Heat Setting of Silk/Poly(Lactic Acid) Blend Fabric

Kaiqiang Liu [a], Jin-Ping Guan [b] and Ren-Cheng Tang [c]

National Engineering Laboratory for Modern Silk, College of Textile and Clothing Engineering, Soochow University, 199 Renai Road, Suzhou 215123, China

[a] kliu@suda.edu.cn, [b] guanjinping@suda.edu.cn, [c] tangrencheng@suda.edu.cn

Keywords: Poly(lactic acid) Fiber; Silk; Blend; Heat Setting; Thermal Property.

Abstract. Silk/poly(lactic acid) (PLA) blend fabric as a new textile material must be subjected to heat setting treatment. Heat setting can increase the dimensional stability of the fabric, remove the wrinkle marks of the fabric formed in earlier processing, and fix the fabric width, but it also can cause the changes in the structures and properties of the fibers. In this work, the effects of heat setting at different temperatures on the whiteness, tensile strength, dyeability, crystalline structure and thermal properties of silk/PLA fabric were discussed. It was found that 130 ^{o}C was a safe heat setting temperature in terms of tensile strength loss, whiteness, fiber degradation, and heat setting efficiency. High temperature heat setting induced the great degradation of PLA fiber, the decrease in the whiteness of the fabric, and the high tensile strength loss of the fabric.

Introduction

Poly(lactic acid) (PLA) fiber has attracted great attention as a promising replacement of petroleum-based poly(ethylene terephthalate) (PET) fiber [1], and it has been widely applied in textile industry. PLA fiber is usually dyed with disperse dyes at the temperatures ranging from 100 to 110 ^{o}C, whereas the disperse dyeing of PET fiber is carried out at 130 ^{o}C. Because silk fiber suffers from the degradation at high temperatures under a wet heat condition, PLA fiber gains an advantage over PET fiber in the development of silk and synthetic fiber blends. Silk/PLA blend fabric can be dyed at a low temperature. Heat setting is an important physical process of silk/PLA blend fabric, and it can improve the dimensional stability of the fabric, remove the wrinkle marks of the fabric formed in earlier processing, and fix the fabric width. Because PLA fiber has a low glass transition temperature and heat setting can change its structures and properties, the heat setting of silk/PLA blend fabric should be carefully controlled. In this work, silk/PLA blend fabric was subjected to heat setting at different temperatures, and the effects of heat setting on the whiteness, tensile strength, dyeability, crystalline structure and thermal performance of the fabric were discussed. This research aimed to provide the basis for selecting the suitable heat setting temperature of silk/PLA fabric.

Experimental

Materials. The scoured silk/PLA satin fabric was friendly provided by Jiangsu Xinmin Textile Science and Technology Co., Ltd.; its warp and weft were silk and PLA fiber, respectively, and the mass ratio of two fibers was about 1:1. Disperse Red 3B (C.I. Disperse Red 60) and Dispertex RP-131 (a disperse agent) were commercial products. Other chemicals were of laboratory reagent grade.

Heat Setting. The heat setting of the fabric was carried out at different temperatures for 90 seconds in the tension-free state using a continuous mini tenter.

Dyeing. The heat set fabric was dyed in the XW-ZDR oscillated dyeing machine using a 50: 1 liquor ratio and the dye solution (2%owf dye, 2g/L Dispertex RP-131, and 0.3 g/L acetic acid). After immersing the fabric in the dye solutions at 40 ^{o}C, the temperature was increased to 110 ^{o}C at 1 ^{o}C /min and held for 50 min, then cooled to 70 ^{o}C at 1 ^{o}C /min. At the end of dyeing, the dyed fabric was washed in the mixture solution of 2 g/L sodium hydrosulfite and 1 g/L sodium bicarbonate at 70 ^{o}C for 10 min, and then rinsed thoroughly in distilled water, and allowed to dry in the open air.

Measurements. The color space coordinates (lightness [L], redness-greenness [a], and blueness-yellowness [b]) and the apparent color depth (K/S) of the fabric were measured with the

HunterLab UltraScan PRO reflectance spectrophotometer using illuminant D65 and 10^{o} standard observer. The Hunter whiteness index (WI) were calculated using Eq. (1):

$$WI = 100-[(100-L)^2+a^2+b^2]^{0.5} \tag{1}$$

The tensile strength of the fabric was measured with the Instron 5967 tensile tester at a crosshead speed of 10 mm/min. The wide angle X-ray diffraction measurement of fabric powder was carried out on the X'Pert-Pro MPD X-ray diffractometer equipped using copper K alpha radiation of wavelength 0.15418 nm at room temperature; the scattering angle range was 5^{o}-45^{o}, and scans were collected at 40 kV and 35 mA. The differential scanning calorimetry (DSC) analysis was conducted with the SDT 2960 DSC-TGA thermal analyzer at the scan rate of 10 ^{o}C/min under a flow of nitrogen (50 mL/min).

Results and Discussion

Effect of Heat Setting on the Whiteness of Silk/PLA Fabric. The whiteness of the original fabric was 90.49. As shown in Fig. 1, the fabric showed little variation in whiteness in the case of heat setting in the temperature range of 120-150 ^{o}C. When the temperature was above 150 ^{o}C, the fabric whiteness decreased significantly with increasing temperature. This should be attributable to the oxidation of the aromatic amino acids of silk fiber and the degradation of PLA fiber.

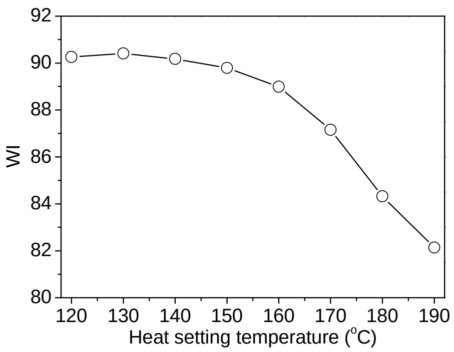

Fig. 1 Effect of heat setting temperature on the whiteness of silk/PLA fabric

Effect of Heat Setting on the Tensile Strength of Silk/PLA Fabric. The silk/PLA fabric consists of the warp silk and the weft PLA. Fig. 2 shows the tensile strength of the heat set fabric in warp and weft directions. The tensile strength of the original fabric in warp and weft directions was 861.0 and 656.3, respectively. Compared with the original fabric, the fabric showed little variation in strength in the case of heat setting in the temperature range of 120 and 130 ^{o}C. When the heat setting temperature exceeded 140 ^{o}C, the strength of the fabric in weft direction decreased remarkably with increasing temperature of heat setting. Undoubtedly, this is caused by the thermal degradation of PLA fiber. The obvious shrinkage of the fabric was found as the heat setting temperature increased. As a consequence, an increase in the strength of the fabric in warp direction was observed. Taking the efficiency of heat setting and the low loss of tensile strength into consideration, it is deemed that 130 ^{o}C is a safe temperature of heat setting, and applicable to the heat treatment of silk/PLA fabric.

Effect of Heat Setting on the Disperse Dyeing Properties of Silk/PLA Fabric. The used silk/PLA fabric has a satin weave, and its front side shows silk surface while its back side is PLA surface. Fig. 3 shows the color depth of the heat set fabric dyed with a red disperse dye. The K/S value of the front side was hardly affected by heat setting. However, the color depth of the back side showed obvious increase at the heat setting temperature exceeding 150 ^{o}C, which should be primarily due to the change in the crystalline structure of PLA fiber.

Effect of Heat Setting on the Crystalline Structure of Silk/PLA Fabric. Fig. 4 shows the X-ray diffraction patterns of the silk/PLA fabrics subjected to heat setting at different temperatures. A weak diffraction was at 2θ=20.8^{o}, showing the crystalline structure of silk fiber [2]. A sharp intense diffraction at 2θ=16.6^{o} and a less intense diffraction at 2θ=18.9^{o} corresponded to the crystalline structure of PLA fiber [3]. The fabrics subjected to heat setting in the temperature range of 120-160

^oC showed little variation in the intensity of diffraction peaks compared with the original fabric. The fabric treated at the temperature of 170 ^oC close to the melting point of PLA fiber displayed obvious decrease in the intensity of diffraction peak at $2\theta=16.6^o$, indicating the greatly destroyed crystalline structure of PLA fiber. For the fabrics treated at the 180 and 190 ^oC, the diffraction peak at $2\theta=16.6^o$ was not found, revealing the disappearance of the crystalline structure of PLA fiber. In the case of silk fiber, the diffraction peak at $2\theta=20.8^o$ had little variation with increasing temperature. The above results suggest that high temperature heat setting exerted little impact on the crystalline structure of silk fiber, but great impact on the crystalline structure of PLA fiber.

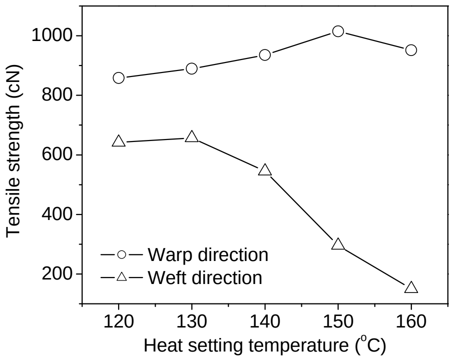

Fig. 2 Effect of heat setting temperature on the tensile strength of silk/PLA fabric

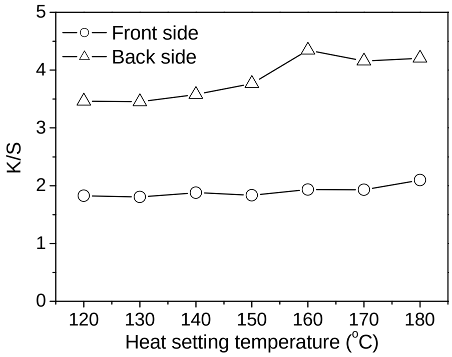

Fig. 3 Effect of heat setting temperature on the color depth of the dyed silk/PLA fabric

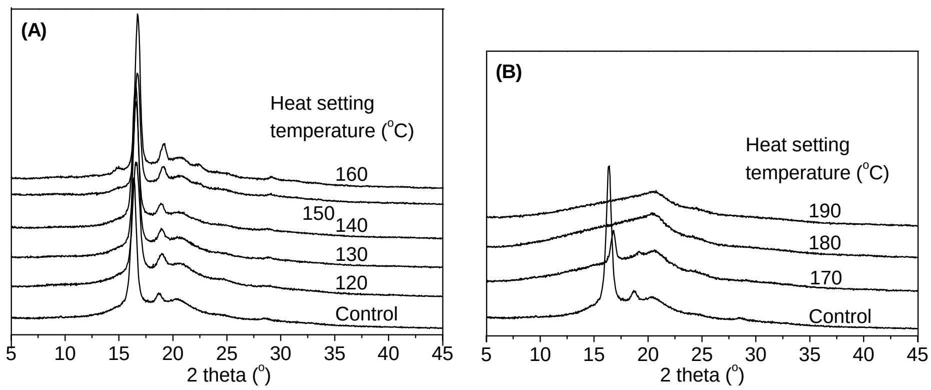

Fig. 4 X-ray diffraction patterns of the silk/PLA fabrics treated at different temperatures

Effect of Heat Setting on the Thermal Properties of Silk/PLA Fabric. As reported previously, the maximum thermal degradation temperature of silk is in the temperature range of 290-330 ^oC [4], whereas that of PLA is about 360 ^oC [5]. Usually, the melting point of PLA is between 160-175 ^oC [3]. The DSC curves of the silk/PLA fabrics subjected to heat setting at different temperatures are shown in Fig. 5, from which the characteristic melting and degradation temperatures of silk and PLA fibers were able to be found. After heat setting, PLA fiber showed great variation in its thermal properties compared with silk fiber. The treated fabrics treated at 120, 130 and 140 ^oC showed two melting peaks at 163 °C or so in their DSC curves, whereas the original fabric displayed one melting peak (the DSC curve not shown). In the heat setting temperature range of 120-150 °C, an increase in the melting temperature of PLA occurred possibly due to the increased orientation of PLA molecule chains. After heat setting at the temperature above 160 °C, the melting temperature of PLA increased obviously, and the maximum thermal degradation temperature of PLA decreased obviously. These results indicate that high temperature heat setting leads to the great changes in the crystalline structure of PLA, and the great thermal degradation of PLA.

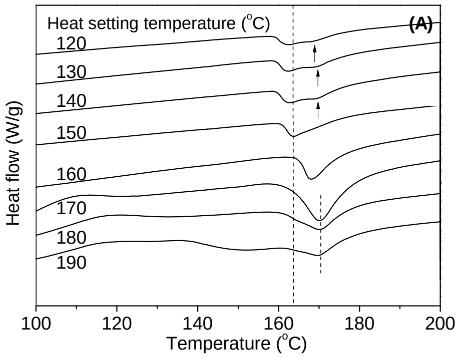

Fig. 5 DSC thermograms of the silk/PLA fabrics treated at different temperatures

Conclusions

The silk/PLA blend fabric was subjected to heat setting at different temperatures, and the dependence of the whiteness, tensile strength, dyeability, crystalline structure and thermal performance of silk/PLA fabric on heat setting were discussed. 130 °C was found to be a safe heat setting temperature according to the evaluations of whiteness, tensile strength, fiber degradation and heat setting efficiency.

Acknowledgements

This work was financially supported by Jiangsu Provincial Natural Science Foundation of China (BK2012197), Joint Innovation Fund of Jiangsu Province of China (BY2014059-04), Suzhou Science and Technology Support Program (SS201422), and the Priority Academic Program Development (PAPD) of Jiangsu Higher Education Institutions.

References

[1] J. Lunt and A.L. Shafer: J. Ind. Text., Vol. 29 (2000), p. 191

[2] M. Tsukada, H. Kato, G. Freddi, N. Kasai and H. Ishikawa: J. Appl. Polym. Sci., Vol. 51 (1994), p. 619

[3] H. Zhou, T.B. Green and Y.L. Joo: Polymer, Vol. 47 (2006), p. 7497

[4] M. Tsukada, M. Obo, H. Kato, G. Freddi and F. Zanetti: J. Appl. Polym. Sci., Vol. 60 (1996), p. 1619

[5] F.D. Kopinke M. Remmler, K. Mackenzie, M. Möder and O.Wachsen: Polym. Degrad. Stabil., Vol. 53 (1996), p. 329