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Dyeing and finishing performance of different PTT/PET bi-component filament fabrics

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The dyeing and finishing performance of different bi-component polytrimethylene terephthalate/polyethylene terephthalate (PTT/PET) filament fabrics along with the elasticity of end-products have been studied. Three kinds of PTT/PET side-by-side bi-component filaments have been selected as weft yarn along with the polyester filament as warp yarn. Fabrics are then woven, dyed and finished under the same conditions. The weight reduction rate, widthwise shrinkage, elastic elongation and elastic recovery percentage of the above fabrics are observed to characterize the changes involved during the process. The results indicate that as denier per filament (DPF) increases, the weight reduction rate decreases but the widthwise shrinkage increases. The weight reduction rate decreases as the weft density increases. The elastic recovery decreases as the elastic elongation increases. Optical microscope, scanning electron microscope, different scanning calorimetry examinations show that due to the finer DPF and larger specific surface area, PTT/PET filament exhibits separation of the two components, due to the caustic corrosion during dyeing and finishing, and hence the high elasticity inherent in bi-component filaments is lost.

Keywords: Alkali de-weighting, Dyeing, PTT/PET bi-component filament, Weft density, Weight reduction rate

1 Introduction

The polytrimethylene terephthalate/polyethylene terephthalate (PTT/PET) side-by-side bi-component filament is a conjugated fibre manufactured by jetting and merging two melting polymers from the same spinneret[1,2]. The filament can form three-dimensional helical crimps like wool fibre due to differential shrinkage of PET and PTT components after certain dyeing and finishing process[3,4]. The most outstanding merit of PTT/PET bi-component filament is the stable and durable elasticity generated by the fully developed crimps[5,6]. The elastic elongation of bi-component filament fabric is superior to PTT and PET monofilament fabric and close to spandex fabric, but its elastic recovery rate is often better than that of spandex fabric[7]. It is found that PTT/PET filament made by different manufacturers has different volume ratio, cross-section shape, fineness, production processes[8-11], etc, which shows fabrics with different properties.

The present study was therefore aimed at investigating the performance of different PTT/PET bi-component filament fabrics during the same dyeing and finishing and the elasticity of their end-products. Therefore, three dominate PTT/PET bi-component filaments with the same fineness and similar specifications were selected as weft yarn. Three series of fabrics were woven with three weft densities, dyed and finished under the same process conditions. The properties of these nine PTT/PET filament fabrics after each dyeing and finishing process were explored.

2 Materials and Methods

2.1 Materials

Three commercially available PTT/PET filaments were selected for this study. The basic parameters of these filaments are listed in Table 1. These three PTT/PET bi-component filaments have the same total fineness but different numbers of monofilaments, cross-section shapes, volume ratios and production processes.

Three kinds of PTT/PET bi-component filaments as weft yarn and PET filament as warp yarn were woven with five heddle satin (5/2). The twist of warp yarn was 1300T/m and the weft yarn was untwisted. Three kinds of weft density were adopted in each kind of filament fabric and then nine kinds of fabrics were obtained. The parameters of grey fabrics are listed in Table 2.

2.2 Dyeing and Finishing

The PTT/PET filament fabrics were processed using the same dyeing and finishing conditions. The process

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Table 1—Specifications of different filaments

Filament	Structure	Fineness dtex	Monofilament number	Cross-section shape	Volume ratio	DPF
A	FDY	166.7	64	Pear-shaped	50/50	2.60
B	FDY		48	Dog-bond-shaped	50/50	3.47
C	DTY		72	Dog-bond-shaped	40/60	2.31

FDY–Fully drawn yarn; DTY–Draw texturing yarn; DPF–Denier per filament.

Table 2—Grey fabrics parameters

Fabric	Weft density ends/cm	Warp density ends/cm	Weaving width, cm	Fineness	
				Warp yarn, dtex/F	Weft yarn, dtex/F
Fabric A					
FA1	24	72	210	PET 166.7/48	166.7/64
FA2	27				
FA3	31				
Fabric B					
FB1	24	72	210	PET 166.7/48	166.7/48
FB2	27				
FB3	31				
Fabric C					
FC1	24	72	210	PET 166.7/48	166.7/72
FC2	27				
FC3	31				

used is as follows: grey fabrics→ scouring → shrinking → dyeing → heat setting.

Scouring—to remove the spinning oil, impurities and oil adhered while weaving preliminary, the fabrics were processed on the open-width scouring machine at 80°C for 2 min using 3g/L sodium hydroxide.

Shrinking—to get a better hand feeling, more alkali (NaOH) (16.7g/L) was used. Fabrics were treated at 130°C for 40 min and then acetic acid was added to neutralize at 50°C for 15 min.

Dyeing—the fabrics were dyed with disperse EXSNF Black in airflow cylinder at 130°C for 20min (Fig.1).

Heat setting—the fabrics were heat-set on the Sun-Super S Thermosetting Machine (I L Sung Machinery Co., LTD.) with the fabric speed of 32m/min at 195°C and 4.0% overfeeding.

2.3 Test Methods

The weight reduction rate and the elasticity of the finished fabrics were tested. Elastic elongation and recovery rate of the finished fabrics were measured by KES bi-axial tensile tester[12] and YG065H tensile instrument respectively according to Chinese standard FZ/T 01034—2008 (Test method of the tensile elasticity for woven fabrics). Both two methods fixed the tensile load and the maximum load was 25N. The results were the average of five samples. All the tensile tests were conducted at the constant temperature (20±2°C) and humidity (65±3%).

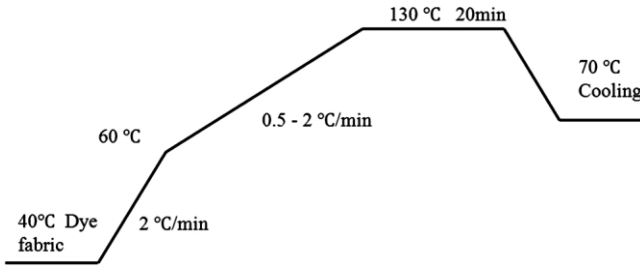

Fig. 1—Dyeing curve for PTT/PET bi-component filament fabrics

2.4 Fibre Cross-section Morphology

The cross-section slices of three kinds of PTT/PET filament before and after dyeing were cut by hardy's cross-sectional device (Y172), and the morphology of the cross-sections was observed by the optical microscope (LABOMED, Labo America, Inc. USA) and scanning electron microscope (Hitachi, SEM TM3000).

To identify the polymer in the filament, the weft yarn was measured by different scanning calorimetry (DSC, 204F1 TG209F1, Germany Netzsch Instruments Manufacturing Co., Ltd) and about 5mg samples were heated at a rate of 10°C/min under nitrogen from 40°C to 280°C.

3 Results and Discussion

3.1 Weight Reduction Rate

Weight reduction rate is the indication of fabric weight changes in the dyeing process which can be calculated using the following equation:

$$R = \frac{W_0 - W}{W_0} \times 100\% \quad \ldots (1)$$

where R is the weight reduction rate; W_0, the weight of grey fabrics; and W, the weight of finished fabrics.

Table 3 shows that the weight reduction rate decreases obviously with the increase in weft density. Fabrics with the larger weft density has smaller space between yarns, which cause less contact with alkali

Table 3—Weight reduction rate and the elasticity of nine fabrics

Fabric	Weft density ends/cm	DPF, detx/F	Weight reduction rate, %	Elastic elongation rate, %		Elastic recovery, %
				Method 1	Method 2	
			Fabric A			
FA1	24		35.41	48.56	47.38	76.07
FA2	27	2.60	30.25	46.24	46.97	78.90
FA3	31		27.26	40.68	40.36	81.30
			Fabric B			
FB1	24		32.61	46.13	44.30	77.14
FB2	27	3.47	28.37	41.52	40.10	79.59
FB3	31		24.44	36.37	34.73	82.98
			Fabric C			
FC1	24		37.35	11.95	8.93	80.77
FC2	27	2.31	33.21	11.80	8.47	81.36
FC3	31		27.58	11.78	8.35	84.76

Table 4—Width changes of fabrics after each dyeing and finishing process

Fabric	Weft density ends/cm	Width, cm				Width-wise shrinkage, %
		Weaving	Scouring	Shrinking	Dyeing	
			Fabric A			
FA1	24		173	118	116	39.58
FA2	27	192	174	118	114	40.63
FA3	31		173	115	115	40.10
			Fabric B			
FB1	24		167	127	117	40.31
FB2	27	196	167	118	114	41.84
FB3	31		167	115	111	43.37
			Fabric C			
FC1	24		169	148	146	23.16
FC2	27	190	169	148	147	22.63
FC3	31		165	134	148	22.11

during the dyeing and finishing process. So, the weight loss is smaller. It can also be seen from Table 3 that fabric C has the maximum weight reduction rate and fabric B has the least weight loss due to difference in their DPF (denier per filament). Table 3 shows that the weight reduction rate is closely related to DPF. When the filament has the same linear density, the fabric with lower DPF has a higher weight reduction rate. This is because when the DPF of filament is lower, its monofilament is thinner and its specific surface area (exposed to the alkali) is larger. So the filament with lower DPF is corroded more seriously by alkali, resulting in higher weight reduction rate.

3.2 Widthwise Shrinkage

There are many factors affecting the widthwise shrinkage, such as the materials properties, fabric constructions, and dyeing and finishing parameters[13]. In addition, mechanical tension and beating-up force[14] while weaving also play an important role. As a consequence, the fabric will contract slightly when taken away from the loom. But this is not enough to release the internal stress coming from the weaving process. Only after relaxation process under low tension in hot and humid environment, the internal stress in fabrics could be fully released and then the fabrics can shrink continuously and evenly. The widthwise shrinkage can be calculated using the following equation:

$$S = \frac{w_0 - w}{w_0} \times 100\% \quad \ldots (2)$$

where S is widthwise shrinkage; w_0, the width of the grey fabric; and w, the width of the dyed fabric. The width changes of 9 kinds of fabrics after each process are shown in Table 4.

Table 4 shows that all the fabrics shrink after heat treatment and the widthwise shrinkage after the shrinking process is largest. Fabrics in the scouring process contract slowly because the concentration of NaOH and treated temperature are lower, and besides, the fabrics move quickly in an open-width scouring machine. But in the shrinking process, fabrics are put in the hotter alkali liquor for a longer time. This is the optimal condition for PTT/PET filament to fully shrink. In this process the internal stress in PTT/PET filament is released and adequate crimps are developed. In the dyeing process, the widthwise shrinkage is not as large as that in the shrinking process in spite of the similar condition. This is due to the enough crimps developed.

The widthwise shrinkage rate of PTT/PET fabrics is found 20-40% and it changes as the weft yarn and weaving density are varied. Fabric B has the highest widthwise shrinkage, and the widthwise shrinkage rate could reach up to 43.37% when the weft density is 31 ends per cm. The widthwise shrinkage rate of fabric A is found about 39%, slightly lower than that of fabric B. This is because filament B has a higher DPF and there is more space between yarns for fabrics to crimp. Compared with other two kinds of PTT/PET fabrics, fabric C has the lowest shrinkage rate which is only 24.2%, as discussed hereunder.

Table 4 also shows that little changes in widthwise shrinkage occur as the weft density is varied. Generally, widthwise shrinkage rate has a great variation when weft density changes. This is because the space between yarns becomes narrow as weft density increases and there is less room for filament to crimp in hot and humid environment. However, in this study, there is little change of widthwise shrinkage as the weft density increases. In order to explore whether the weft density affects the widthwise shrinkage, one-way analysis of variance (Table 5) is employed. Firstly, assume that the average of widthwise shrinkage in different weft density is identical. As shown in Table 5, F-value is less than F crit. This indicates the acceptance of the assumption. Hence, there is no significant relationship between widthwise shrinkage and weft density. This might be because fabrics in the dyeing process shrink not so evenly and the heat-setting process after dyeing is necessary for PTT/PET fabrics. It may also be because of the fact that difference in weft density is too less.

3.3 Elastic Elongation and Elastic Recovery

There are two components with different thermal shrinkage disposed in one cross-section of PTT/PET filament, so three-dimensional helical crimps are developed under the hot and humid conditions which offer PTT/PET fabrics the exceptionally good stretch. Due to their different cross-section shapes and DPF, the elasticity of PTT/PET filaments with the same fineness is different after the same dyeing and finishing processes. In this study, two methods are adopted to test the elasticity of fabrics, one is the KES bi-axial stretching method (Method 1) and the other is the resistance to repeated extension method (Method 2). Because the weft yarns are flexible, the relationship between weft density and the elastic elongation is studied.

Table 3 shows that the elasticity of fabric A and B is excellent; their elastic elongation rate being over 40%. The elastic elongation of fabric A is higher than that of

Table 5—One-way analysis of variance

ANOVA variable	Sources of various	Sums of squares	Degrees of freedom	Mean square	F-value	Fcrit
Widthwise shrinkage and weft density	Weft density	1.203	2	0.601		
	Error	681.696	6	113.616	0.0053	5.14
	Total	682.899	8			
Elastic elongation and weft density (Method 1)	Weft density	0.0119	2	0.0596		
	Error	0.0016	6	120.00	44.06	5.14
	Total	0.0135	8			
Elastic elongation and weft density (Method 2)	Weft density	0.0230	2	0.0115		
	Error	0.0015	6	0.00013	89.30	5.14
	Total	0.0245	8			
Elastic recovery percentage and weft density	Weft density	33.385	2	19.193		
	Error	21.325	6	3.554	5.40	5.14
	Total	59.710	8			

fabric B, although fabric B has larger widthwise shrinkage. This might be attributed to the different spinning process. The elastic elongation rate of fabric C is the smallest (11.8%).

One-way ANOVA analysis (Table 5) shows that weft density has a significant effect on the elastic elongation. The elastic elongation rate decreases dramatically with the rise of weft density as shown in Table 4. As the weft density increases, the interlacing between yarns in fabrics increases and hence yarns are packed tightly. Therefore, it is difficult for yarns to slip when stretched, and the elastic elongation becomes worse.

The two adopted methods are different. For the bi-axial stretching method, the elongation in the warp direction remains unchanged when the weft fabric is stretched. But in the repeated extension method, there is no control in the warp fabric. The results of the two methods are found consistent and the elastic elongation values are approximately the same. Linear fitting method is employed to analyze the relationship between the elastic elongation rates measured by the two methods. The fitting equation is y=1.088x-4.342, where y is the elastic elongation measured by Method 2 and x by Method 1. The linear fitted coefficient R^2 is found to be 0.997. This is because the elasticity in warp fabrics is very small and the warp shrinkage is much lower when stretching the weft fabric under fixed load. The result indicates that both methods are able to measure the tensile property of fabrics with unidirectional elasticity.

From Table 4, it is found that the elastic recovery percentage increases with the increase in weft density. One-way ANOVA analysis (Table 5) shows that weft density has a significant effect on the elastic recovery percentage. The root cause lies in the strong negative correlation between the elastic recovery and the elastic elongation. Therefore, with the increase in the weft density, the elastic elongation rate decreases and the elastic recovery percentage increases.

3.4 Alkali Treatment

3.4.1 DSC Test

The above results show that fabric C has the largest weight reduction rate and the lowest widthwise shrinkage, significantly different from other two kinds of PTT/PET filament fabrics. Generally, properties of PTT/PET filaments with the same fineness but different spinning process are not remarkably different. Analysis suggests that there are two possible reasons. One possible reason is that filament C has a larger surface area and contacts more alkali in the shrinking process. Therefore, it is seriously corroded and its structure changes. Another possible reason is that due to the use of other filaments as weft yarn in weaving fabric C is distinct from other two PTT/PET fabrics.

Differential scanning calorimetry (DSC) is employed to further identify whether the wrong weft yarn has been used. The DSC result shows that there are two obvious melting peaks in Fig. 2. One peak at 222.1°C shows the existence of PTT component and the other peak at 251.7°C indicates the PET component. The DSC result confirms that the weft yarn is indeed PTT/PET bi-component filament and it is strong alkali treatment which causes the distinct performance of fabric C.

3.4.2 Microscope Image

Figures 3-5 show the cross-sections of three PTT/PET filaments before and after dyeing. The differences in cross-sections of filament C before and after dyeing are apparently distinct. The cross-sections of dyed filament have a uniform color, some are darker and others lighter (different fibres have

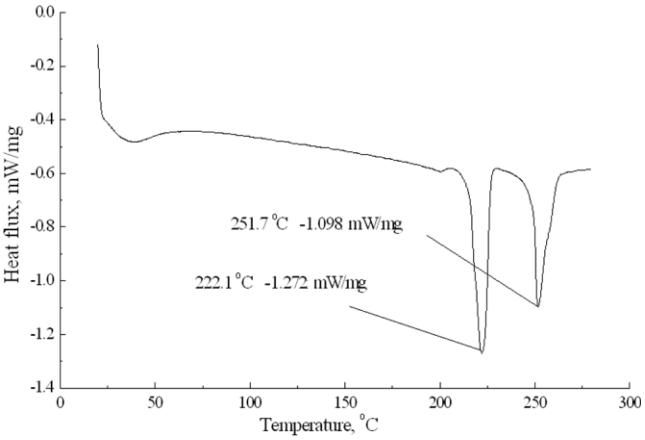

Fig. 2—DSC curve of filament C

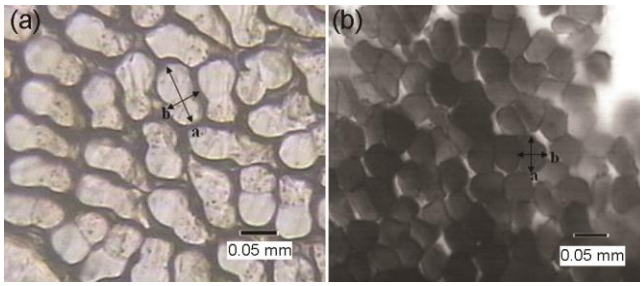

Fig. 3 —Cross-sectional view of filament C, before dyeing (a) and after dyeing (b)

distinct color absorption). There is no obvious interface between the two components. Due to its lower DPF, filament C cannot afford the strong alkali treatment and two components might be divided into two separated parts. Filament C is no longer side-by-side bi-component filament, and hence the structure of helical crimp and excellent elasticity is lost. The darker component is supposed to be PTT and the lighter one should be PET as shown in Fig.3 (b). While filaments A and B still remain side-by-side in the structure, their properties remain unchanged [Figs 4(a) & (b) and Figs 5(a) & (b)].

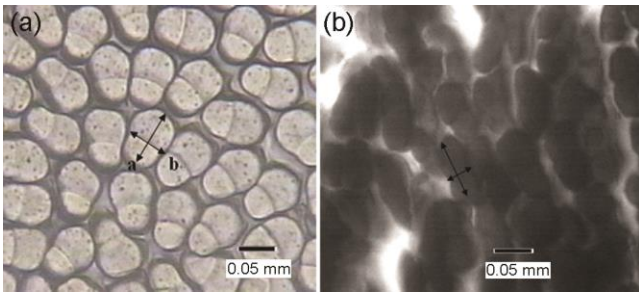

Fig. 4—Cross-sectional view of filament A, before dyeing (a) and after dyeing (b)

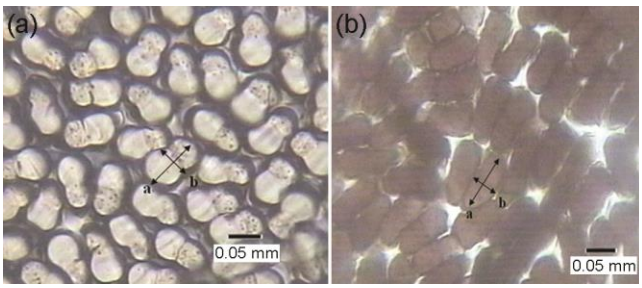

Fig. 5— Cross-sectional view of filament B, before dyeing (a) and after dyeing (b)

3.4.3 SEM Image

Figure 3 (b) shows that the two components of filament C might be divided into two parts after the strong alkali treatment, but the images of optical microscope are not so clear. SEM image (Fig. 6) further confirms that the cross-sections of filament C show the clear separation after the strong alkali treatment.

In Fig. 6 (a), two components could be seen in the cross-section, but in Fig. 6(b), the bi-component cross-sections are rarely seen. Although there are several unbroken cross-sections, there is a great crack in their interface. The two components separate clearly with the increase in alkali concentration. This fully proves that due to its smaller fineness, two components of filament C separate by the excessive alkali treatment and then the helical crimps of filament C are lost. In consequence, fabric C has a larger weight reduction rate and smaller widthwise shrinkage. The separation of the two components along the interface is also related to the spinning process. The earlier the two melting polymer fluids are met, the more difficult is their separation.

This phenomenon is similar to the shrinking splitting technology of citrus shaped fibre[15, 16]. Under the condition of high temperature, shearing force generates in the two or more components with the different thermal shrinkage and makes these components to separate when the shearing force is large enough. This approach could be applied to the fibres with a great difference of components to produce ultrafine fibres. But PTT and PET components have similar monomers and it is difficult for the two components to be separated currently. This study shows that the two components of PTT/PET side-by-side bi-component filament can be separated under the certain conditions.

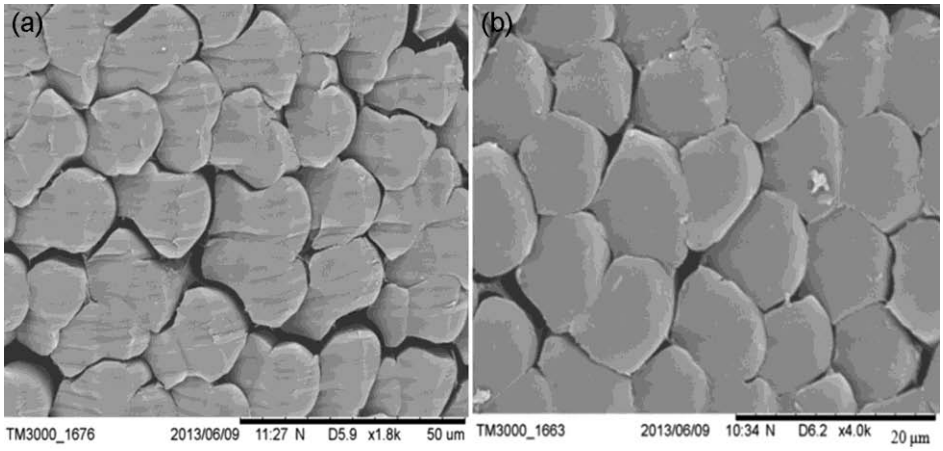

Fig. 6—SEM images of filament C, before dyeing (a) and after dyeing (b)

4 Conclusion

4.1 Under the same dyeing and finishing process, fabrics woven by different PTT/PET bi-component filaments have different properties. PTT/PET filament fabrics with higher DPF have a lower weight reduction rate but higher widthwise shrinkage. Because the thinner monofilament has a larger specific surface to access more alkali and loses more weight. The thinner monofilament has less space between yarns and then the widthwise shrinkage of its fabric is lower.

4.2 During all the dyeing and finishing processes, the widthwise shrinkage of PTT/PET bi-component filaments in the shrinking process is the largest. To control the widthwise shrinkage of fabrics, it needs to adjust the parameters of this process primarily.

4.3 Generally, three series of PTT/PET bi-component filaments have less difference in elasticity. The elastic elongation rate of fabric A is slightly higher than that of fabric B. As the weft density increases, the elastic elongation rate of fabrics becomes lower and elastic recovery percentage keeps rising.

4.4 Both methods of the KES bi-axial stretching and the resistance to repeated extension are able to measure the tensile property of fabrics with unidirectional elasticity.

4.5 The two components of PTT/PET bi-component filament C separate and lead to the poor elasticity when its fabric loses too much weight during the dyeing and finishing process. PTT and PET components can be made to produce ultrafine fibre like citrus shaped fibre under certain conditions.

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