Preparation and dyeing of super hydrophilic polyethylene terephthalate fabric

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Abstract: In this study, the dyeing properties of PET fabrics modified with sulfuric acid was investigated using disperse red E-4B and disperse blue 2BLNG-L at high temperature and high pressure. The results revealed that the sulfuric acid modification improved the K/S value of dyeing PET fabrics, and the modified PET fabric could be dyed uniformly. The \(a, b, C, L\) and \(H\) of modified PET fabric were almost the same as that of original PET fabric. The water contact angles were still 0\(^\circ\) after 10s, indicating that the hydrophilic property of modified PET fabrics still kept excellent. The wash fastness of dyed PET fabrics after modification was generally good.

1. Introduction

Polyethylene terephthalate (PET) fabric was widely used in apparel, home furnishings and various industrial products due to its excellent properties such as high strength, wear-resistant, washable \cite{1,2}. However, PET fabric has poor hydrophilicity and hygroscopicity, which restricts its application \cite{3}. Thus it is very important to improve the hydrophilicity and comfort of PET fabric, and it has become a hotspot in research over the decades.

To date, numerous hydrophilic modification methods for PET fabrics have been proposed. For example, the surface oxidation \cite{4}, surface grafting method \cite{5,6}, coating. Our group has prepared super hydrophilic PET fabric by dilute sulfuric acid with gradually concentrating method under microwave irradiation \cite{8}.

PET fabric is generally dyed under the severe condition of high temperature and high pressure, where the disperse dyes penetrated into internal space of PET fibers. Introduction of sulfonic acid
groups in PET macromolecules may affect the dyeing properties of modified PET fabric. So this paper study the dyeing properties of PET fabrics modified with sulfuric acid. In this paper, the K/S value, levelling property $\Delta E$, wash fastness, lightness(L), chroma(C), hue(H) of the modified PET fabric were analyzed and compared with that of the original PET fabric.

2. Experimental

2.1. Material

PET fabric (27.0tex×22.2tex/500×360) was bought from Chaotianmen market, Chongqing China. Sulfuric acid was bought from the ChengDu Kelong Chemical Reagent Company, Sichuan China. Disperse red E-4B and disperse blue 2BLNG-L were purchased from Dyeing Plants Wenling, Zhejiang China.

2.2. Sulfuric acid modification and dyeing of PET fabrics

PET fabric was soaked in a certain concentration of sulfuric acid solution, padded through the nip to reach wet pickup of about 100%, then irradiated for 6 minutes with microwave at 600 W. Finally after washing and drying, super hydrophilic PET fabric was obtained.

The modified PET fabric was putting into the disperse dye solution with mass concentration of 1.0% o.w.f at a ratio of 1:30 (w/w), heated up to 120 °C at a rate of 2 °C/min and kept for 50 min. Subsequently, the dyed PET fabric was washed and dried at room temperature.

2.3. Characterization techniques

The K/S values represent the dyeing depth of the fabric under the maximum absorption wavelength. The test using D65 light source with perspective angle of 10°. Five different points on the fabric samples were tested, and the average values of which were calculated. The larger the K/S value is, the deeper the dyeing is. The calculation formula is as follows:

$$\frac{(1 - R)^2}{2R}$$

(1)

Where K is the light absorption coefficient of the fabric; S is the light scattering coefficient of the fabric; and R is the light reflectance of the fabric at the maximum absorption wavelength.

Levelling property of the fabric was measured with Data color 650 instrument. One position on the dyed PET fabric was selected as comparison. Then $\Delta E$ value of PET fabric at different position was measured.

The lightness(L), chroma(C), hue(H) of PET fabric were measured by Data color 650 instrument. These data could show the color of fabric based on Munsell color system.

The water contact angle(WCA) of the dyeing PET fabrics was measured with horizontal single-shot method using JGW-360 contact determination instrument. The WCA of the samples was calculated as following formula.

$$\theta = \arctan \frac{4dh}{d^2 - 4h^2}$$

(2)
where h is the height from top of the water droplet to the fabric surface; d is the contact diameter of water droplet on fabric.

The wash fastness of the dyeing PET fabrics was evaluated by the AATCC 61-2006 standard method using a soaping fastness tester (Roaches Co., England). The color change was rated according to the appropriate ISO grey scale.

3. Results and discussion

3.1. The K/S values of the samples

The super hydrophilic PET fabrics were dyed with disperse blue 2BLNG-L and disperse red E-4B. Figure 1 shows the relationship between the dilute sulfuric acid concentration and the K/S values of the dyed fabrics modified with gradually concentrating dilute sulfuric acid method. The results showed that the K/S value increased obviously with the increase of the concentration of sulfuric acid. When using disperse blue 2BLNG-L to dye fabrics, the K/S value of the original PET fabric was 6.68, and increased to 8.62 after modified with 8.0 g/L sulfuric acid. When dyed with disperse red E-4B, the K/S value of the unmodified PET fabric was 6.25, after modified with 8.0 g/L sulfuric acid, the K/S value of the modified PET fabric increased to 8.37. The higher the K/S value was, the higher the degree of exhaustion was, and the better the dyeing performance of PET fabric was. These show that the dyeing property of sulfuric acid modified PET fabrics is better than that of the unmodified PET fabrics. This should be because PET fabric modified with sulfuric acid has sulfonic acid groups on the PET macromolecule of the surface layer. The sulfonic acid groups are negative charges, which mutually exclusive on the PET fiber surface, maybe resulting in the interspaces among the PET macromolecule chains increasing greatly. Then the dyestuff molecules can entry the PET fibers inner space more easily. Thus the dyeing properties of the sulfuric acid modified PET fabric are better than that of unmodified PET fabric.

![Figure 1. The K/S values of original PET fabric and PET fabrics modified by H₂SO₄.](image-url)

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3.2. The levelling property of sulfuric acid modified PET fabric

Table 1 shows the color value $\Delta E$ of PET fabrics before and after modified by 8.0 g/L $\text{H}_2\text{SO}_4$. From table 1 it can be seen that the color values $\Delta E$ of different position on the dyeing modified PET fabrics dyed with disperse red E-4B and disperse blue 2BLNG-L only changed a little, and the average values were less than 0.6. When using disperse red E-4B and disperse blue 2BLNG-L to dye, the average $\Delta E$ values of modified PET fabric of 0.362, 0.304, respectively, are slightly higher than that of original PET fabric. Thus the levelling property of the sulfuric acid modified PET fabric is extremely excellent. The modification of PET fabric with sulfuric acid as modifying agent does not affect the levelling property of PET fabric.

| Disperse red E-4B | Color value $\Delta E$ of different point on PET fabrics | Average $\Delta E$ |
|-------------------|----------------------------------------------------------|-------------------|
| Original PET      | 0.12 0.43 0.27 0.33 0.16 0.23 0.61 0.37 0.11 0.22 | 0.285            |
| Modified PET      | 0.46 0.19 0.32 0.53 0.59 0.66 0.32 0.30 0.11 0.14 | 0.362            |

| Disperse blue 2BLNG-L | Color value $\Delta E$ of different point on PET fabrics | Average $\Delta E$ |
|-----------------------|----------------------------------------------------------|-------------------|
| Original PET          | 0.42 0.15 0.43 0.26 0.22 0.23 0.17 0.31 0.20 0.35 | 0.274            |
| Modified PET          | 0.19 0.41 0.34 0.25 0.26 0.13 0.56 0.34 0.12 0.44 | 0.304            |

3.3. Relative dyeing values of sulfuric acid modified PET fabrics

Table 2 lists the relative dyeing values of PET fabrics before and after modified by 8.0 g/L $\text{H}_2\text{SO}_4$. PET fabrics were dyed with disperse blue 2BLNG-L and disperse red E-4B respectively. The color of the modified PET fabric was almost the same as that of the original dyeing PET fabric. The L and C value of modified dyeing PET fabric both decreased slightly, which corresponded to the increasing of K/S value of modified PET fabric. The Hunter a value of modified dyeing PET slightly decreased, the color was a little greener than that of original PET fabric; the Hunter b value of modified dyeing PET increased slightly, the color tended to yellow. The change of a, b value resulted that the H value of modified PET fabric dyed with disperse red E-4B changed from 1.20° to 1.66°, the H value of modified PET fabric dyed with disperse blue 2BLNG-L changed from 248.86° to 246.14°, the color of modified PET fabrics tended to be yellow-green. But the degree was very small, which could not be seen by naked eyes.

| Disperse blue 2BLNG-L | a      | b      | C      | L      | H(°)  | %R corresponding wavelength (nm) |
|-----------------------|--------|--------|--------|--------|-------|---------------------------------|
| Original PET          | -14.09 | -36.44 | 39.07  | 49.54  | 248.86| 640                             |
| Modified PET          | -15.26 | -34.51 | 37.73  | 47.28  | 246.14| 640                             |

| Disperse red E-4B     | a      | b      | C      | L      | H(°)  | %R corresponding wavelength (nm) |
|-----------------------|--------|--------|--------|--------|-------|---------------------------------|
| Original PET          | 59.36  | 1.23   | 59.37  | 52.13  | 1.20  | 520                             |
| Modified PET          | 58.87  | 1.73   | 58.90  | 49.37  | 1.66  | 520                             |
3.4. The hydrophilic property of modified PET fabrics after dyeing

Figure 2 shows the hydrophilicity of modified and dyed PET fabrics. From figure 2, it can be seen that the water droplet could disappeared thoroughly. This directly proved that the dyed PET fabric modified by sulfuric acid still has super hydrophilicity.

Table 3 shows the hydrophilicity of the PET fabric modified by H₂SO₄ after dyeing. The hydrophilic property of modified PET fabrics after dyeing was characterized by the water contact angles when water droplet was on the PET fabric surface at 10s. It is shown that with the WCA of 0° at 10s, the PET fabrics maintain excellent hydrophilicity after dyed with disperse dyestuff.. It can also be seen that the hydrophilic property of the modified PET fabric dyed with disperse dyeing was not affected. The dyeing performance of the fabric was improved greatly, while the hydrophilic property kept well.

![Figure 2. The hydrophilicity of modified and dyed PET fabrics.](image)

**Table 3.** Hydrophilicity of the PET fabric modified by H₂SO₄ after dyeing.

| WCA at 10s /(^°) | Concentration of H₂SO₄/(g/L) |
|------------------|-----------------------------|
|                  | 0          | 4.0    | 5.0    | 6.0    | 7.0    | 8.0    |
| Modified PET fabric | 157.36 | 0       | 0       | 0       | 0       | 0       |
| Modified PET fabric dyed by disperse blue 2BLNG-L | 157.31 | 0       | 0       | 0       | 0       | 0       |
| Modified PET fabric dyed by disperse red E-4B | 157.43 | 0       | 0       | 0       | 0       | 0       |

3.5. Wash fastness of fabrics

Table 4 lists the wash fastness of original and modified PET fabrics after dyeing. In wash fastness of red and blue dyes, staining of original PET fabrics was very good (grade 5). Compared to the original PET fabrics, the Wash fastness of modified PET fabrics and dyed by disperse blue 2BLNG-L only
decreased a little to grade 4, and the grade of wash fastness for modified PET fabrics dyed by disperse red E-4B was 4-5. During the washing process, dye molecules would migrate from interior to surface of the fibers.

| Table 4. Color fastness to washing of original and modified PET fabrics after dyeing. |
|---------------------------------|-----------------|----------------|-----------------|----------------|
| Samples                        | Disperse blue 2BLNG-1 | Disperse red E-4B |
|                                 | Original PET | Modified PET | Original PET | Modified PET |
| Wash fastness                  | 5            | 4             | 5             | 4-5           |

4. Conclusion
In this work, the effect of sulfuric acid modified on the dyeing properties of PET fabrics was discussed. The dyeing property of PET fabric modified by sulfuric acid is better than that of original PET fabric, and the value of K/S increased with the increase of the modifying concentration of sulfuric acid. The levelling property and wash fastness of PET fabrics maintains well after the modification, without significant change in the color of the fabric after dyeing. And the hydrophilic property of modified PET fabrics keeps excellent after dyeing.

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