light in the dark state without an excitation light source.
Thus far, many studies have focused on the afterglow performance and principles of luminous coated fabrics, and research on the influencing factors and diversity of the light color of luminous coated fabrics is rarely reported [12–15].

The main luminescent material of the luminous coated fabric is SrAl₂O₄: Eu²⁺, Dy³⁺ luminescent powder. The emission spectrum of the luminescent powder is mainly distributed in the yellow-green light region of 510–530 nm. The light color is single and lacks diversity, which limits the application. Therefore, expanding and enriching the luminous color of the fabrics, especially the application of light color for red-shift and blue-shift, is still a hot spot for future research. Existing preliminary studies have found that by adding inorganic transparent pigments of different colors to the spinning raw materials of luminous fibers, the luminous color of luminous fibers can be changed to a certain extent, but experiments have shown that the addition of pigments ultimately leads to a decrease in the afterglow brightness of luminous fibers [16]. Inspired by this, our research groups tried to find a material that can effectively adjust the light color of the fabric without changing the afterglow brightness of the coated fabric.

According to literature, fluorescent pigments are colorless when irradiated by general visible light. By contrast, when irradiated using a 365/254 nm ultraviolet lamp, they exhibit red, yellow, green, blue, and other luminous colors [17–20]. Fluorescent dyes are compounds with special structures. They contain fluorescence-emitting groups such as carbonyl groups, nitrogen-nitrogen double bonds, and carbon-nitrogen double bonds. It also contains some auxochrome groups, such as primary amino groups, secondary amino groups, hydroxyl groups, ether bonds, amide groups, etc., which can redshift the spectrum and improve fluorescence efficiency [21]. Furthermore, fluorescent dyes can be divided into inorganic fluorescent pigments and organic fluorescent pigments. With regard to performance, inorganic fluorescent pigments are superior to organic fluorescent pigments in terms of lightfastness, heat resistance, cost, and hiding power.

For luminous coated fabrics, the SrAl₂O₄: Eu²⁺, Dy³⁺ luminescent materials act as the source of luminescence. However, these luminescent materials only exhibit a single color of luminescence, which causes a significant inconvenience in the process of the development and application of coated fabric product when it is prepared by using these materials. Based on above, our research groups tried to prepare luminous coated fabrics by adding fluorescent pigments of different colors, which aimed to change the emitting-light color characteristics of the luminous coated fabrics without affecting the luminous brightness. Accordingly, this study adopts colored inorganic fluorescent pigments as the coloring pigments for luminous coated fabrics. SrAl₂O₄: Eu²⁺, Dy³⁺ luminescent materials and four types of colored inorganic fluorescent pigments are used as the raw materials to prepare luminous pastes, and woven fabric is used as the coating substrate. A total of five types of colored luminous coated fabrics were prepared using a coating machine. The addition of inorganic fluorescent pigments affects the color of the luminous coated fabric during daytime and also that in the dark. In addition, the prepared fabrics were tested. The morphologies, afterglow attenuation performances, and spectral characteristics of the luminous coated fabrics after adding fluorescent pigments were analyzed, and the effect of adding fluorescent pigments on the light and color properties of the luminous coated fabrics were clarified. This work and its results are expected to provide theoretical guidance and serve as a basis for the processing and development of coated fabrics.

2. Experimental

2.1. Raw materials

Al₂O₃, SrCO₃, Eu₂O₃, Dy₂O₃, and H₃BO₃ were purchased from Sinopharm Chemical Reagent Co., Ltd. Woven fabric and coating slurry were purchased from Anhe Textile Co., Ltd. Inorganic Fluorescent Pigments (blue, red, orange, and yellow-green) were supplied by Hunan Kelai New Material Co., Ltd.

2.2. Synthesis of SrAl₂O₄: Eu²⁺, Dy³⁺ materials

SrAl₂O₄: Eu²⁺, Dy³⁺ luminescent materials were prepared by high-temperature solid-phase method [7]. SrCO₃, Al₂O₃, Eu₂O₃, and Dy₂O₃ (analytical purity, Sinopharm Chemical Test Co., Ltd.) were mixed according to the ratio of (Sr:Eu:Al:Dy) of 1:2:0.03:0.02, in which the H₃BO₃ accounts for the total mixture 3% of the amount (the amount of the substance). Put the raw materials into a mortar to grind and mix for 30 min, then stir in an appropriate amount of absolute ethanol for 15 min, and then ultrasonically disperse 15 min. The mixture was dried in an oven at 60 °C, ground and mixed thoroughly, and then loaded into an alumina boat, and calcined at 1400 °C in a reducing atmosphere for 2 h. The heating rate was 10 °C min⁻¹, and the temperature was naturally lowered. The SrAl₂O₄: Eu²⁺, Dy³⁺ obtained by calcination was ground and screened to obtain SrAl₂O₄: Eu²⁺, Dy³⁺ powder.
2.3. Preparation of luminous coated fabrics with fluorescent pigments

In our experiment, woven fabric was adopted as the base cloth, and the homemade SrAl2O4: Eu²⁺, Dy³⁺ (aluminate afterglow material excited by rare earth ions that mainly emits yellow and green light) was selected as the luminescent material. Briefly, SrAl2O4: Eu²⁺, Dy³⁺ luminescent material (relative to the total mass of the slurry) with 30% and inorganic fluorescent pigments (blue, red, orange, and yellow-green) were added to the coating slurry in a mass ratio of 3:1. Then use a magnetic stirrer to stir evenly to make a luminous coating slurry, brush the coating slurry on the woven fabric, and dry the fabric use a vacuum drying box [(160 ± 5) °C for 5 min]. Finally, the luminous coated fabrics are cut into pieces with dimensions of 2 cm × 2 cm and are denoted as COAT-W and COAT-B, COAT-R, COAT-O, and COAT-K. The properties of the colored inorganic fluorescent pigments are listed in table 1, and figure 1 shows a schematic diagram of the preparation process of luminous coated fabrics with fluorescent pigments.

2.4. Instrumental measurements

Scanning electron microscopy (Quanta200, Netherlands Fei Company) was used to observe the surface morphology of the colored luminous coated fabrics. The samples were gold-plated before the test.

Inverted fluorescence microscopy (Zeiss model Axio Vert.A1) was used to test the fluorescence distribution of the coated fabrics. The samples were excited using the 359–371 nm excitation module, and the received light wavelength exceeded >397 nm, under a magnification of 100.

The F-4600 fluorescence spectrophotometer (Japan HITACHI company) was used to test the emission spectrum of the colored luminous coated fabrics; the detection wavelength interval was 5 nm, and the voltage was 380 V.

The PR-305 long afterglow phosphor tester from Zhejiang University was used to test the afterglow attenuation brightness of the colored luminous coated fabric. The illuminance was set to 1000 lx, and the illumination time was 15 min. The measurement was commenced 10 s after the illumination, and the test interval was 1 s.

The spectrophotometer (model CS-5960GX) was employed to test the light and color performances of the colored luminous coated fabric, under illumination d/8 (scattering light source, 8°observation angle), measuring wavelength of 400–700 nm, wavelength interval of 10 nm, and half bandwidth of 5 nm. The interval time was 2 s, and the measurement time was 0.5 s.

3. Experimental results and discussion

3.1. Micromorphology of colored luminous coating fabric

Figure 2 shows the appearance of the colored luminous coated fabrics under different magnifications. It is evident from figures 2(a) and (b) that the surface morphology of the luminous coated fabric without a pigment
and that of the coated fabric with the blue pigment are not significantly different. The coating surface of figures 2(a) and (b) is relatively smooth. Owing to the coated SrAl2O4: Eu2+, Dy3+ particles are uniform, the coating performance is good. The addition of pigments does not aggravate the agglomeration of the luminescent powder on the surface of the fabric substrate. Considering both figures 2(c) and (d), it is clear that the luminescent material particles attached to the surface of the luminous coated fabric are smoother and that the addition of pigments and luminescent materials does not affect the film-forming performance of the coating. Based on the aforementioned analysis, it is evident that, during the preparation process for the colored luminous coated fabric, the pigment and SrAl2O4: Eu2+, Dy3+ luminescent powder are uniformly coated over the coated substrate. Furthermore, the addition of pigments does not affect the dispersion performance of the luminescent powder on the surface of the fabric. The luminescent powder shows no apparent agglomeration on the surface of the colored luminous coated fabric.

Figure 3 shows the fluorescence distribution of the luminous coated fabrics after adding the different fluorescent pigments. As shown in figure 3, the fluorescence color of the white luminous coated fabric (i.e., the luminous coated fabric without fluorescent pigments) is green. On adding fluorescent pigments with different colors, the area of the fluorescence distribution of the coated fabric varies considerably. Furthermore, the fluorescence color distribution shifts toward the respective hue.

3.2. Influence of fluorescent pigments on afterglow performance of colored luminous coated fabrics

Figure 4 shows the variation in the brightness of the colored luminous coated fabric with respect to time. It is clear that the afterglow brightness of the colored luminous coated fabric decreases exponentially with time. The initial brightness and attenuation speed of the colored luminous coated fabrics are also different. Over the first 200 s, the brightness loss of each colored coated fabric is more significant. Subsequently, the afterglow brightness of each colored fabric tends to become stable, and the afterglow curves of the 5 samples almost converge after 1200 s.

Figure 5 shows the initial brightness of the colored luminous coated fabric. The brightness of the colored luminous coating exhibits the same regularity in the initial stage, followed by a stable brightness stage: COAT-K > COAT-O > COAT-R > COAT-W > COAT-B. Among these, COAT-K and COAT-O exhibit higher brightness values. COAT-R, COAT-W, and COAT-B show small differences in their brightness values. Therefore, the results obtained from the analysis above implied that the brightness loss of the blue luminous coated fabric is relatively large and that its initial brightness value is also lower, which has a significant impact on the brightness of the luminous coated fabric. In addition, the yellow-green fluorescent pigment has the weakest
Figure 3. Fluorescence microscope photo (magnification 100 times): (1) White luminous coated fabric (luminous coated fabric without fluorescent pigment added); (2) Blue luminous coated fabric; (3) Red luminous coated fabric; (4) Orange luminous coated fabric; (5) Yellow-green luminous coated fabric.

Figure 4. Color luminous coated fabric brightness change curve with time.
effect on the brightness loss of the luminous coated fabric. The addition of the yellow-green fluorescent pigment increases the initial brightness of the luminous fabric. This is due to the hue of the yellow-green fluorescent pigment and the yellow-green light emitted by the luminescent material remains consistent, and the color of the pigment itself is superimposed with the color of light from the fabric, thus increases the initial luminous brightness of the fabric.

3.3. Influence of fluorescent pigments on the emission spectral properties of colored luminous coated fabrics

Figure 6 shows the emission spectrum of the colored luminous coated fabric with a detection wavelength of 360 nm. As shown in figure 6(a), the emission spectrum of the white luminous coated fabric is a broadband spectrum that spreads outward from the emission peak at 520 nm. The emission wavelength is essentially the wavelength range of the yellow-green visible light, to which the human eye is sensitive. This peak originates from the SrAl$_2$O$_4$: Eu$^{2+}$, Dy$^{3+}$ luminescent material in the fabric. Figure 6(b) shows that the emission spectrum intensity of the luminous coated fabric is relatively high with adding the colored fluorescent pigments, as compared to the emission spectrum in figure 6(a) for the white luminous coated fabric (luminescent coated fabric without fluorescent pigments). Despite the phenomenon of blue or red shift, its overall emission spectrum is still consistent with the emission spectrum in figure 6(a). At the peak, the luminous intensity of the red luminous coated fabric is the highest, followed by those of the yellow-green, orange, blue, and white pigments, respectively. The emission peak of the blue luminous coated fabric is located at 460 nm, and exhibits a significant blue-shift phenomenon, as compared to that of the white luminous coated fabric. The emission spectra of the red and orange luminous coated fabrics show a significant red-shift phenomenon, which has been caused by the
stronger pulling effect of the red or orange pigments on the emission spectrum of the luminescent material, and forces the main emission peaks of the red and orange luminous coated fabrics to approach the red wavelength band. The red and orange luminous coated fabrics also have weak emission peaks at 510 nm, but their relative intensity is lower than that of the white luminous coated fabric.

In addition, the emission peak of the luminous coated fabric with the yellow-green fluorescent pigment was located around 520 nm. However, at the peak position, the emission peak intensity of the yellow-green luminous coated fabric exceeded that of the white luminous coated fabric, shown in 6(a). This indicates that the addition of the kelly fluorescent pigments has a certain influence on the luminous intensity of the luminous coated fabrics, but it does not affect the characteristic peaks of their emission spectra. The reason for this phenomenon is because the hue of the yellow-green fluorescent pigment is consistent with the yellow-green light emitted by the $\text{SrAl}_2\text{O}_4: \text{Eu}^{2+}, \text{Dy}^{3+}$ luminescent material in the luminous coating fabric. Hence, the emission peak has not changed. However, the color of the pigment itself is superimposed with the color of light from the fabric, resulting in an increase in the intensity of the light emitted from the fabric.

3.4. Influence of fluorescent pigments on luminescence chromatography properties of luminous coated fabrics

Table 2 lists the luminescence chromatography properties of the colored luminous coated fabrics. It is clear that the color purity of the colored luminous coated fabrics is relatively low. The highest value is only 0.665, which was observed from the white luminous coated fabric, and the lowest value is 0.514, which was noted for the red luminous coated fabric. This phenomenon can be explained as follows. The emission spectra of the colored luminous coated fabrics contained the yellow-green light band, blue-light band, the broadband spectrum of the orange-light band, and the red-light band. Hence, the light emitted by the colored luminous coated fabrics was mixed light, which results in low color purity.

It is evident from figure 6 that the emission spectrums of the colored luminous coated fabric are a set of high-brightness and continuous broadband spectra. Their spectral characteristics are similar to those of visible light.
and fluorescent lamps. Therefore, the color rendering index of the colored luminous coated fabric is relatively high, and the Ra value is approximately 90. This indicates the excellent color rendering performance of the light source.

The position of the colored luminous coated fabric in the CIE 1931 standard chromaticity diagram is marked according to the chromaticity coordinates, X matt and Y matt in table 2. The position details is shown in figure 7. It could be noticed that, compared with the white luminous coated fabric, the dominant wavelength of the colored luminous coated fabric has slightly changed. Among the samples, the white luminous coated fabric has no pigment, and its dominant wavelength is 520 nm. The chroma of the yellow-green color is closer to the chroma of the luminescent material. In this case, the dominant wavelength of the light from the yellow-green luminous coated fabric is closer to that from the white luminous coated fabric. The dominant wavelength of the red luminous coated fabric shifts toward the red-light region considerably, exhibiting the largest deviation from the dominant wavelength of the white luminous coated fabric, followed by those of the blue and orange luminous coated fabric, which may be attributed to the addition of fluorescent pigments exerts a traction effect on the luminous color of the luminous coated fabric. The color brilliance of the colored luminous coated fabric is biased toward the color of the pigment itself.

4. Conclusion

In this study, luminous coated fabrics were successfully prepared by using inorganic fluorescent pigments and SrAl₂O₄:Eu²⁺, Dy³⁺ luminescent materials via a series of simple and effective methods, and the following conclusions are drawn:

1. The addition of fluorescent pigments did not aggravate the agglomeration of SrAl₂O₄: Eu²⁺, Dy³⁺ luminescent materials in the coating and the dispersion performance over the coating surface.
2. The initial brightness of the luminous fabric increased on adding the yellow-green fluorescent pigment, owing to the color of the pigment itself was superimposed with the color of light from the fabric, thus increased the initial luminous brightness of the fabric.
3. The fluorescent pigments in red, blue, and orange color had a greater impact on the emission spectra of the fabrics. The addition of the blue and red fluorescent pigment caused a significant blue-shift and red-shift in the emission spectrum of the fabric, which had been caused by the stronger pulling effect of the blue or red pigments on the emission spectrum of the luminescent material, and forced the main emission peaks of the blue or red luminous coated fabrics to approach the hue of their own color.
4. The color purity of the luminous coated fabrics after adding the fluorescent pigments was relatively lower compared to the fabric without fluorescent pigments, but the color rendering index was relatively high. Thus, the color rendering performance of the light source for the colored luminous coated fabrics was excellent.

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Data availability statement

The data that support the findings of this study are available upon reasonable request from the authors.

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