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Properties of alginate fiber spun-dyed with fluorescent pigment dispersion

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ABSTRACT

Spun-dyed alginate fiber was prepared by the spun-dyeing method with the mixture of fluorescent pigment dispersion and sodium alginate fiber spinning solution, and its properties were characterized by SEM, TGA, DSC, and XRD. The results indicate that fluorescent pigment dispersion prepared with esterified poly (styrene-*alt* maleic acid) had excellent compatibility with sodium alginate fiber spinning solution, and small amount of fluorescent pigment could reduce the viscosity of spun-dyed spinning solutions. SEM photo of spun-dyed alginate fiber indicated that fewer pigment particles deposited on its surface. TGA, DSC, and XRD results suggested that thermal properties and crystal phase of spun-dyed alginate fibers had slight changes compared to the original alginate fibers. The fluorescence intensity of spun-dyed alginate fiber reached its maximum when the content of fluorescent pigment was 4%. The spun-dyed alginate fiber showed excellent rubbing and washing fastness.

1. Introduction

Alginate fiber derived from brown algae consists of β-(1-4)-linked-D-mannuronic acid (M) and α-L-guluronic acid (G) segments (Chart 1) (de Kerchove Alexis & Elimelech, 2006; Khan & Ahmad, 2013; Turco et al., 2011). Presently, alginate fibers are extensively used in wound care due to their potential bioactivity, non-toxicity, and biocompatibility (Knill et al., 2004; Lian, Wu, Zhou, & Wang, 2011; Mikolajczyk, Wolowska-Czapnik, & Bogun, 2004; Mikolajczyk, Boguń, Kurzak, & Szparaga, 2009; Yimin, 2008; Lian et al., 2011). During the wound care process, the moist gel formed by ions exchange between Ca^{2+} and Na^{+} when alginate fibers interact with the wound exudates, thereby preventing fiber entrapment in the wound (Lihong et al., 2005, 2006; Murakami et al., 2010; Thomas, Harding, & Moore, 2000).

With the increasing emphasis on functional textile coupled with the clarion call for eco-friendly textile materials and production processes (Dangelico, Pontrandolfo, & Pujari, 2013; Faqeer, 2014; Kate, 2014), alginate fibers applicable to the manufacture of textile products such as underwear, sportswear and bed clothes (Bogu, Mikolajczyk, Szparaga, & Kurzak, 2010; Senthil Kumar, 2013) have attracted more research attention. As a result, suitable, sustainable and eco-friendly coloration of these products is very crucial for their sustenance in the ever-changing world of fashion. However, coloration of alginate fibers presents huge challenge because these fibers easily get damaged in salt solution due to ion exchange. Using the traditional method of dyeing (piece/bath dyeing) makes it impossible because large amount of salts are required to ensure complete dye exhaustion, fixation and levelness during the dyeing process (Lv, Zhu, & Wang, 2002). Therefore, it is necessary to find a method for coloring these novel fibers.

Spun-dyeing presents a very unique opportunity in this regard because it yields excellent color fastness, low coloration costs and less environment impact compared to the tradition bath dyeing (Fujikawa, Kushino, & Yamamoto, 1988; Maniana, Ruef, & Bechtold, 2007; Munukutla & Bajaj, 1990; Nava, Bianchi, & Pitea, 1983; Wang, Du, Tian, Fu, & Xu, 2014), yet there are still few publications for successful dyeing of alginate fibers (Lv et al., 2002). Pigment as one of the most commonly used colorant in spun-dyeing also has its downsides because improperly dispersed pigment could lead to agglomeration, resulting in large particle sizes and unequal distribution in the spinning solution which can significantly affect the spinning process, microstructure, surface morphology, color performance and the mechanical properties of the spun-dyed fibers (Munukutla & Bajaj, 1990; Wang et al., 2014). Even though a lot of success has been achieved in the use of pigments for spun-dyeing over the years in terms of good dispersion and dope compatibility, this has been limited to fibers, such as viscose rayon, polyester fibers, acrylic fibers, lyocell fibers (Chen, Lai, & Sun, 2006; Hirota, Kado, & Shosuke, 1989).

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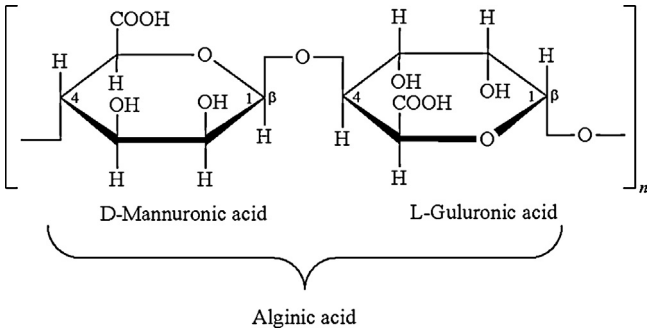


Chart 1. Chemical structure of alginate fiber derived from brown algae.

The compatibility of pigment dispersions and alginate fiber spinning solution has not been reported yet hence the need for this research. In this article, we first prepared fluorescent pigment dispersion and then investigated the compatibility of fluorescent pigment and alginate fiber spinning solution. Properties of spun-dyed alginate fibers were also studied by various techniques. This research provides further insight into spun-dyeing of alginate fibers with pigment dispersions.

2. Experiments

2.1. Materials

Fluorescent pigment (WLX-15) was purchased from fine chemical North American industry Co. Ltd., China. Alginate sodium was supplied by Qingdao chemical industry Co. Ltd., China. The esterified poly (styrene-*alt* maleic acid) (SMAE, *M*n = 5363, acid value = 163) was prepared in our lab. Sodium hydroxides (NaOH, AR) and calcium chloride ($CaCl_2$, AR) were purchased from Guoyao chemical reagent Co. Ltd., China. Distilled water was used in all the experiments.

2.2. Preparation of fluorescent pigment dispersion

Six grams SMAE was dissolved in 264 g distilled water containing with 0.7 g NaOH, followed by the addition of 30 g fluorescent pigment. The mixture was stirred at 600 r/min for 30 min, and then homogenized with bead mill (Minizeta 03E, Netzsu, Germany) at 2000 r/min for 3 h. Finally, the prepared dispersion was filtered (pore size 1000 nm) to obtain the fluorescent pigment dispersion.

2.3. Preparation of spun-dyed alginate fiber spinning solutions

A 10% mass concentration of sodium alginate acid solution was prepared. Different amounts of fluorescent pigment (0–4%, on the weight of alginate fiber) and corresponding amount of water were added to sodium alginate acid solution to prepare the spun-dyed alginate fiber spinning solutions, and kept the mass concentration of sodium alginate acid at 5%. The spun-dyed alginate fiber spinning solution was stirred with strong shear force for 30 min and then filtered using 155 mesh filter cloth under pressure of 0.3–0.5 mPa. The filtered spun-dyed alginate fiber spinning solution was degassed in spinning tank for 24 h.

2.4. Spinning

The prepared spun-dyed alginate fiber spinning solution was heated to 55 °C and then extruded through 20 hole (90 μm diameter) spinneret plate into coagulating bath ($CaCl_2$ concentration 5 wt%) to produce alginate fiber. The spun-dyed alginate fibers were washed and drafted in distilled water (draft ratio 1:1.2), and then dried at room temperature.

2.5. Characterization

2.5.1. Properties of fluorescent pigment dispersion

The sample was diluted 2000 times with distilled water. Particle size and its distribution were measured by dynamic light scattering method (DLS) using Malvern Zetasizer Nano ZS90 instrument at 25 °C.

The sample was centrifuged at 3000 r/min for 30 min, and the particle size of the dispersion in the upper and bottom of the centrifugal tube was tested, respectively. The centrifugal stability was evaluated by the changing rate of particle size (S_c) as given by Eq. (1).

$$S_c = \frac{|d_u - d_b|}{d_b} \times 100\% \quad (1)$$

where d_u is the particle size of the dispersion in the upper centrifugal tube, d_b is particle size of the dispersion in the bottom of the centrifugal tube.

The sample was sealed and stored at −10 °C for 24 h and then put in an oven at 60 °C for another 24 h. The above method was repeated for different cycles. The freeze-thaw stability was evaluated by the change rate of particle size (S_{F-T}) as given by Eq. (2).

$$S_{F-T} = \frac{|d_0 - d_T|}{d_0} \times 100\% \quad (2)$$

where d_0 is the particle size before treatment, d_T is particle size after freeze-thaw treatment.

2.5.2. Compatibility of fluorescence pigment and alginate fiber spinning solutions

The distribution of fluorescent pigment particles in alginate fiber spinning solutions was observed under Digital Scanning Microscope (Zeiss DSM 955). DSM photos were taken at magnification 2000 times.

The apparent viscosity against time of spun-dyed alginate fiber spinning solutions was measured using DV-III Rheometer.

The spun-dyed alginate fiber spinning solutions was placed in an oven at 60 °C, and its apparent viscosity was measured by DV-III rheometer for every 2 h. The stability of the spinning solution was evaluated by the changing rate of apparent viscosity according to Eq. (3)

$$S_\eta = \frac{|\eta - \eta_0|}{\eta_0} \times 100\% \quad (3)$$

where η is the viscosity before treatment, η_0 is the viscosity after storage at 60 °C for different times.

2.5.3. Color measurement

The color strength (K/S) of fabric prepared from spun-dyed alginate fiber was measured using X-rite 8400 spectrophotometer under illuminant D65 and 10° standard observers. The color strength was calculated from the reflectance at 540 nm using the Kubelka–Munk equation as given in Eq. (4).

$$K/S = \frac{(1-R)^2}{2R} - \frac{(1-R_0)^2}{2R_0} \quad (4)$$

Where R and R_0 are the reflectance of the colored and uncolored fabrics made from the spun-dyed alginate fiber.

The fluorescence intensity was measured on Shimadzu RF-5301PC luminescence spectrometer at excitation-emission wavelength 272 nm.

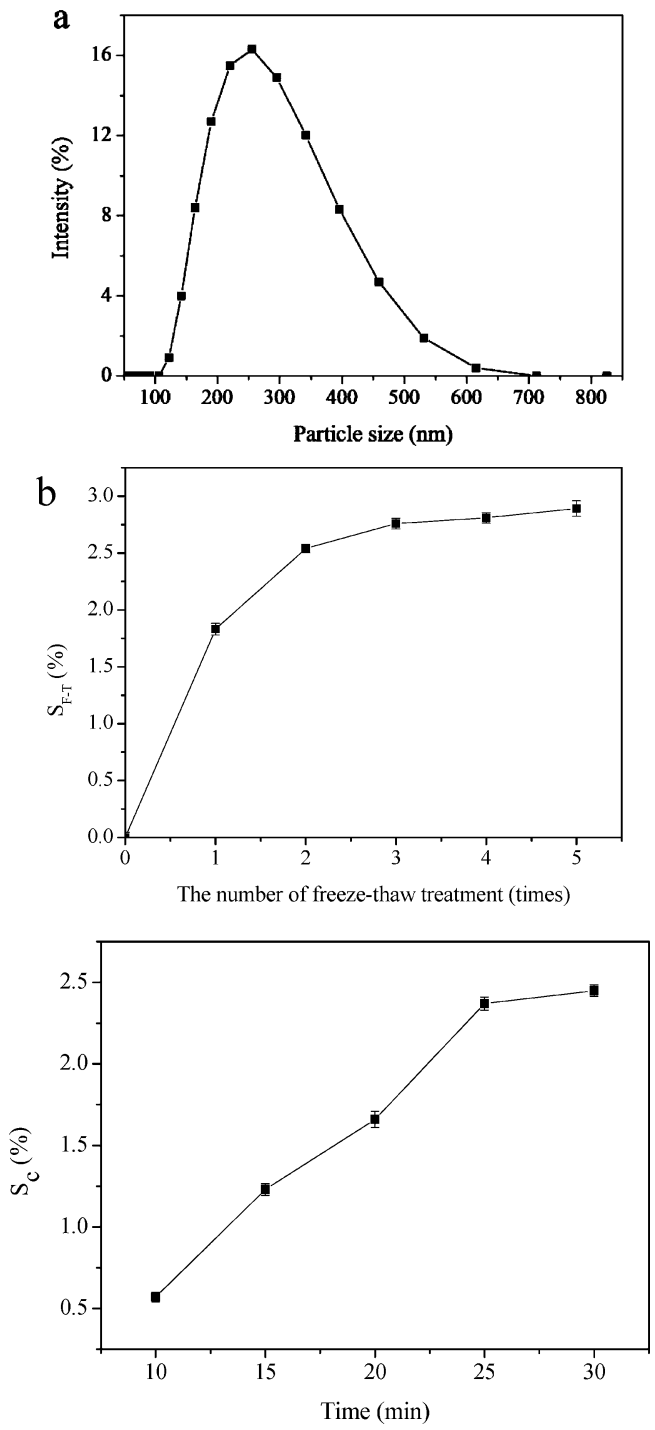


Fig. 1. (a) Particle size distribution, (b) freeze-thaw stability, and (c) centrifugal stability of fluorescent pigment dispersion.

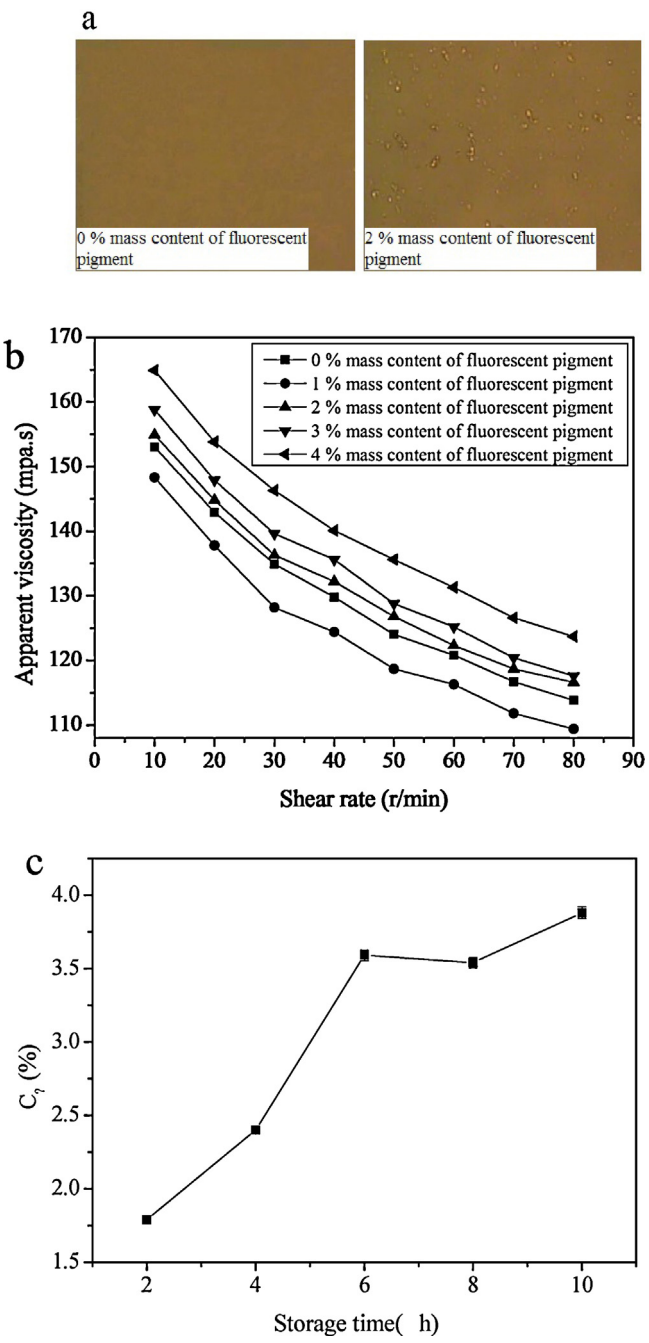


Fig. 2. (a) DSM photos of fluorescent pigment in alginate fiber spinning solution (mass content of fluorescent pigment 4%, magnified by 2100 times), (b) rheological behavior of the alginate fiber solution with fluorescent pigment dispersion; (c) storage time effect on apparent viscosity change rate of fluorescent pigment/alginate fiber spinning solution (mass content of fluorescent pigment 4%).

The color fastness to rubbing and washing were evaluated according to the standard methods of GB/T 3921-2008 and GB/T 3922-1995, respectively.

2.5.4. Characterization of the spun-dyed alginate fibers

Moisture regain was determined by gravimetrically method. The samples were pre-humidified under standard atmospheric conditions (temperature 20 °C, relative humidity 65%) for 24 h to balance the humidity, and then placed into a box and weighted together by an electric balance (minimum scale value 0.001 g). After that, the box containing the samples was opened the lid and stored into a blast oven (precision = ±3 °C) for 1 h at 105 °C. The box was quickly covered with the lid and put into the desiccator. The box was weighed when it was cooled to room temperature. Each sample was measured three times. The moisture regain of the samples was evaluated by Eq. (5).

$$\text{Moisture region}(\%) = \frac{W_M - W_H}{W_H} \times 100 \quad (5)$$

where W_M and W_H are the weights of the unheated and heated samples, respectively.

Tensile test was carried out using single-fiber strength tester at 25 °C and 55% humidity according to GB/T 3921-2008. Seven

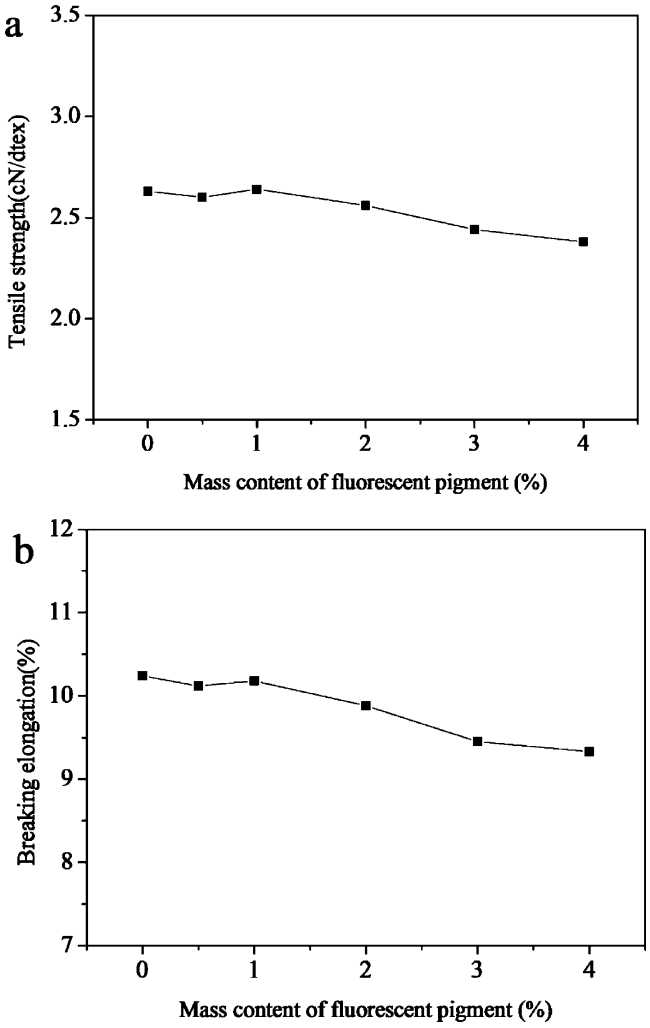


Fig. 3. Effect of mass content of fluorescent pigment on (a) tensile strength and (b) breaking elongation of the spun-dyed alginate fibers.

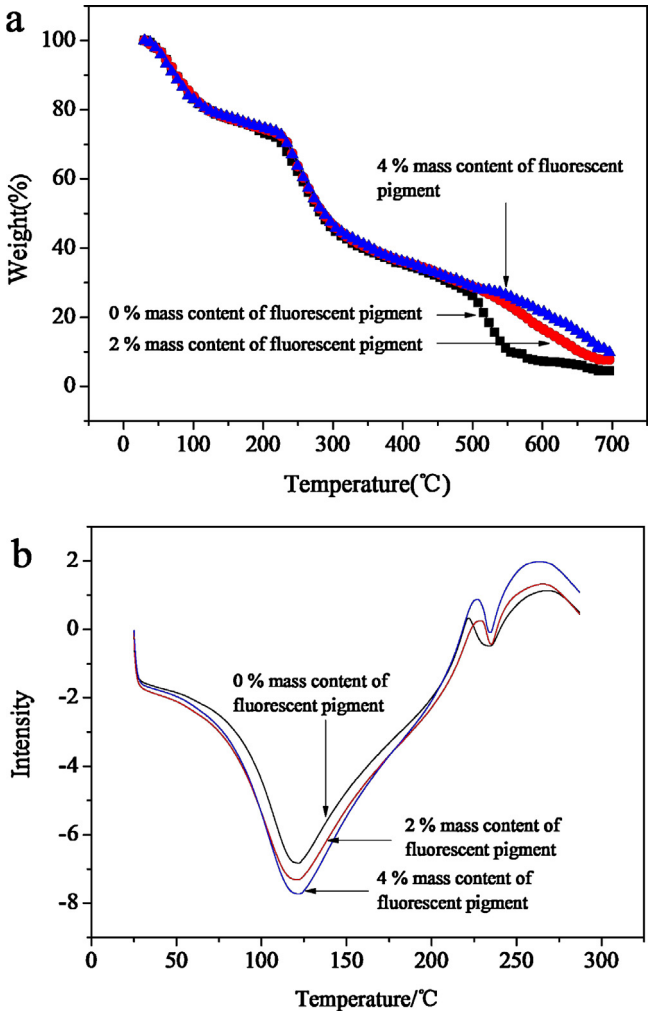


Fig. 4. (a) TGA and (b) DSC curves of spun-dyed alginate fibers with different mass content of fluorescent pigment.

specimens were tested with Instron universal mechanical testing machine with load of 0.3 cN at grip separation speed of 55 mm/min.

The spun-dyed alginate fiber was sputter-coated with gold. SEM was performed using Zeiss EVO scanning electron microscope.

The X-ray diffraction (XRD) spectra of the samples were determined by XRD (ARL-X' TRA) using CuKa as radiation at wavelength of $\lambda = 1.54183$ Å. The generator setting was 40 kV and 35 mÅ. The diffraction data were collected over 120 min range of 3–90°, with step width of 0.02° and counting time of 1 s per step.

Samples were prepared by spreading the powders into the holder (about 3 mm thick) and pressing slightly with glass slide to ensure flat surface. TGA was measured using TG apparatus (TGA/SDTA851e, Mettler Toledo instrument co., LTD, Switzerland) with 10 °C/min ramp between 25 and 700 °C. The thermal behavior of the alginate fibers was studied with DSC (Q200, TA Instruments, United States).

3. Results and discussion

3.1. Particle size distribution and stability of fluorescent pigment dispersion

Fig. 1a shows that the particle size distribution of the fluorescent pigment dispersion is in the range of 100 nm and 700 nm. The changing rate of particle size of the fluorescent pigment dispersion remained less than 3% when it went through freeze-thaw treatment (Fig. 1b) or centrifugal treatment (Fig. 1c), which indicated that the fluorescent pigment dispersion prepared with esterified poly (styrene-*alt* maleic acid) had excellent stability. In aqueous media, the hydrophobic chains of the esterified poly (styrene-*alt* maleic acid) tightly adsorbed onto the surface of fluorescent pigment and the hydrophilic chains build voluminous shell around particles, which help avoid fluorescent pigment flocculation and agglomeration, thus leading to small particle size and excellent stability.

3.2. Compatibility of fluorescent pigment dispersion and alginate fiber spinning solution

Fig. 2 Compatibility of alginate fiber spinning solution and fluorescent pigment dispersion is one of the most important considerations for successful spinning of alginate fibers, because the compatibility determines the quality of the crystal phase, microstructure, mechanical properties and color performance of the spun-dyed alginate fiber. Fig. 2a shows that fluorescent pigment mixed homogeneously with alginate fiber spinning solution, with no "bridge" phenomenon observed in the DSM photo. This may be due to the fact that the negative charges obtained on the surface of fluorescent pigment after adsorption of esterified poly (styrene-*alt* maleic acid), thus creating the electric repulsive forces between the alginate fibers and fluorescent pigment.

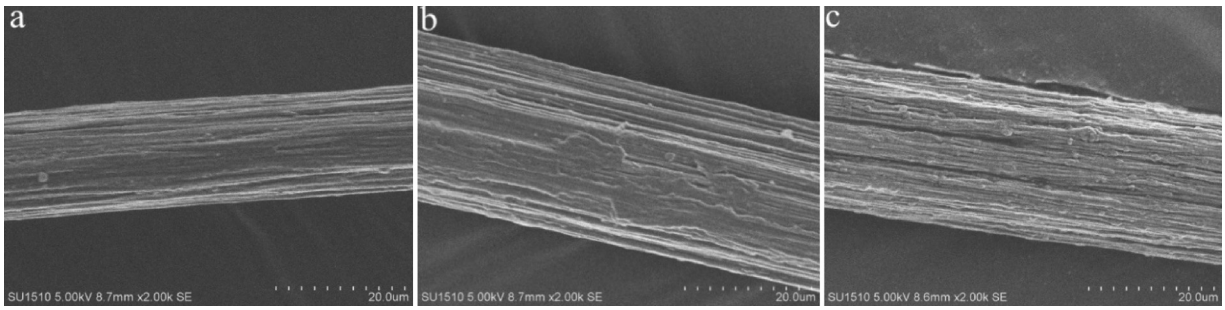


Fig. 5. SEM images of spun-dyed alginate fibers with different mass content of fluorescent pigment, (a) 0 wt%, (b) 2 wt%, and (c) 4 wt%.

Rheological behavior of spun-dyed alginate fiber spinning solution is another important parameter for spun-dyed alginate fibers. Fig. 2b shows that the apparent viscosity of both alginate fiber solution and spun-dyed alginate fiber spinning solutions (1–4%, mass content of fluorescent pigment) decreased continuously with the improvement in shear rate. At the same shear rate, the apparent viscosity of spun-dyed alginate fiber spinning solution decreased first and then increased with an increase in the content of fluorescent pigment. This occurrence is due to the fact that low content of fluorescent pigment can effectively reduce the attractive forces among the alginate fiber molecules, while too high content of fluorescent pigment will enhance the internal friction among fluorescent pigment and alginate fiber molecules.

Stability of spun-dyed alginate fiber spinning solution was measured by the changing rate of apparent viscosity (C_η) at 60 °C. Fig. 2c shows that C_η increased with an extend of storage time and reached an equilibrium after 6 h. The changes of C_η value could be attributed on the presence of bubbles in the spinning solution which crushed after storage for 6 h. It is worth noting that the maximum value of the changing rate (C_η) was about 3.8% after storage for 10 h, which suggests that the fluorescent pigment was stably dispersed in the alginate fiber spinning solution, that is to say the fluorescent pigment dispersion has excellent compatibility with alginate fiber spinning solution.

3.3. Properties of spun-dyed alginate fiber

3.3.1. Color and moisture regain performance

Table 1 shows the color and moisture regain of fabrics woven from spun-dyed alginate fiber based on different fluorescent pigment content. Fluorescence intensity reached maximum when the content of fluorescent pigment was 4%. Beyond this value, fluorescence intensity began to decline steadily as a result of "self-absorbance" of fluorescence light. In addition, K/S value improved as the content of fluorescent pigment increased but with virtually no significant change in K/S value when the content of fluorescent pigment was higher than 4%. Also, excellent rubbing and washing fastness was achieved when the content of fluorescent pigment was lower than 4% in the spun-dyed alginate fiber. The reason was that esterified poly (styrene-*alt* maleic acid) absorbed by fluorescence pigment would coordinate with $CaCl_2$ in the coagulation bath, which is beneficial of the fluorescence pigment becoming integral part of the alginate fiber (Scheme 1). Moisture regain as an important property of the spun-dyed alginate fibers was also studied, it can be seen that the moisture regain reduced a little with an increase amount of fluorescent pigment in the spun-dyed alginate fibers. Unlike the alginate fibers, fluorescent pigment cannot absorb water due to its high hydrophobic performance, thus leading to an adverse effect on the moisture regain.

3.3.2. Tensile strength and breaking elongation

Fig. 3 shows that the tensile strength and breaking elongation of the spun-dyed alginate fiber changed marginally when the content of fluorescent pigment was lower than 2%, and reduced a little with further increase in the content of fluorescent pigment. The content of fluorescent pigment in alginate fiber was responsible for the changes in tensile strength and breaking elongation. Small amount of fluorescent pigment particles in alginate fiber might have plasticizing effect, while too large amount of fluorescent pigment particles might actually destroy the orientation degree of alginate fibers, thereby reducing its tensile strength and breaking elongation.

3.3.3. Thermal properties

Fig. 4a shows that the decomposition behaviors of alginate fibers and spun-dyed alginate fibers were similar in the temperature range of 50–500 °C, while fibers with low fluorescent pigment content decomposed sharply when temperature continue increased from 500 to 700 °C. The first weight loss in the range of 40–155 °C was desorption of physically absorbed water, and the subsequent weight loss in the ranges of 160–550 °C was the decomposition of alginate fiber. The weight loss in the range of 550–700 °C may be attributed to the deterioration of coordination product of esterified poly (styrene-*alt* maleic acid) and calcium.

Fig. 4b shows that, as the same as alginate fibers, the spun-dyed alginate fibers contain two endothermic peaks. The main peak at 120 °C was the change in crystal structure of spun-dyed alginate fibers. Meanwhile, it is clear that the endothermic peaks of spun-dyed alginate fibers appeared at different temperatures, which implying that the more amount of fluorescent pigment content result in spun-dyed alginate fibers having higher stability to temperature. In another words, the spun-dyed alginate fibers have better thermal stability than ordinary alginate fibers.

3.3.4. Scanning electron microscopic analysis

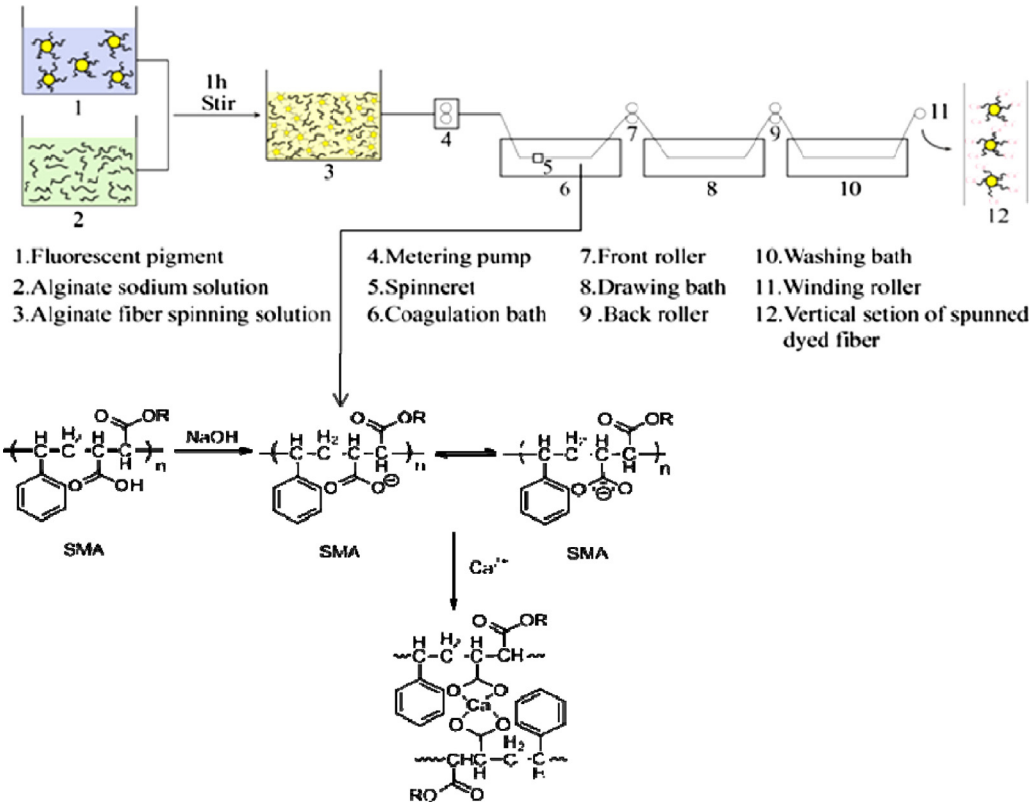
Fig. 5 shows that the surface of spun-dyed alginate fiber became coarser and coarser when fluorescent pigment content increased, and some pigment particles are observed deposited on the alginate fiber surface when the content of fluorescent pigment was high enough. This result indicates that, although large amount of fluorescent pigment was fixed into the alginate fibers, some pigment was inevitable on migration and deposition on the surface of the alginate fibers during the spinning of spun-dyed alginate fiber. The amount of fluorescent pigment that deposited on the surface of the alginate fibers is proportional to the content of fluorescent pigment.

3.3.5. XRD Analysis

Fig. 6 shows the XRD curves of spun-dyed alginate fibers with different fluorescent pigment content. It can be seen that 2θ and diffraction intensity of spun-dyed alginate fibers almost have the same value with alginate fibers. This suggests that the content of

Table 1
Effect of mass content of fluorescent pigment on color and moisture regain of spun-dyed alginate fibers.

Mass content of fluorescent pigment (%)	*K*/*S*	Fluorescence intensity	Rubbing fastness (grade)		Washing fastness (grade)		Moisture regain (%)
			Dry	Wet	Staining	Changing	
0	–	–	–	–	–	–	20.81
1	10.38	832.6	5	5	5	4–5	19.73
2	12.23	865.2	5	5	5	4–5	19.24
3	12.60	933.4	4–5	4–5	4–5	4	19.01
4	13.39	978.2	4–5	4–5	4–5	4	18.90
5	13.47	964.3	4	4	4	4	18.54
6	13.51	955.1	4	3–4	4	4	18.27



Scheme 1. Reaction between SMA and Ca^{2+} during the preparation of spun-dyed alginate fiber.

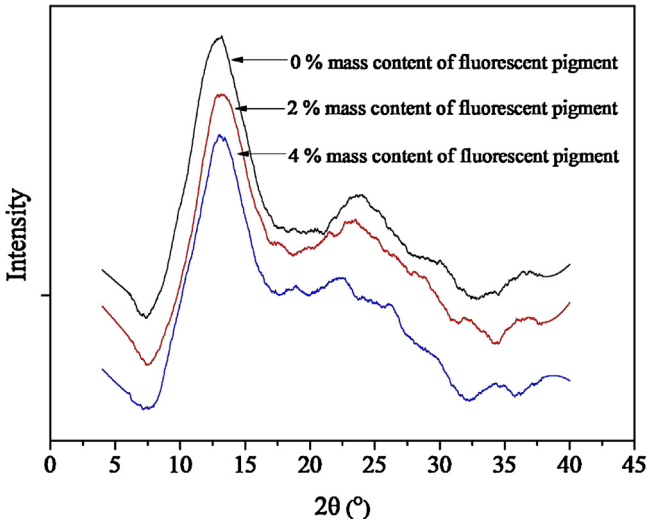


Fig. 6. XRD of spun-dyed alginate fibers.

fluorescent pigment has invisible influence on the crystal phase of spun-dyed alginate fibers.

4. Conclusion

Alginate fibers can be colored by fluorescent pigment dispersion via spun-dyeing method. Fluorescent pigment dispersed with esterified poly (styrene-*alt* maleic acid) showed excellent compatibility with alginate fiber spinning solution. The content of fluorescent pigment has a significant effect on the apparent viscosity of spun-dyed alginate fiber spinning solution. The mechanical performance, thermal stability and crystal phase of spun-dyed alginate fibers vary little with the increase of the content of fluorescent pigment in fibers. The fluorescence intensity of spun-dyed fibers reached maximum when the content of fluorescent pigment was 4%, and the spun-dyed alginate fiber showed excellent rubbing and washing fastness.

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References

Bogu, M., Mikolajczyk, T., Szparaga, G., & Kurzak, A. (2010). Water-soluble nanocomposite sodium alginate fibres. *Fibers and Polymers*, *11*(3).

Chen, Mei-yu, Lai, K., & Sun, Run-jun. (2006). Color variation on spun-dyed polyester filaments during processing. *Textile Research Journal*, *76*(6), 550–555.

Dangelico, R. M., Pontrandolfo, P., & Pujari, D. (2013). Developing sustainable new products in the textile and upholstered furniture industries: Role of external integrative capabilities. *Journal of Product Innovation Management*, *30*(4), 642–658.

de Kerchove Alexis, J., & Elimelech, M. (2006). Structural growth and viscoelastic properties of adsorbed alginate layers in monovalent and divalent salts. *Macromolecules*, *39*(19), 6558–6564.

Faqeer, M. (2014). Emerging green technologies and environment friendly products for sustainable textiles. In *Roadmap to sustainable textiles and clothing*. Singapore: Springer.

Fujikawa, I., Kushino, M., Yamamoto, Y. (1988). Coloring agent for dope-dyeing viscose rayon, US. 8–30.

Hirota, F., Kado, T., Shosuke, O. (1989). Black liquid colorant and polyester fibers dope-dyed therewith, US. 11–17.

Kate, F. (2014). *Sustainable fashion and textiles: design journeys*. London, UK: Routledge Press.

Khan, Ferdous, & Ahmad, S. R. (2013). Polysaccharides and their derivatives for versatile tissue engineering application. *Macromolecular Bioscience*, *13*(4), 395–421.

Knill, C. J., Kennedy, J. F., Mistry, J. M. M., Smart, G., Groocock, M. R., & Williams, H. J. (2004). Alginate fibres modified with unhydrolysed and hydrolysed chitosans for wound dressings. *Carbohydrate Polymers*, *55*(1), 65–76.

Lian, Y., Wu, J. Y., Zhou, D. P., & Wang, H. M. (2011). Preparation and properties of alginate fibre. *Advanced Materials Research*, *419*, 335–336.

Lihong, F., Yumin, D., Huang, R., Wang, Q., Wang, X., & Zhang, L. (2005). Preparation and characterization of alginate/gelatin blend fibers. *Journal of Applied Polymer Science*, *96*(5), 1625–1629.

Lihong, F., Yumin, D., Zhang, B., Yang, J., Zhou, J., & Kennedy, J. F. (2006). Preparation and properties of alginate/carboxymethyl chitosan blend fibers. *Carbohydrate Polymers*, *65*(4), 447–452.

Lv, F., Zhu, P., & Wang, C. (2002). Preparation, characterization, and dyeing properties of calcium alginate fibers. *Journal of Applied Polymer Science*, *126*, 382–387.

Maniana, A. P., Ruef, H., & Bechtold, T. (2007). Spun-dyed lyocell. *Dyes and Pigments*, *74*(3), 519–522.

Mikolajczyk, T., Wolowska-Czapnik, D., & Bogun, M. (2004). Precursor alginate fibres containing nano-particles of SiO_2. *Fibres & Textiles in Eastern Europe*, *12*(3), 19–23.

Mikolajczyk, T., Boguń, M., Kurzak, A., & Szparaga, G. (2009). Zinc alginate fibres with a tricalcium phosphate (TCP) nanoadditive. *Fibres & Textiles in Eastern Europe*, *73*(12).

Munukutla, S. K., & Bajaj, P. (1990). Effect of spinning dope additives on dyeing behavior of acrylic fibers. *Textile Research Journal*, *90*(3), 113–118.

Murakami, K., Aoki, H., Nakamura, S., Nakamura, S., Takikawa, M., Hanzawa, M., et al. (2010). Hydrogel blends of chitin/chitosan, fucoidan and alginate as healing-impaired wound dressings. *Biomaterials*, *31*(1), 83–90.

Nava, A., Bianchi, D., & Pitea, D. (1983). Colors of dope and yarn of spun-dyed cellulose acetate. *Color Research and Application*, *8*(1), 23–24.

Senthil Kumar, R., & Vigneswaran, C. (2013). *Textiles for industrial applications*. Boca Raton, Florida, US: CRC Press.

Thomas, A., Harding, K. G., & Moore, K. (2000). Alginates from wound dressings activate human macrophages to secrete tumour necrosis factor-α. *Biomaterials*, *21*(17), 1797–1802.

Turco, G., Donati, I., Grassi, M., Marchioli, G., Lapasin, R., & Paoletti, S. (2011). Mechanical spectroscopy and relaxometry on alginate hydrogels: A comparative analysis for structural characterization and network mesh size determination. *Biomacromolecules*, *12*(4), 1272–1282.

Wang, C., Du, C., Tian, A., Fu, S., & Xu, C. (2014). Regenerated cellulose fibers spun-dyed with carbon black/latex composite dispersion. *Carbohydrate Polymers*, *102*, 905–906.

Yimin, Q. (2008). Alginate fibres: An overview of the production processes and applications in wound management. *Polymer International*, *57*(2), 171–180.