

Polypropylene: Poly (Lactic Acid) Polyblend Fibres and their Dyeability and Structural Properties

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Abstract— Polypropylene (PP) based polyblend fibres with lower concentration of poly (lactic acid) (PLA) 2.5-10% are formed to modify fibre structure for inducing disperse dyeability and to understand the relationship between dyeability behaviour and structure-morphology of PP:PLA blend fibres. The structural changes in fibres were analyzed using wide angle X-ray diffraction, differential scanning calorimetry, thermal stability and tensile properties. The dyeability of polyblend fibres increased with increase in PLA content with good wash fastness and light fastness properties.

Key words: Polypropylene, Poly (Lactic Acid) Polyblend Fibres,

I. INTRODUCTION

Polypropylene (PP) fibres are termed as technical fibre due to its vast variety of usage in technical textiles. PP fibres exhibit a unique combination of excellent physical properties, ease of processability and cost [1]. The PP fibre structure exhibits better tensile properties, light weight and resistance to both chemical and biological agents. However, due to its highly crystalline structure and absence of reactive sites for dyeing, colouration of PP fibres is a challenge by conventional process.

PP fibres can be made disperse dyeable by forming polyblend fibres with polyester, nylon and polystyrene etc [2-4]. Polyblend fibres are formed by melt blending two or more different polymers prior to melt-spinning of fibres.

Among Polyester, poly (lactic acid) (PLA) has the same melting temperature range (T_{melt} 155-165°C) as that of PP, whereas, polyethylene terephthalate (PET), polybutylene terephthalate (PBT) and polytrimethylene terephthalate (PTT) need to be processed at much higher temperature. Studies on PP:PLA polyblend fibres formed using meltblending technique [5-8] and bicomponent fibre spinning [9] have been reported. However, the disperse dyeability behaviour of PP:PLA polyblend fibres for lower concentration of PLA addition (i.e. less than 10%) has not been studied extensively. The effect of PLA addition on polyblend fibres needs to be studied for understanding the processability, structure formation and its correlation with disperse dyeability.

In our previous work, disperse dyeable PP polyblend fibres have been studied by meltblending PP with PTT, PBT and cationic dyeable polyester (CDPET) [4,10]. In our present work, PP:PLA polyblend fibres were meltspun with 2.5, 5, 7.5 and 10% PLA additive concentration. The polyblend fibres formed were studied for their disperse dyeability behaviour and physical structural changes in terms of crystallinity, compatibility, thermal stability and mechanical properties.

II. MATERIALS AND METHODS

A. Materials

PP (Repol H350FG) chips, having MFI 35 were supplied by Reliance Industries Ltd, India. PLA (Ingeo biopolymer 6201D) having MFI 30 were supplied by NatureWorks LLC, USA. Disperse dyes (Dianix Blue ER, Dianix Yellow S-6E and Dianix Rubine S-2G 15%) were supplied by Dystar India Pvt. Ltd., Mumbai, India.

B. Fibre spinning

PP and PLA polymer chips were pre-dried in vacuum oven for 24 hrs and melt blended in twin-screw extruder (APV Baker, UK). The melt blended compounded chips were subsequently melt spun into fibres using laboratory-scale melt spinning machine (Fair Deal Associates, India). The temperatures of the extruder zones were kept 15-20 °C above the melting temperature of polyblend fibres. The spun filaments were subsequently drawn and wound on bobbins.

C. Dyeing of Fibres

The polyblend fibres were pre-scoured and disperse dyed in high temperature / high pressure beaker dyeing machine using standard technique of disperse dyeing [11]. The disperse dyed polyblend fibre samples were then subjected to reduction clearing treatment for removing unfixed dye.

D. Characterization of fibres

The disperse dyed polyblend fibre samples were evaluated for colour depth by computer colour-matching system in terms of Kubelka Munk function (K/S), using spectra flash SF 300 (Datacolor International, USA) [12]. Kubelka Munk function (K/S) is calculated using following equation:

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

Where, R is reflectance at complete opacity, K is the absorption coefficient and S is scattering coefficient. Colour fastness to washing was evaluated as per ISO 105-C10:2006 B and colour fastness to light was evaluated as per BS 1006 test method [13]. X-ray diffraction analysis was performed using powder technique on a XRD-6100 (Shimadzu, Japan). Crystalline orientation factor (fc) and amorphous orientation factor (fa) were calculated by Wilchinsky's method [14] and Stein-Norris method [15] respectively. The birefringence of fibre was calculated by retardation method using Berek compensator fitted in polarizing microscope [16].

The thermal behaviour and fibre crystallinity were studied using differential scanning calorimetry (DSC) (Shimadzu, Japan). The thermal stability of the samples was evaluated by performing thermogravimetric analysis (TGA) using DTG-60H thermogravimetric analyzer (Shimadzu, Japan). Tensile testing of filaments was carried out on tinus olsen tensile testing machine. The gauge length was 100 mm

and strain rate was kept at 50 mm/min and an average of 10 readings is reported.

III. RESULT AND DISCUSSION

A. Dyeability

The results in Table 1, given in terms of K/S values of disperse dyed PP:PLA blend fibres indicate that the disperse dyeability of fibres increased with increase in PLA content in the fibre. The increase in disperse dyeability can be attributed to formation of internal fibre structure more conducive for disperse dye diffusion and its retention. In general for all the three disperse dyes studied, the increase were in the range of a Values in bracket represent percentage increase in K/S values over that of pure PP 1330 to 1700 % indicating the enormous increase in disperse dyeability over that of virgin PP fibre.

The disperse dyed polyblend fibres were subjected to fastness evaluation and results are given in Table 2. Results show that wash fastness ratings are in the range of 3-4 and light fastness ratings are in the range of 4-5. Thus the polyblend fibres formed showed very good fastness ratings in comparison with that of the virgin PP fibres.

Fibre (PP:PLA)	Disperse Dyeing		
	Dianix Yellow S-6E ER	Dianix Rubine S-2G 150%	Dianix Blue ER
100:0	0.9116 (--)	1.2502 (--)	1.0862 (--)
97.5:2.5	2.6223 (187.6)	4.530 (162.3)	5.5101 (307.3)
95:5	7.4675 (719.2)	10.5124 (740.8)	11.907 (996.2)
92.5:7.5	11.1872 (1127.2)	14.10777 (1028.4)	16.27012 (1397.8)
90:10	14.1956 (1457.2)	17.9012 (1331.8)	19.6399 (1708.1)

Table 1: K/S values of disperse dyed polyblend fibres (shade 3%)

Fibre (PP:PLA)	Washing Fastness			Light Fastness		
	Dianix Yellow S-6E ER	Dianix Rubine S-2G 150%	Dianix Blue ER	Dianix Yellow S-6E ER	Dianix Rubine S-2G 150%	Dianix Blue ER

Fibre (PP:PLA)	Onset temp (°C)	Endset temp (°C)	Melting peak (°C)	Heat of melting (J/g)	Crystallinity (%)
100:0	161.34	171.81	169.23	134.7	64.45
97.5:2.5	160.88	171.16	167.3	124.49	59.56
95:5	159.16	170.38	165.36	116.28	55.64
92.5:7.5	157.52	169.73	164.65	105.08	50.28
90:10	155.16	168.88	163.32	98.6	47.18

Table 4: The melting behaviour data of polyblend fibres obtained from DSC analysis.

C. Thermal Analysis

Results of DSC analysis for PP:PLA polyblend fibres are given in Table 4. The polyblend fibres showed single melting peak. The melting point of both PP and PLA are in the same range and it also indicates that PLA has been uniformly

100:0	*	*	*	*	*	*
97.5:2.5	3	3	2	4	4	4
95:5	3	3	3	4	5	4
92.5:7.5	4	4	4	5	5	5
90:10	4	4	4	5	5	5

Table 2: Wash and light fastness properties of disperse dyed PP: PLA blend fibres

B. XRD Analysis

The X-ray diffraction plots of polyblend fibres shown in Fig. 1 and crystallinity values shown in Table 3 exhibit the influence of PLA on PP internal fibre structure formation. The presence of PLA, has led to formation of polyblend fibre structure with reduced crystallinity. The overall crystallinity, crystalline orientation (fc) and amorphous orientation (fa) has decreased with the increasing addition of PLA, thus making the fibres more accessible for disperse dyeing. This explains the radically improved disperse dyeability in the case of PP:PLA blend fibres.

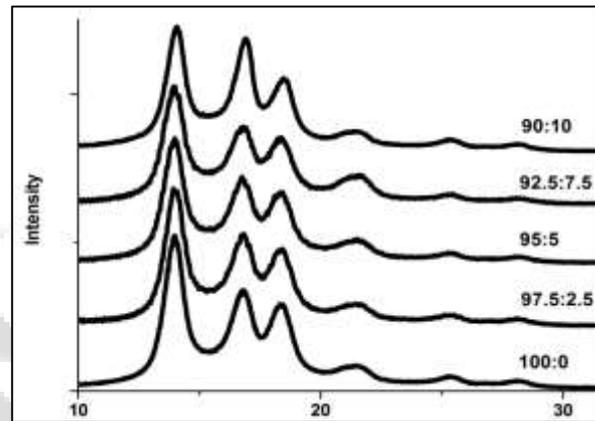


Fig. 1: X-ray diffractogram of polyblend fibres.

Fibre (PP:PLA)	Crystallinity (%)	Orientation	
		Crystalline	Amorphous
100:0	60.34	0.92	0.65
97.5:2.5	57.58	0.91	0.61
95:5	54.15	0.90	0.59
92.5:7.5	53.62	0.88	0.58
90:10	50.53	0.87	0.54

Table 3: X-ray crystallinity and orientation of polyblend fibres

distributed in the PP matrix. The presence of PLA has influenced the crystallization process during fibre formation, thus altering its structural properties. The melting peak of fibres shifted to lower values with the increase in PLA addition and subsequently reducing the extent of crystallization of PP. PP:PLA fibres formed showed overall

reduced crystallinity with open fibre structure formation, justifying improved disperse dyeability which follows diffusion mechanism.

D. Thermal Stability

The thermal stability of fibres assessed by thermogram is shown in Fig 2. The thermal stability of the fibres decreased in comparison to that of virgin PP fibres. The decrease in thermal stability of fibres could be attributed to the reduced crystallinity which leads to early onset of thermal degradation as seen from Table 5. However, the onset temperatures for degradation of polyblend fibres are much above the processing temperature of the fibres (above 350°C). Thus the polyblend fibres formed can be easily processed and applied for various applications.

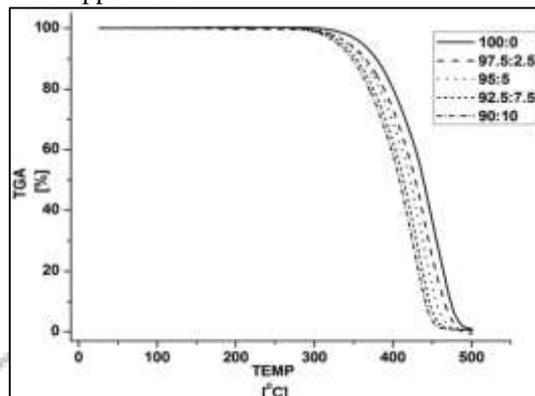


Fig. 2: Thermogravimetric analysis of PP: PLA polyblend fibres.

Fibre (PP:PLA)	Onset Temp (°C)	10% wt loss (°C)	50% wt loss (°C)	100% wt loss (°C)
100:0	394	398	444	481
97.5:2.5	384	396	432	479
95:5	373	381	420	460
92.5:7.5	370	376	406	452
90:10	359	365	397	443

Table 5: TGA derived decomposition temperatures and weight loss

E. Tensile Properties

Results in Table 6 show that tenacity values for polyblend fibres are lower in comparison with that of pure PP fibres. The reduced tenacity of the fibres could be attributed to reduced crystallinity, as well as crystalline and amorphous orientation factor as observed from the X-ray analysis and thermal analysis. Thus a balance has to be made between loss in tensile properties and phenomenal increase in disperse dyeability of fibres, as per our requirements.

Fibres (PP:PLA)	Tenacity (gf/d)	Elongation (%)	Strength Loss (%)
100:0	4.83	15.36	--
97.5:2.5	4.46	16.18	7.7
95:5	4.08	16.92	15.5
92.5:7.5	3.82	17.74	20.9
90:10	3.69	18.25	23.6

Table 6: Tensile properties of PP:PLA polyblend fibres

IV. CONCLUSION

Disperse dyeing of PP:PLA polyblend fibres is possible by conventional processing techniques. The presence of PLA has led to increase in disperse dyeability upto 1700 % and this behaviour could be attributed to polyblend fibres becoming more accessible by forming open structure due to reduced crystallinity. However, the reduced crystallinity resulted in slightly early onset of degradation temperature and reduction in tensile strength which was well within the acceptable limits. Hence, depending upon the requirement of dyeability, the proper PP:PLA blend could be selected so that one can control the loss in tensile strength, thermal sensitivity at the same time high degree of improved disperse dyeability with satisfactory fastness properties.

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