Journal of Cleaner Production 176 (2018) 382–390

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Dyeing of recycled Poly(lactic acid) fibers from disposable packages flake with low energy consumption and effluent

Sh. Bayati, M.A. Tavanaie*

Textile Engineering Department, Faculty of Engineering, Yazd University, Yazd, Iran

ARTICLE INFO

Article history:
Received 18 April 2017
Received in revised form
6 November 2017
Accepted 5 December 2017

Keywords:
Recycled poly(lactic acid) fibers
Dyeing behavior
Fastness properties
Exhaustion rate

ABSTRACT

Poly(lactic) acid as a biodegradable polymer has attracted a lot of attentions due to its environmental merits and availability in sufficient quantities for use in the packaging industry. Recycling of poly(lactic) acid and converting it to a new product, instead of a compost material or primary monomer, is an economical and environmental solution. In this paper, recycled poly(lactic) acid fibers melt-spun from disposable package flakes were dyed by using three disperse dyes having different molecular weights and their dyeing behavior and fastness properties have been studied. Dyeing temperature, time and concentration were fully investigated. The results showed that with an increase in the temperature from 80 °C to 120 °C, the amount of dyeing exhaustion rate increased for different disperse dyes. The recycled poly(lactic) acid fibers exhibited a good exhaustion rate in a short time (20 min), low concentrations (0.5% on weight of the fabric) and low temperature (80 °C). The good to excellent washing fastnesses between 4 and 5 were observed for the recycled poly(lactic) acid fibers which were dyed by the three selected disperse dyes under the optimized conditions. Accordingly, it could be considered that the recycled poly(lactic) acid fibers have a great capability to be dyed with low damage, energy consumption, costs and effluent with disperse dyes.

1. Introduction

Recycling and reusing of renewable resources help a lot to protect the environment and to save the economic resources. Polymer PLA, a linear and biodegradable aliphatic thermoplastic polyester (Karst et al. (2009); and Hutchinson et al. (2006)), has high elastic modulus and transparency (Jamshidian et al., 2010). Some remarkable applications of this polymer include hard plastic containers, disposable plastic containers, clothing and home textiles, nanofibers in medical textiles and engineering plastics (Gupta et al., 2007; Auras et al., 2010; and Nowpashani et al., 2014). Over the past decades, landfill of plastics wastes has become a major problem in the industrialized countries. The most common options for the management of wastes produced from fossil fuels include burning, disposal and mechanically recycling. Recycling allowed saving large amount greenhouse gas emission (Simon et al., 2016). Given that PLA is compost derived from fast resources, there is much hope to lessen the problem of wastes disposal. Thus, more research and development work is required to reuse different types of recycled plastics, rather than using them as new materials (Burkinshaw and Jeong, 2008). A PLA fiber is important to substitute polyester in apparel and home textiles (Hussain et al., 2015). In the previous study, Tavanaie (2014) melted the r-PLA flakes obtained from PLA plastic containers and prepared biodegradable fibers using melt spinning process. He showed that the PLA flakes were suitable to be recycled and converted into a fiber with good features.

Due to linear aliphatic nature, the fibers made of PLA are sensitive to alkaline hydrolysis and high temperatures. In addition, dyebath temperatures of 90–100 °C were necessary to minimize loss in properties due to hydrolysis and shrinkage of the fabrics. Careful selection of temperature and pH is critical to achieving the right depth of color without affecting physical properties of the fiber or fabric (Lunt and Bone, 2000). Lunt and Bone, reported that disperse dyes migrate on-tone on PLA fibres and show considerably improved migration values over those typically seen on PET. Medium energy disperse dyes exhibited equally good on-tone build-up on PLA as on PET PLA fiber is highly similar to other man-made fibers, however, since this type of fiber is considered as a new category by its own and its properties have some sensitivity to

* Corresponding author.
E-mail addresses: bayati.sh05@yahoo.com (Sh. Bayati), ma.tavanaie@yazd.ac.ir (M.A. Tavanaie).

https://doi.org/10.1016/j.jclepro.2017.12.038
0959-6526/

temperature degradation, it is necessary to enhance its dyeing and finishing treatment according to its properties in order to achieve the fiber with the best condition (Peters, 1975; and Suesat and Suwanruji, 2011). Suesat and Suwanruji, 2011 claimed thermal degradation of the PLA polymer during melt spinning can be prevented by addition of a thermal stabilizer. It was explained that the degradation reactions involved cleavage of the ester bonds on the main chain of the polymer (Jamshidi et al.). Due to the hydrophobic and non-polar nature, these fibers need to be dyed using disperse dye pigments (He et al., 2007; and Karst and Yang, 2005). He et al., 2007 have developed new hydrophobic anthraquinone dyes with high affinity for PLA as an alternative to the existing commercial disperse dyes. Several model dyes with hydrophobic chains were synthesized. Anthraquinone dyes containing an aliphatic chain exhibited higher exhaustion improvement compared to anthraquinone dyes containing an aromatic chain. This suggests that dyes that have a structure similar to PLA (aliphatic polyester) will have high affinity with PLA. Karst and Yang, proposed general structures for new disperse dyes, that could be made commercially for PLA fabrics and that may have high exhaustion on PLA. The authors stated that disperse dyes with solubility parameters close to that of PLA are mainly azo dyes. The solubility parameters of most of the anthraquinone dyes are not close to that of PLA. The authors claimed that anthraquinone dyes may have close solubility parameters to that of PLA if they contain only functional groups with an R group, which should be a large $-(CH2)nCH_3$ groups.

If PLA fiber is dyed under neutral or alkaline condition for a long time, the polymer will be hydrolyzed and consequently loses its strength. PLA fiber possesses many comparable properties to the conventional polyester, PET, but its thermal and alkaline sensitivities are inferior, therefore, milder processing conditions used in textile production are suggested for PLA. The hydrolysis mechanism of PLA was said to be strongly pH dependent and it was claimed to undergo bulk erosion under acidic and neutral conditions whereas under concentrated alkaline media, it was dominated by surface erosion (Suesat and Suwanruji, 2011). In appropriate dyeing conditions, there are a limited number of commercial disperse dyes with desirable exhaustion rate which can be applied for dyeing PLA fibers (Avinc and Khoddami, 2010; and Choi et al., 2007). Some researchers have studied on the dyeing behavior of PLA fibers with a wide variety of disperse dyes with 2% dyebath concentration at the temperature of 100–110 °C, in which 7 out of 9 studied disperse dyes have an exhaustion rate of 80% or more (Choi and Seo, 2006; Avinc and Khoddami, 2010). Choi and Seo, reported that the photostabilities of nitrodiphenylamine, monoazo, and anthraquinone dyes on PLA were very similar to those observed on PET apart from the case of one blue monoazo dye (C.I. Disperse Blue 284). Choi and Seo stated that the yellow and blue dyes were greener in hue on PLA than on PET, whereas orange/red dyes were yellower. Moreover, it has been shown that most commercial disperse dyes have an exhaustion rate more than 60% (Choi and Seo, 2006; Choi et al., 2010). Choi and Seo, stated dyebath exhaustion percentages following application to PLA of the 22 disperse dyes are. The extent of exhaustion varied widely within both the 'high light fastness' and 'diacetate' dye subsets. Choi, reported Monoazo dyes with N-alkylphthalimide ring systems fused to benzenoid diazo components have been applied to PLA as dispersions through exhaustion dyeing.

As mentioned above, recycling of PLA and converting it to a new product, instead of compost material or primary monomer is an economical and environmental solution. In the present study, the dyeing treatment of recycled PLA fibers has been performed for the first time by employing three different disperse dyes with different molecular weights (dyes molecular size) on recycled poly lactic acid (r-PLA) fibers at different temperatures, times and concentrations. According to the obtained results, the highest exhaustion rate on the r-PLA fibers was obtained and determined for a specific type of dye in a certain concentration. Furthermore, the wash and light fastness of the optimized samples were examined to control the color characteristics of the recycled poly lactic acid fibers for all three used disperse dyes.

2. Experimental

2.1. Materials

Bio-degradable PLA food packages were purchased from Cuptainers Co. (New Jersey, USA) with an average viscosity molecular weight of (M_v) 39518 (Tavanaie, 2014). Commercial disperse dyes of C.I. Disperse Red 167, C.I. Disperse Yellow 3 and C.I. Disperse Yellow 64 and Alovlan IS dispersing agent were used. Acetic acid (Merck) was used for adjusting the bath to a pH within the range 4.5–5.0. Triton X100 (Sigma-Aldrich) was used in washing solution for washing fastness evaluations. Characteristics of the three commercial disperse dyes are shown in Table 1.

2.2. Methods

2.2.1. Melt spinning

To prevent the r-PLA molecular chains from hydrolysis during hot temperature of the melt spinning, the PLA flakes were dried in a hot air oven at 80 °C for 14 h (Cicero and Dorgan, 2001). The r-PLA flakes were melt spun by using a laboratory LME single screw melt spinning machine (Dynisco, USA). The speed of spinning was 70 m/min and the extrusion temperature was adjusted at 190 °C for producing the r-PLA fiber samples. According to the design method of this device, the fiber samples are solidified in output distance through the spinneret to winding machine and winded on small coils at the end.

2.2.2. Drawing

The low oriented melt spun r-PLA fibers samples were drawn with a draw ratio of 1.8 using the tensile tester machine of the fibers made with Elima Co. (Iran). The fiber samples were cold drawn between the gauges of this machine. We tried to adjust the elongation-at-break of the drawn fibers at 30 ± 5% to convert them into fully drawn fibers.

2.2.3. Washing procedure

Poly(lactic acid) fibers samples were scoured using 2 g/L of a non-ionic surfactant, with a 20:1 liquor ratio at 60 °C for 10 min. After scouring, the fiber samples were rinsed with cold water and dried at room temperature. This process was done to remove the impurities derived from melt spinning.

2.2.4. Dyeing procedure

The r-PLA fibers stabilized were dyed using a laboratory dyeing machine (Datacolor, England). The r-PLA fibers were dyed at the temperature range of 80–110 °C, during zero (the first moment of reaching the maximum temperature of dyeing) to 120 min with 0.5–2% on the weight of fabric (o.w.f.) of disperse dyes. The dyeing was carried out by using a 2% dispersing agent at a liquor ratio of 60:1 and acetic acid for adjusting the pH of the bath according to Fig. 1. Strong alkaline conditions must be avoided during the PLA fibers dyeing and using carriers, levelers and defoamers is not recommended (Hussain et al., 2015). After dyeing, the r-PLA fiber was rinsed for 2 min using cold water and subsequently dried at room temperature. Each of the dyeing treatments was repeated at least two times for reputation confidence of the results.