THE EFFECT OF KNITTING PARAMETER AND FINISHING ON ON ELASTIC PROPERTY OF PET/PBT WARP KNITTED FABRIC

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Abstract:

This study investigated the elastic elongation and elastic recovery of the elastic warp knitted fabric made of PET (polyethylene terephthalate) and PBT (polybutylene terephthalate) filament. Using 50/24F PET and 50D/24F PBT in two threading bars, the tricot, locknit and satin warp knitted fabrics were produced on the E28 tricot warp knitting machine. The knitting parameters influencing the elastic elongation under 100N were analyzed in terms of fabric structure, yarn run-in speed and drawing density set on machine. Besides, dyeing temperature and heat setting temperature/time were also examined in order to retain proper elastic elongation and elastic recovery. The relationship between elastic elongation and knitting parameter and finishing parameter were analyzed. Finally, the elastic recovery of PET/PBT warp knitted fabric was examined to demonstrate the elastic property of final finished fabric. This study could help us to further exploit the use of PET/PBT warp knitted fabric in the development of elastic garment in future.

Keywords:

Warp knit, elastic, PBT, elongation, recovery.

1. Introduction

Elastic knitted fabric was widely used in sportswear, underwear or seamless garment. Generally, elastic yarns like spandex, core-spun yarn using spandex, PU (poly urethane)/PA (Nylon), PTT (polytrimethylene-terephthalate) were used in the plating structure of weft knitted fabric. Pure spandex was mainly used in the production of warp knitted elastic fabric due to its smooth yarn structure. But spandex has some disadvantages such as poor dyeing property, water absorption and sun resistance. Besides, the durability and strength was affected by sunshine, chlorine and ageing. PBT filament had 100% chlorine resistant.

Much research was conducted on the elastic knitted fabric using various elastic yarns. Verdu et al. compared the DOW XLA fiber of a core spun yarn with elastic PBT fiber in woven polyester/cotton fabrics used for professional wear end use. [1] The effect of inlay yarn pretension at the time of manufacturing of stretch fabrics on the pressure generated by the garments was studied. [2] Results show that change in inlay pre-tension significantly changes the structural characteristics of the fabric, but the load elongation behavior remains unchanged up to 100% extension. Serkan et al. have studied the 44dtex spandex and Ne 30/1 ring spun cotton yarn loop length value (loose, medium and tight) on the fabric weight, density, thickness, bursting strength, air permeability of cotton/spandex half plating single jersey knitted fabrics. [3] 210D textured nylon yarn along with 20D covered spandex filament yarn was used as elastic inlay yarns in single jersey for the production of pressure garments. [8] Das et al. studied the interaction effect of elastane stretch, proportion of elastane core and twist multiplier on low stress mechanical

properties of the woven fabrics made of stretchable elastane-cotton core-spun yarns. [10] The physical and dimensional properties of single jersey fabrics made from cotton sheath-elastomeric core spun – were investigated. [17] The effect of stitch length, relaxation and machine washing treatments on flexural stiffness of core spun cotton/spandex weft knitted structures in single jersey, 1x1 rib and interlock under were studied. [15]

The plating elastic weft knitted fabrics were widely investigated. Zhou et al. studied the full plating elastic XLA (30D and 40D)/Coolmax (75D/72f) single jersey knitted fabric. [4] Wang et al. examined the dynamic pressure attenuation of elastic knitted plain and rib fabric in different plating ratio of spandex (2.22 tex). [5] Zhao et al. developed the plating single jersey seamless garments using the 50D polytrimethylene terephthalate (PTT)/polyester (PET) bi-component filament. When compared with polyurethane (PU)/polyamide (PA) core-spun yarn (20/30D), it had better extensibility and elastic recovery property. [6] Manishahia et al. studied the effect of filament shape factor and fabric constructional parameters on thermophysiological comfort of the elastane-plated fabrics intended to be used in high active sportswear. [9] Gokarneshan et al. studied the 20tex polyester/spandex core air-covered high-stretch yarn that was used to produce single-jersey fabrics with different loop length. [7] Spandex-plated cotton fabric and spandex core cotton spun (SCCS) fabric were also investigated. [14]

Some properties related to the comfort of elastic fabric were studied. Thermo-physiological comfort of the compression athletic wear was studied. [11] Onofrei investigated the effect

of moisture on the thermal comfort properties of single jersey knitted fabric made of Outlast® and PolyesterCoolmax® plated with elastane (Creora®) 77 dtex.[12] Air permeability variations of core spun cotton/spandex single jersey and 1×1 rib knitting structures were studied under the relaxation treatments.[16]

Although there were some experimental studies on spandex weft knitted fabric, little work has been done on the effect of structure, knitting parameter such as yarn run-in speed, drawing density set on machine, dyeing temperature, heat setting temperature and duration on elongation of PET/PBT warp knitted fabric. This paper presents a study about the warp knitting parameters that are important to the physical elastic elongation and elastic recovery of warp knit. The relationship and significance correlation analysis have been carried out.

2. Sample

2.1 PBT filament

PBT yarn [50D/24F DTY (Draw texturing yarn)] and PET yarn [50D/24FFDY (Fully Drawn Yarn)] were used in this study. They were supplied by Sinopec Yizheng Chemical Fibre Company Limited in China. Table 1 lists the physical specification of PBT and PET yarn (tested by YG063T Changling®).

Table 1. The physical specification of PBT yarn

	Count	Filament number	Breakage tension (cN/Tex)	Initial modulus (cN/Tex)	Elongation at breakage (%)	Boiling water shrinkage (%)
PBT	50D	24	30.2	123.1	26.9	20.1
PET	50D	24	33	36.6	10.8	3

Table 2. Factors and levels included in fractional factorial design of experiment

Level/Factor	Factor A Drawing density	Factor B Structure		Factor C Material arrangement
Level 1	12			GB1-PET GB2-PBT
		GB1:1-0/1-2//	GB2:1-2/1-0//	
Level 2	16			GB1-PBT GB2-PBT
		GB1:1-0/2-3//	GB2:1-2/1-0//	
Level 3	20			GB1-PBT GB2-PET
		GB1: 1-0/3-4//	GB2: 1-2/1-0//	

2.2 Knitting

E28 tricot warp knitting machine was used to knit the PET/PBT fabric. Orthogonal experiment was designed to examine the three factors such as the knitting structure, material arrangement and drawing density set on machine on the elasticity properties and three levels for each factor. The three levels of drawing density set on machine were 12, 16 and 20 CPC (course per centimeter). The three structures were tricot, locknit and satin. The material PBT filament was arranged for GB1, GB2 or both GB1 and GB2. Table 2 summarizes the details of orthogonal experiment. Table 3 shows the orthogonal array of 9 experiments.

The effect of drawing density set on machine on elastic elongation under 100N

After the orthogonal experiment, suitable knitting structure and yarn arrangement (locknit structure; GB1 is PET, GB2 is PBT) were determined to further study the effect of knitting parameter on elastic elongation. Six different drawing densities set on machine (16, 18, 20, 22, 24 and 26 CPC) were selected to examine its effect on the elastic elongation under 100N. Consequently, the yarn run-in speed were varied according to the drawing density set, while keeping the yarn tension at 3-6.3 cN. The corresponding yarn run-in speed of GB1 and GB2 is listed in Table 4.

Table 3. The orthogonal array of 9 experiments

Sample No	A	B	C
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	2
9	3	3	1

The fabric loop density at weft and warp directions and weight after the hot water washing are shown in Table 4. When the drawing density set on machine increased from 16–26 CPC, the washed fabric density increased dramatically at warp direction from 26 to 35 CPC, but not significantly at weft direction ranging from 19–20 CPC. The knitted fabric density has a greater impact on shrinking characteristics after the knitting process.[18] The increase of drawing density set on machine results in the increase of fabric weight ranged from 175–192g/m² gradually.

Table 4. Different CPC on machine, yarn run-in speed, yarn tension and fabric density, weight after hot water washing

Course per centimeter on machine (loop/cm)	Yarn feeding speed (mm/rack)		Yarn tension on machine (cN)		Density(after washing) (loop/cm)		Weight(g/m ²) (after washing)
	GB1	GB2	GB1	GB2	CPC	WPC	
16	1430	1300	4.8	3.5	19	26	175
18	1390	1250	3.8	3	19	28	177
20	1360	1170	4.7	3	20	30	178
22	1320	1120	5.2	4	19	32	180
24	1280	1080	5.8	5	20	34	185
26	1260	1060	6.3	5	20	35	192

Table 5. Fabrics knitted at 20 CPC on machine, yarn run-in speed, yarn tension and fabric density, weight after washing

Course per centimeter on machine (loop/cm)	Yarn feeding speed (mm/rack)		Yarn tension on machine (cN)		Density(after washing) (loop/cm)		Weight(g/m ²) (after washing)
	GB1	GB2	GB1	GB2	CPC	WPC	
20	1320	1120	7.8	4.7	21	30	192
20	1320	1170	5.5	2.5	19	31	183
20	1320	1220	4.5	0	19	32	181
20	1360	1120	6	4.5	21	30	182
20	1360	1170	4.7	3	20	30	178
20	1360	1220	3	2	21	29	176
20	1400	1120	5	3.5	20	29	177

The effect of yarn run-in speed on elastic elongation under 100N

After the examination of drawing density on machine, the fabrics knitted at 18–20 CPC on machine obtained the highest elongation. Hence, different yarn run-in speed was tested under fabrics produced at 20 CPC on machine. When keeping GB1(front threading bar) at 1320mm/rack or 1360mm/rack, the GB2(back threading bar) varied at 1120, 1170 and 1220 mm/rack. When keeping GB2 1120mm/rack, the GB1 varied at 1320, 1360 and 1400mm/rack. As shown in Table 5, an increase in draw-ratio of elastic yarn led to an increase in stitch density and fabric weight.[19]

Dyeing

In order to examine the effect of dyeing temperature on the elastic elongation of fabric, three dyeing temperatures (130°C, 135°C and 140°C for 30min) were selected to treat the PET/PBT warp knitted fabric. LA2002A IR dyeing machine (Rapid®) was used to conduct the dyeing process. The detailed ingredients were disperse dye (1%), high temperature leveling agent (3ml/l), dispersing agent (1ml/l). Bath ratio is 1:10.

Dye process (as shown in Figure 1):

1. From 20°C to 90°C for 15 min
2. From 90°C to 120°C for 30 min

3. From 125°C to 130°C/135°C/140°C for 15min
4. Retain 130°C/135°C/140°C for 30min
5. From 130°C/135°C/140°C to 80°C for 30min

After that, the fabric should be washed with NaOH (2g/L) at 80°C for 10min at 1:30.

Figure 1. Dyeing process

Heat setting

The four levels of temperature and three levels of duration time of heat setting were selected to treat fabrics. The continuous dryer Mini-Tenter (Rapid®) was used to conduct the heat setting process. The temperatures are 145°C, 155°C, 165°C and 175°C, while the duration times are 40s, 45s and 50s.

2.3 Test

According to Chinese standard FZ/T 70006 (stretch and recovery testing method for knits), a constant-rate-of-extension (CRE) type tensile testing machine (YG026C, Changyi Fangyi®) was used to measure the fabric elastic elongation under certain tension and elastic recovery at certain percent elongation at repeated cycle testing. The specimen is 200mm*50mm (length* width). The testing distance is 100mm at length and 50mm at width.

Table 6. The elongation testing condition

Fabric width	Testing distance	Loading speed	Unloading speed	Pre-tension	Tension
50mm	100mm	100mm/min	100mm/min	1N	100N

Table 7. The elastic recovery testing condition

Item	Setting parameter
Extension percentage	10%, 30%, 50%
Fabric width	50mm
Testing length	100mm
Loading speed (unload speed)	100mm/min
Unloading speed (unload speed)	100mm/min
Repeated cycles	1, 3, 5
Extension time	1 min
Relaxation time	3min

The elongation under 100N

The testing condition of elongation under 100N tension is listed in Table 6. The specimen was extended at 100mm/min speed, and returned at 100mm/min speed to zero tension. The elongation of fabric was recorded by the tester. The fabric was given 1N pre-load. Every specimen was tested 3 times for the calculation of average at both weft and warp directions.

The elastic recovery property

Since human body movement expands the skin by 10 to 50% at different parts, [22] the elastic recovery at 10%, 30% and 50% extensions at 1, 3, 5 cycles were measured. The fabric was stretched to 10% extension at 100mm/min speed, and was held at this extension for 1 min, and then the tension was unloaded at 100mm/min to the original position for 3 min relaxation, and after that the fabric was reloaded 1N to measure the length of elongation. The whole process for 10% extension for 1 cycle is presented above. Additionally, the testing cycle was repeated for 3 and 5 cycles separately for 10% extension. 30% and 50% extensions for 1 cycle, 3 cycles and 5 cycles stretch were tested using the same process. The final elongation and percentage of elastic recovery were recorded corresponding to 10%, 30% and 50% extensions. Every specimen was tested 3 times for calculation of average at both weft and warp direction. The testing parameters are listed in Table 7. The equation of elastic recovery is demonstrated in Eq 1.

$$\text{The elastic recovery}(\%) = \frac{L_{01} - L_0'}{L_{01} - L_0} \times 100\% \quad (\text{Eq 1})$$

L_0 —fabric length when loaded pre-tension (mm)

L_0' —fabric length after test when loaded pre-tension (mm)

L_{01} —fabric length*(1+ percentage of extension) (mm)

3. Results and discussion

The effect of knitting parameters on extension property

The analysis of the experiment is reported in Table 8. The R value indicates that the level of influence of the three factors is $C > A > B$ for sum of warp and weft direction. The optimum extraction condition is predicted to be A1B1C2. This is because if the fabric structure is loose, it is easy to stretch to a large extent. PBT was used in two needle bars for factor C at level 2; the high stretchability is highest due to the presence of 100% PBT. Locknit (factor B at level 2) was determined to be a better structure to knit elastic fabric.

Table 8. The values of extracted and range analysis for the orthogonal array of 9 experiments

Sample No	A	B	C	Elongation under 100N (Warp+Weft)
1	1	1	1	386.33
2	1	2	2	413.03
3	1	3	3	258.6
4	2	1	2	401.1
5	2	2	3	260.93
6	2	3	1	226.47
7	3	1	3	207.5
8	3	2	2	222.34
9	3	3	1	275.57
K1	1057.96	994.93	835.14	
K2	888.50	896.30	1089.70	
K3	705.41	760.64	727.03	
k1	352.65	331.64	278.38	
k2	296.17	298.77	363.23	
k3	235.14	253.55	242.34	
R	117.52	78.10	120.89	

Table 9. The relationship between elongations in weft /warp direction and CPC on machine

	Regression equation	R ²	significance
Y ₁ : elongation in weft direction	$Y_1 = -6.5967x + 237.97$	0.9737	P=0.000<0.05
Y ₂ : elongation in warp direction	$Y_2 = 0.0934x + 105.36$	0.0018	P=0.0936>0.05

Note: x—density(CPC) set on machine

The effect of drawing density on elastic elongation under 100N

Figure 2 illustrates the increase of drawing density on machine (CPC) results in the decrease of elongation at weft direction. When density varied from 16 to 18 CPC, the elongation at weft direction was larger than that at warp direction. When density increased from 20 to 26 CPC, the reverse trend was found. Furthermore, the decrease at weft direction was much larger than the increase at warp direction.

When the drawing density set on machine was 16 CPC, the elongation reached the highest value at 131.62cm at weft direction, while there was 102.75cm at warp direction. In general, the balance point of elongation between weft and warp direction was found at 18 or 20 CPC for drawing density set on machine. Consequently, the drawing density set on machine can be selected from 18 to 20 CPC on E28 tricot machine.

Figure 2. The fabric elongation under different CPC on machine

The linear regression is given in Table 9. The relationship between elongation in weft direction and density set on machine is negatively, highly and significantly related ($Y_1 = -6.5967X + 237.97$, $R^2 = 0.9737$, $P = 0.000$). The elongation in weft direction linearly decreased as the density increased. But there is no relationship between elongations in warp direction ($R^2 = 0.0018$).

The effect of yarn run-in speed on elastic elongation under 100N

After the examination of drawing density on machine, at 18–20 loop/cm densities on machine, relatively balanced elongation was obtained at both weft and warp direction. Hence, different

yarn run-in speeds were tested under 20 CPC (course per centimeter) on machine. The yarn run-in speed of GB1 (front threading bar) and GB2 (back threading bar) varied to examine its effect on the elastic elongation of fabric under constant density (CPC).

When keeping the yarn run-in speed of GB1 at 1320 mm/rack, the increase of GB2 yarn run-in speed from 1120 to 1220 rack/mm resulted in the increase of elastic elongation at warp direction. But, the elongation at weft direction did not show this trend. Warp elongation increased from 104.16 cm to 124.97 cm, while weft elongation decreased from 110.34 cm to 98.03 cm (see Figure 3). The sum of elongation at weft and warp direction reached the highest value (226.62 cm) under 100N tension.

The relationship between the elongation and the run-in speed of back threading bar has been examined in Table 10. When the front threading bar (GB1) yarn run-in speed is kept at 1320 mm/rack, an increase in the yarn run-in speed of back threading bar (GB2) increased the warp elongation ($Y_2 = 0.2081X - 131.31$, $R^2 = 0.8625$), but not significantly ($P = 0.242 > 0.05$). There was no relationship found between the run-in speed of back bar with weft elongation ($R^2 = 0.3337$).

When the yarn run-in speed of GB1 is 1360 mm/rack, the increase of run-in speed of GB2 from 1120 mm/rack, 1170 mm/rack, to 1220 mm/rack decreased the elongation at weft direction dramatically, while the elongation of warp direction did not differ much (see Figure 4). The highest balanced elongation for the combination of GB1 and GB2 (1360:1170) was found with weft direction at 126.32 cm and warp direction at 115.88 cm respectively. This evidence is different when GB1 is kept at 1320 mm/rack. This may be because the yarn tension

of GB1 and GB2 are not controlled to be exactly same when GB1 is supplying yarn at 1360 or 1320 mm/rack.

When keeping yarn run-in speed of front threading bar at 1360 mm/rack, the relationship between run-in speed of back threading bar and weft elongation is negatively related ($Y_1 = -0.3219x + 493.46$, $R^2 = 0.7934$). There is a positive relationship between yarn run-in speed of back threading bar and warp elongation ($y = 0.0537x + 51.654$, $R^2 = 0.8313$). However, the linear regression is not significant, as indicated by high P values in Table 11 ($P = 0.300 > 0.05$, $P = 0.269 > 0.05$).

When keeping the yarn run-in speed of GB2 constant at 1120 mm/rack and varying the run-in speed of GB1 from 1320 mm/rack, 1360 mm/rack to 1400 mm/rack, warp elongation increased from 104.16 cm to 124.97 cm, while weft elongation decreased from 110.34 cm to 98.03 cm. When the yarn run-in speed of GB1 and GB2 were retained at 1360 mm/rack and 1120 mm/rack, it not only balanced the two directions of elongation but also reached the highest elongation in both directions (128.19 cm and 111.1 cm) among this group of run-in speed (see Figure 5).

As listed in Table 12, the weft and warp elongation was weakly related with the run-in speed of front threading bar due to low R^2 values ($R^2 = 0.3034$ for weft, $R^2 = 0.4399$ for warp). It demonstrated that PBT yarn run-in speed constant at back threading bar will determine the elongation of PET/PBT warp knitted fabric. It is found that the weft and warp elongations were influenced more by the back threading bar than the front threading bar. It is because the PBT filament threaded in back bar, which is dominated by the elastic property of PET/PBT warp knitted fabrics.

Figure 3. The fabric elongation under 1320 mm/rack run-in speed of GB1

Figure 4. The fabric elongation under 1360 mm/rack run-in speed of GB1

Table 10. The relationship between elongations in weft /warp direction and GB2 yarn run-in speed

	Regression equation	R ²	significance
Y ₁ : elongation in weft direction	Y ₁ = -0.1231x + 253.23	0.3337	P=0.608>0.05
Y ₂ : elongation in warp direction	Y ₂ = 0.2081x - 131.31	0.8625	P=0.242>0.05

Note: X—the yarn run-in speed of GB2 when yarn run-in speed of GB1 is 1320 mm/rack

Figure 5. The fabric elongation under 1120 mm/rack run-in speed of GB2

The effect of dyeing temperature on elongation under 100N

The heat treatment temperature had an impact on proportional extensibility and shrinkage ratio of spandex.[20] The Figures 6 (a) and (b) demonstrate the elongation results of dyed fabric at 130°C, 135°C and 140°C for different drawing density on machine. It is found the fabric dyed at 140°C shows the lowest elongation. It means that the higher temperature will destroy the elastic elongation of the PET/PBT warp knitted fabric. Generally, the highest value was found at 130°C for majority of fabric density.

The relationship between drawing density and temperature and elongation was negatively correlated (see Table 13). The higher fabric drawing density and higher dyeing temperature can be associated with elongation.

The effect of dyeing temperature on elastic recovery

The higher temperature also impacts the elastic recovery of PET/PBT warp knitted fabric. As shown in Figures 7 (a) and (b),

the fabric treated at 130°C mainly had higher elastic recovery test ed under 30% extension for 3 cycles stretch, for majority of densities expected at 16 CPC. It is because the fabric at 16 CPC had a much looser structure and higher temperature caused high fabric shrinkage. As the treatment temperature increased, the extensibility increased proportionally to the standard length of sample and the shrinkage ratio in the direction of course and

(a)

(b)

Figure 6. The fabric elongation under different dyeing temperature for 16-26 CPC

Table 11. The relationship between elongations in weft /warp direction and GB2 yarn run-in speed

	Regression equation	R ²	significance
Y ₁ : elongation in weft direction	Y ₁ = -0.3219x + 493.46	0.7934	P=0.300>0.05
Y ₂ : elongation in warp direction	Y ₂ = 0.0537x + 51.654	0.8313	P=0.269>0.05

Note: x—the yarn feeding speed of GB2 when yarn feeding speed of GB1 is 1360 mm/rack

Table 12. The relationship between elongations in weft /warp direction and GB1 yarn run-in speed

	Regression equation	R ²	significance
Y ₁ : elongation in weft direction	Y ₁ = 0.1231x - 47.877	0.3034	P=0.629>0.05
Y ₂ : elongation in warp direction	Y ₂ = -0.1818x + 348.81	0.4399	P=0.538>0.05

Note: x—the yarn feeding speed of GB1 when yarn feeding speed of GB2 is 1120 mm/rack

Table 13. The relationship between the elongation and dyeing temperature and density set on machine

	Regression equation	R ²	significance
Y ₁ : elongation in weft direction	Y ₁ = -3.124X ₁ - 1.079X ₂ + 325.923	0.772	0.000
Y ₂ : elongation in warp direction	Y ₂ = -2.523X ₁ - 0.813X ₂ + 279.155	0.862	0.000

X₁— density; X₂— temperature

wale increased.[20] The fabric structure will become dense, and then the elastic recovery will increase within certain range.

(a)
Figure 7. The elastic recovery under 30% extension for 3 cycles stretch for 16-26 CPC

(b)
There is no linear correlation between fabric recovery and temperature/density(CPC) set on machine (see Table 14). However, it is found that when the density is kept around 20 CPC, it will result in relatively high and balanced recovery (82.95% and 83.65% for weft and warp direction, respectively). The higher elongation does not associate with higher elastic recovery. In Figure 7, the fabric with 16 CPC shows highest elongation, but in Figure 8, it demonstrates the low elastic recovery due to its loose structure.

The effect of heat setting on elongation under 100N

The heat setting process like heat setting duration time and temperature is an important factor to influence the elastic property. In this study, 4 levels of temperature were applied at 145°C, 155°C, 165°C and 175°C for each heat setting time. In addition to this, 3 levels of heat setting duration time were applied at 40s, 45s and 50s for each temperature. . Before

heat setting, the washed fabric had 128.32cm and 115.88cm elastic elongation under 100N tension.

As shown in Figures 8 (a) and (b), when the fabric was treated at 145°C, the elongation under 100 N had the highest values among 4 levels of temperature, whatever was the duration time selected for both weft and warp directions. It was also observed that when the duration time increased from 40s to 50s, the elongation under 100N at weft and warp directions had an inclined trend expect the weft direction at 145°. It is proved that the long heat setting duration will damage the elasticity of PBT filament. In general, fabric treated at 145° at 40s and 45s had better balanced elongation at weft and warp directions (Elongation_{weft} = 106.22cm, Elongation_{warp} = 123.66cm at 40s; Elongation_{weft} = 102.32cm, Elongation_{warp} = 128.25cm at 45s).

(b)
Figure 8. The elongation under different heat setting temperature and duration time

For fabric after hot water wash, the weft elongation was larger than warp elongation. And for dyed fabric, it was the same observation. However, after heat setting, the weft elongation was smaller than the warp elongation. It might be that during heat setting, there was external tension to stretch the fabric

Table 14. The relationship between the recovery and dyeing and density on machine

	Regression equation	R ²	significance
Y ₁ :recovery in weft direction	Y ₁ =-0.322X ₁ -0.290X ₂ +124.077	0.150	0.297
Y ₂ :recovery in warp direction	Y ₂ =-0.311X ₁ -0.2X ₂ +111.824	0.203	0.182

X₁-density;X₂-temperature

width slightly. It was concluded that any stretch at heat setting process will destroy the elastic elongation of PBT fabric.

The relationship between elongation and temperature and duration time was analyzed (see Table 15). High temperature and long duration time of heat setting significantly diminished the elongation of PET/PBT fabrics to different extent due to high R^2 values ($R^2_{\text{weft direction}}=0.915, P<0.000$; $R^2_{\text{warp direction}}=0.844, P<0.000$)

The elastic recovery property of final finished fabrics

The elastic property not only includes the elongation at certain tension but also elastic recovery, which determines the dimensional stability of elastic garment. Hence, the PET/PBT warpknitted fabric was examined in terms of elastic recovery after repeated stretch at different extension ratios. After the fabric was dyed in 130°C for 30 min, and heat setting at 145°C for 40 s, the finished fabric was tested to examine the elastic recovery. The elongation under 100N of this fabric is 142.63cm at weft direction and 108.28 cm at warp direction.

Figures 9 (a) and (b) indicate that the elastic recovery at 1 cycle was higher than 3 and 5 cycle repeated stretch generally. That is because the fabric was stretched at low cycle, which affects the elastic recovery at limited extent. But when 3 and 5 cycles were compared, the 5 cycles at 10%, 30% and 50% extension had higher recovery than 3 cycles at weft direction, and similar at warp direction.

For 3 cycles and 5 cycles, the recovery at 30% extension was highest among three extension levels. It was found in Mani's study[21] that recovery increased from 20% to 30% extension after 10 cycles stretch, while it decreased from 40% and 50% in both weft and warp direction. Fabric extension from 10% to 30% may cause only loop deformation, which may not affect the residual energy of the spandex.[21] But the fabric at extensions from 30% to 50% resulted in yarn stretch from its loop structure and at this extension level, the spandex in the fabrics reduced its residual energy.[21]

However, there is no such finding for 1 cycle extension. It might be for 1 time extension; the tension only stretched the loop structure into initial balanced stage. During normal wear, the garment will be stretched for more than 1 cycle. The value of recovery after repeated stretch is more important. The highest recovery is 83.39% for weft direction and 79.35% for warp direction at 30% extension for 5 cycles stretch.

Figures 10 (a) and (b) show the final elongation after 1, 3 and 5 cycles stretch at 10%, 30% and 50% extension. For weft

direction, the shortest value (112.3cm) was observed at 30% extension for 5 cycles stretch. For warp direction, the shortest value (103.7 cm) also was found at 30% extension but for 1 cycle stretch. 3 cycles stretch had the highest values both in weft and warp directions, no matter at what extension. Although the recoveries at weft and warp directions were similar, the final elongation at weft direction after repeated test was higher than that at warp direction.

Stress at Specific Extension

Analysis of stress imposed for the applied extension is important to study the pressure between the body and garment. The higher the stress value, the higher the skin strain. The stress values of the fabrics for applied extension levels are given in Figure 11.

Figure 9. The elastic recovery after recovery test under 10%, 30% and 50% for 1, 3 and 5 cycles

Table 15. The relationship between the elongation and heat setting temperature and duration time

	Regression equation	R^2	significance
Y_1 : elongation in weft direction	$Y_1 = -0.376X_1 - 0.807X_2 + 239.99$	0.915	0.000
Y_2 : elongation in warp direction	$Y_2 = -0.923X_1 - 0.803X_2 + 111.824$	0.844	0.000

X_1 – duration time; X_2 – temperature

In general, the fabric stress values for applied extensions in warp direction are higher than that of stress values in weft direction. At 10% extension, the 1N should be applied to stretch the fabric. At 30% stretch, 3.5N should be applied at weft direction, 8N at warp direction. At 50% extension, 13N and 29N should be loaded on the fabric.

(a)

(b)

Figure 10. The elastic elongation after recovery test under 10%, 30% and 50% for 1, 3 and 5 cycles

Figure 11. The stress values of the fabrics for applied extension levels

4. Conclusions

Elastic knitted fabrics were widely used in active sportswear due to their stretch property. PET/PBT warp knitted fabric had 100% chlorine resistance when compared with spandex fabrics. In order to achieve the desirable stretch, this paper investigates the effect of knitting parameter on the elastic elongation of

warp knitted fabric. Besides, the dyeing temperature, heat setting temperature and heat setting duration time was studied to achieve better elastic elongation and recovery. The high shrinkage effect of the filament should be taken into consideration at the knitting stage to make sure that the finished product has the correct size and weight. These results provide a better understanding of the characteristics of PET/PBT warp knitted fabric, and its elastic elongation and recovery behavior for development and effective applications.

Further study should be conducted to examine other wearing properties, such as heat and moisture comfort, pressure comfort and fabric physical property for different end usage. It is needed to extend the investigation to garment pressure on human body, as well as to analyze the deformation of human body under the balanced biaxial stretchability, which simulates the real application state of elastic knitted fabric pressure and compression.

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