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The dyeing of poly(lactic acid) fibres with disperse dyes using ultrasound: Part 1 – Initial studies

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ABSTRACT

Six disperse dyes were applied at 0.5%, 1% and 2% omf depths of shade to poly(lactic acid) fabric at 30–80 °C for 20, 50 and 90 min in both the presence and absence of ultrasound. Whilst ultrasound enhanced the colour strength obtained for three of the six disperse dyes used at temperatures upto 70 °C, ultrasound did not always result in enhanced colour strength being achieved in the case of the three other dyes. The observed intensification of colour strength was attributed to dye disaggregation. Dyeing at 80 °C in the presence of ultrasound resulted in pale, dull dyeings of reduced colour strength, which was attributed to breakdown of the dye dispersions at this particular temperature.

1. Introduction

Textile fibres made from the aliphatic polyester, poly(lactic acid) (PLA), which is derived from an annually renewable resource such as corn, resemble those obtained from their more famous relative, poly(ethylene terephthalate) (PET), in that they are dyeable with disperse dyes. However, the high temperatures (125/130 °C) that are normally used for the aqueous phase dyeing of PET with disperse dyes cannot be used for PLA because of its marked hydrolytic sensitivity and lower T_m (~170 °C compared to ~250 °C for PET); hence, dyeing conditions of 110–115 °C for 15–30 min at pH 4.5–5 are recommended for poly(lactic acid) [1,2]. Disperse dyes generally behave differently on PLA fibre than on PET fibre [1,3–5], displaying lower exhaustion [1,3,6], with dyeings being brighter [1], of higher colour yield [1,3] and with λ_{max} occurring at a shorter wavelength than on PET [1]. The low sorption of disperse dyes on PLA compared to PET has been explored [7] using solubility parameter concept [8] as well as molecular modelling [9]; several researchers have sought to maximise dye uptake onto PLA through the synthesis of specific disperse dyes [6,10–12].

Ultrasound, with a frequency above the upper limit of human hearing (>20 kHz), has been widely explored as a means of intensifying various wet textile processes, including dyeing, since ultrasound influences mass transfer processes within textile substrates by means of transient cavitation in the vicinity of the textile surface [13]. Several workers have reported that the use of ultrasound can have beneficial effects upon dyeing, resulting in lower dyeing temperatures, reduced dyeing times, increased colour yield and reduced consumption of dyeing auxiliaries. Whilst research interest has attended the dyeing of various substrates with ultrasound, including cotton [14–20], wool [21,22], silk [23,24], nylon [25–27], polyacrylonitrile [28], polyester [29–33] and leather [34–36], hitherto, the effects of ultrasound on the dyeing of poly(lactic acid) has not received attention. The purpose of this work was to determine whether ultrasound could be used to intensify the dyeability of PLA with disperse dyes and, at the same time, enable dyeings of adequate wet fastness to be obtained. This first part of the paper concerns the effects of ultrasound on the dyeing of PLA with disperse dyes; the second part of the paper will report the effects of ultrasound on the fastness of dyeings to both rubbing and repeated washing.

2. Experimental

2.1. Materials

Poly(lactic acid) knitted fabric (224.8 gm^{-2}), obtained from *NatureWorks LLC*, was scoured using 2 gl^{-1} Na_2CO_3 and 1 gl^{-1}

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Table 1
Dyes used.

Commercial name	C.I. Disperse	Energy level	Supplier
Foron Brilliant Red E-2BL 200	Red 60	low	Clariant
Foron Blue E-BL 200	Blue 56	low	
Foron Yellow SE-FL	Yellow 42	medium	
Foron Rubine S-GFL 150	Red 167:1	high	
Dianix Yellow Brown CC	none ascribed	medium	DyStar
Dianix Crimson SF	none ascribed	high	

Sandozin NIN (non-ionic surfactant; Clariant) using a 20:1 liquor ratio at 60 °C for 15 min. The scoured sample was rinsed thoroughly in tap water and allowed to dry in the open air. Commercial samples of the six disperse dyes shown in Table 1 were used without purification; the structures of only four of the dyes C.I. Disperse Red 60 (**I**), C.I. Disperse Blue 56 (**II**), C.I. Disperse Yellow 42 (**III**) and Disperse C.I. Red 167:1(**IV**) (Fig. 1) are disclosed in the Colour Index [37]. The dyes were selected for use on the basis that they provided two representatives of low, medium and high energy classes of disperse dye (Table 1). All other chemicals were of general laboratory grade supplied by Aldrich.

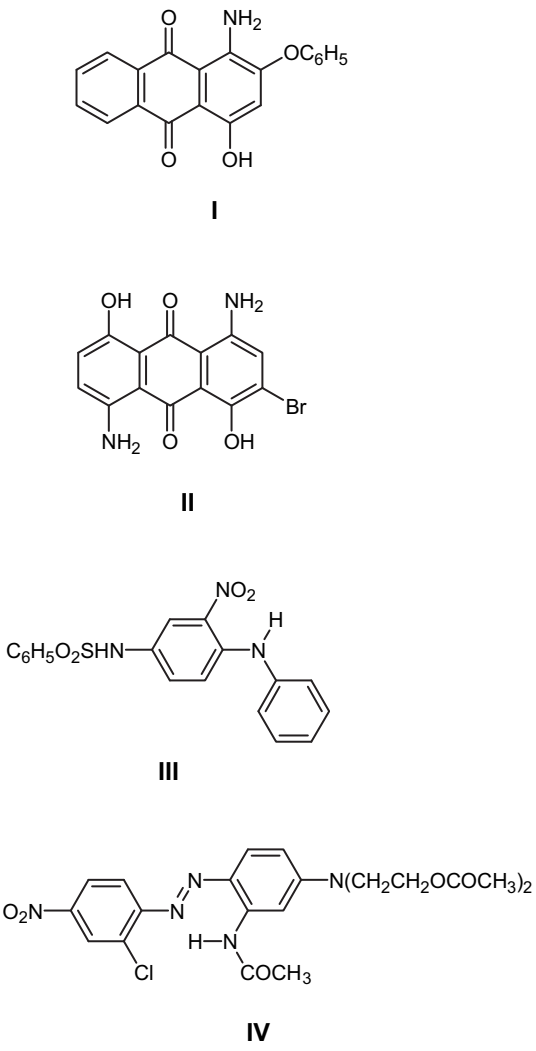

Fig. 1. Dye structures.

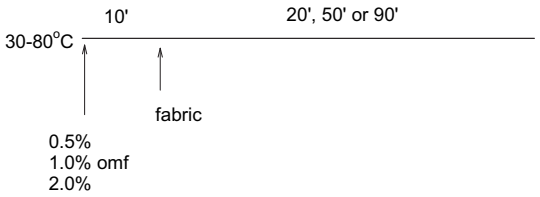

Fig. 2. Dyeing method.

2.2. Dyeing

PLA fabric was dyed at 0.5, 1.0 and 2.0% omf depths of shade, for 20, 50 and 90 min at 30, 40, 50, 60, 70 and 80 °C, in both the absence and presence of ultrasound, using a 100:1 liquor ratio in partially sealed glass dyepots of 250 cm^3 capacity housed in a Grant *OLS 200* laboratory scale shaker water bath using the method shown in Fig. 2; the pH was maintained at 4.5 using acetic acid/sodium acetate buffer. In the case of the ultrasound assisted dyeing, a Grant *MXB 22* (32–38 kHz; 300 W) ultrasound bath was employed. At the end of dyeing, the dyed samples were removed, rinsed in tap water and allowed to dry in the open air.

2.3. Colour measurement

The CIE L^* a^* b^* C^* and h° co-ordinates and the corresponding f_k values were calculated from the reflectance values for each dyeing, obtained using a *Datacolor Spectroflash 600* spectrophotometer under illuminant D_{65}, employing a 10° standard observer with UV component included and specular component excluded. The samples were folded so as to realise four thicknesses.

3. Results and discussion

The colorimetric data for 1% omf dyeings obtained for each of the six dyes at 30–80 °C, in both the absence and absence of ultrasound, are shown in Tables 2–7; for comparison purposes, the colorimetric data for the scoured, undyed fabric is shown in Table 2. For ease of discussion, the results obtained for C.I. Disperse Blue 56 (displayed in Table 2) will be used as an examplar. In terms of dyeing in the absence of ultrasound, Table 2 shows that, as might be expected, the depth of shade of the dyeings increased with increasing dyeing temperature, as evidenced by the decrease in lightness (L^* value) that accompanied an increase in temperature from 30 to 80 °C. This is also reflected in the corresponding colour strength (f_k values) of the dyeings (Fig. 3) from which it is evident that the increase in f_k that accompanied an increase in dyeing temperature was much

Table 2
Colorimetric data for C.I. Disperse Blue 56 (1% omf; 50 min).

Treatment	Temp./°C	L^*	a^*	b^*	C^*	h°	λ_{max}/nm
Undyed fabric	–	95.3	−0.1	0.6	0.7	94.6	400
Absence of ultrasound	30	85.1	−1.6	−6.6	6.8	256.6	620
	40	83.1	−1.6	−8.6	8.8	259.4	620
	50	81.3	−2.1	−11.0	11.2	259.4	620
	60	76.9	−2.1	−16.4	16.5	262.6	620
	70	70.3	−1.7	−23.2	23.2	265.8	620
	80	59.8	−0.6	−32.9	32.9	271.1	620
Presence of ultrasound	30	83.4	−1.5	−7.8	7.9	259.2	620
	40	82.9	−2.0	−9.0	9.2	257.7	620
	50	80.1	−1.9	−11.9	12.1	261.2	620
	60	73.8	−1.1	−18.1	18.1	266.7	620
	70	68.9	−1.2	−24.1	24.2	267.3	620
	80	63.4	−0.7	−30.1	30.1	268.8	620