

Effect of Fibre Cross-sectional Shape on the Properties of POY Continuous Filaments Yarns

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(Received October 1, 2011; Revised June 5, 2012; Accepted June 6, 2012)

Abstract: There are various structural parameters (number of filament, cross-sectional shape, linear density, etc.) determined during the production of synthetic fibre and these parameters influence product features. Among these parameters, cross-sectional shape of fibres has a significant importance. Desired features can be added to the products by varying the cross-sectional shape and in this way; new products with improved features or with high added value can be produced. As a consequence, studies on this subject have increased recently. In this study, the effects of different cross-sectional shapes and yarn linear density on the features of polyester partially oriented yarn (POY) have been investigated. Five different cross-sectional shapes named round, trilobal, tetra, hexsa and octolobal and two different linear densities have been used in the study. Tenacity-elongation and unevenness tests have been applied onto yarns. As a result of the study, it was seen that round, tetra and octolobal cross-sectional shapes lead to production of yarn with high tenacity and breaking elongation while trilobal and hexsa leads to production of yarn with low tenacity. In addition, due to its deep-channelled structure, hexsa cross-sectional shape led to POY yarn structure with a high unevenness rate. It was also seen that an increase in the rate of linear density decreased the tenacity and breaking elongation rates of yarn and reduced POY unevenness.

Keywords: Polyester POY, Fibre cross-section, Tenacity, Breaking elongation, Unevenness

Introduction

Polyester (PES) has a highly important place among synthetic fibres. The importance of PES stems from both the indispensable features it adds to products (high tenacity, resistance to sunlight, etc.) and its widespread, easy and cheap production technology. The amount of production of PES fibre across the globe between 2009 and 2010 rose by 5.3 % compared to the previous year and reached 31.9 million tones. 19.3 million tones of this amount is composed of filament yarn while 12.6 million tones of it is comprised of staple fibre [1]. It is considered that this increase in PES fibre production, as in other synthetic fibres, is both due to the increasing world population and the increase in the demand for products with functional features. Various development studies are carried out in the process of production regarding the functional features which are aimed to be added to PES. Titles such as producing products with new features by using fibres with different cross-sectional structures, production of coloured filament from polymer, preparing a basis for micro and nano-fibre production can be listed as examples of these development activities.

It is known that a change in fibre cross-sectional shape has an important effect on the features of fabric such as feel, mechanical feature, comfort, etc. In a study carried out in 1993, Matsudaira et. al. investigated the effect of fibre cross-sectional shape on fabric mechanical features and feel. Eight different cross-sectional shapes were used in the study and the effect of the factor of cross-sectional shape on basic mechanical features of fabric such as breaking strength,

flexural rigidity, tear strength and compressibility and feel was examined. As a result, they discovered that cross-sectional shape and fibre fineness has an important effect on the mechanical features of fabric [2]. In a study in 2000, Bozdoğan examined the effect of fibre cross-sectional shape on the aesthetic appearance of textile material. As a result of the study, it was emphasized that the parameter of cross-sectional shape has an effect on the gloss, slickness, silky touch, etc. of textile products [3]. In a study carried out in 2004, Bueno *et al.* searched the effect of different fibre cross-sectional shapes on the surface features of knit fabric. In the study, the friction features of knit fabric structures were evaluated and the effect of cross-sectional shape factor and linear density values on knit fabric slickness-friction behaviours was revealed [4]. In a study which was carried out in 2008 by Tascan and Vaughn, the effects of cross-sectional shape and linear density parameters on the acoustic insulation feature of nonwoven textures was investigated. It was concluded that the two parameters have an effect on the sound insulation of nonwoven surfaces. Nonwoven surfaces with fine numbered fibres provided better insulation than those with thick numbered fibres. In addition, nonwoven surfaces with 4DG (deep grooves) and trilobal cross-sectional shapes provided better insulation than surfaces with round cross-sectional shapes [5].

We see that studies in this area have been continuing in recent years. Varshney et. al. carried out an extensive study on this subject in 2010. As a result of the study, it was seen that the increase in fibre linear density and the non-circularity of the cross-sectional shape (trilobal and tetrakelion) led to an increase in fabric porosity and thickness. The increase in linear density value and the fact that the cross-

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sectional shape was trilobal and tetrakelion led to a decrease in thermal conductivity. In addition, it was concluded that the increase in linear density and the non-circularity of the cross-sectional shape made the air permeability of fabric increase. More unique effects were observed in scalloped oval cross-sectional shapes [6]. In a study carried out in 2011, Varshney *et al.* investigated the effect of fibre fineness and cross-sectional shape factors on yarn and woven fabric features. In the study, polyester and viscose fibres were used as raw material. In addition, four different cross-sectional shapes as circular, trilobal, tetrakelion and scalloped and various fibre fineness were used. It was seen that increasing fibre fineness provided the formation of fabric with higher compressibility and that non-circular cross-sectional shapes led to the formation of less fine fabric with lower compressibility. Trilobal and tetrakelion yarns provided fabric output with high formability. It was seen that fabric obtained from scalloped oval cross-sectional shape has low rigidity and formability but high flexibility. In addition to these, it was concluded that fabric woven from high denier and trilobal, tetrakelion cross-sectional shaped yarns has higher flexural strength than scalloped oval cross-sectional shaped fabric [7].

When these studies are examined, it is seen that structural parameters of synthetic fibres affect product features to an important degree. Among these parameters, fibre cross-sectional shape, the number of filament forming the yarn and linear density value are the most prominent one in terms of degree of effect. It is known that especially the cross-sectional shape affects the feature of the product to be obtained to a significant degree. For instance, while trilobal cross-sectional shape is preferred for the output of glossy products;

hollow cross-sectional shape is preferred to obtain products with warm feel. As there are standard cross-sectional shapes world-wide, studies are continuing on the new fibre cross-sectional shapes shown in Table 1 [8].

In this study, based on different cross-sectional shapes and linear density values, the effect of these factors on the structure and features of PES POY (partially oriented yarn) yarns has been examined. Five different cross-sectional shapes (round, trilobal, tetra, hexsa and octolobal) and two different linear density values (133 and 283) have been used in the study, keeping all other production parameters constant.

Material and Method

Material

In this study, PES POY, which has an important place and an extensive area of use among synthetic yarns, has been used as material. Details on these yarns have been provided in Table 2.

There are two different yarn groups in the study with 34 and 47 filaments. The first group of yarns has round, trilobal, tetra and octolobal cross-sectional shapes while the second group has round, hexsa and octolobal cross-sectional shapes.

Method

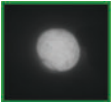
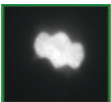
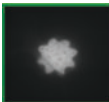
PES POY fibres have been produced according to melt spinning principle. During the production process, all other parameters except for the factors whose effects were aimed to be investigated (cross-sectional shape and linear density) were kept constant (Table 3).

Before investigating the effect of cross-sectional shape and linear density factors on the features of yarns, various

Table 1. Examples of specialized cross-section [8]

Trade mark	Producer	Cross-section	Basic technology	Specialities of the product
Solo Sowaie®	Asahi Chemical Industries Ltd.		Hollow, triangular, thick and thin	Higher bending stiffness, mild color
Fontana µ®	Asahi Chemical Industries Ltd.		W-shaped, self crimping	Bulky, crispy, dry and cool hand
Soielise N®	Kanebo Ltd.		Pentagonal cross section	Mild luster, dry hand and water-absorbent
Vivan®	Kanebo Ltd.		U-shaped cross-section, thick and thin.	Mild luster, dry, spun-yarn like and bending stiffness
Deforl®	Kuraray Ltd.		Flat cross-section, self-crimping	Deep color, bulky and higher bending stiffness
MSC®	Unitika Ltd.		Arrow-like cross-section.	Dry and cool hand
Mixy®	Unitika Ltd.		Random and multi-shaped cross-section	Dry hand, natural appearance, higher bending stiffness

Table 2. Properties of the yarns used in this study

Yarn linear density (dtex)	Group no	Number of filament	Cross-sectional shape	POY cross-sectional shape	
283	1	34	a. Round		
			b. Trilobal		
			c. Tetra		
			e. Octolobal		
	2	47	a. Round		
			d. Hexsa		
			e. Octolobal		
133	1	34	a. Round		
			b. Trilobal		
			c. Tetra		
			e. Octolobal		
	2	47	a. Round		
			d. Hexsa		
			e. Octolobal		

tests were applied onto the yarns for the control of the parameters which need to be kept constant during production. Yarn cross-sectional shapes were examined with Microtome Leica branded/model microscope (Figure 1). In addition, filament yarns were scrutinized under microscope for control of number of filament. DT (Draw Tension) level detection tests of POY fibres were carried out with Draw Tension Instrument Device according to ASTM D 5344-99, 2005 tests standard [9]. Finish material amount tests on POY yarns were carried out with Oxford MQA 7020 Device according to BS 3582 test standard [10].

After these tests which were applied with the purpose of

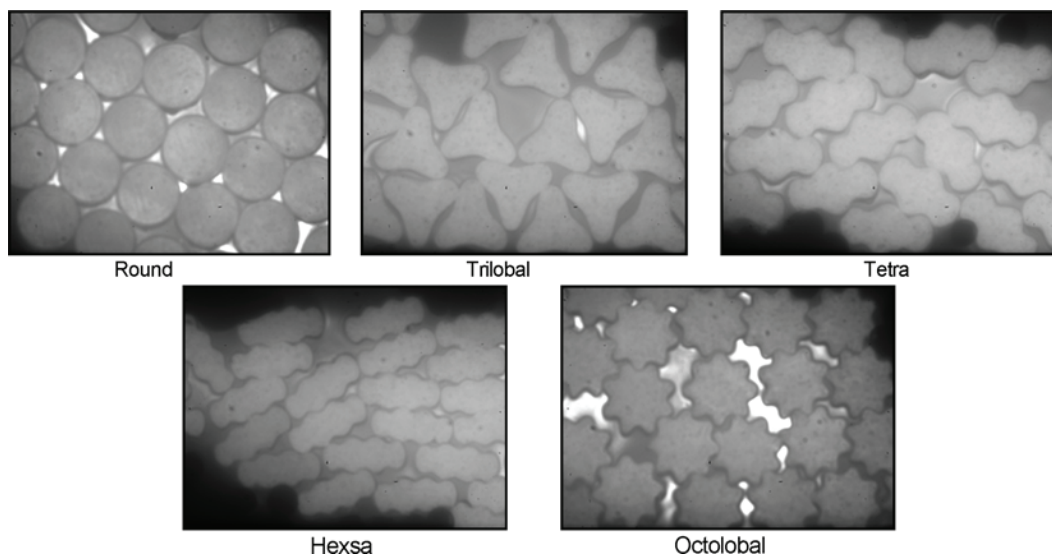
Table 3. POY production parameters

POY	
Flow speed of air-quench (m/sn)	60
The amount of lubricant (%)	0,3
Godet 1 speed (m/min)	2900
Pressure at intermingling (bar)	4
Godet 2 speed (m/min)	2880
DT (Draw Tension) Value-cN	96 (283 dtex)
	50 (133 dtex)

control, various tests were implemented upon yarns to investigate factor effects. Yarn samples were conditioned for 24 hours at 20 ± 2 °C temperature and 65 ± 2 % relative humidity, which are the standard atmospheric conditions.

To determine the effect of cross-sectional shape and linear density parameters on yarn features, tenacity-elongation and unevenness tests were applied on POY yarns which were taken as basis of the study. Tenacity-Elongation Tests were carried out with Uster Tensorapid-3 Test device according to BS EN ISO 2062, 1995 test standard and POY unevenness tests were carried out with Uster Unevenness Measurement device according to DIN 53817-1 test standard [11,12]. While tenacity and breaking elongation tests were applied to POY yarns at 200 mm length, unevenness tests were applied to POY yarns at 100 m length. The tenacity, elongation and unevenness tests made in the study were repeated six times for each yarn and the values obtained were averaged. In other meaning, six tests for each samples were performed during experimental studies of tenacity, elongation and unevenness.

The effects of cross-sectional shape factor on the characteristics of POY filament yarns were statistically analyzed

**Figure 1.** Cross-sectional shapes of yarns used in the study (X500 magnification).

by using the general linear model-university method. The statistical study was carried out at a reliability level of $\alpha = 0,05$.

Experimental Results

Tenacity and Breaking Elongation

The first group of test results in this study is comprised of 34 filament and round, trilobal, tetra and octolobal cross-sectional shaped yarns. The results obtained from the tenacity and breaking elongation tests applied onto POY yarns have been graphically shown in Figures 2 and 3. As can be seen, when both yarns were examined, tenacity and breaking elongation values of POYs produced with trilobal cross-sectional shape structure were found to be lower than those with other cross-sectional shapes and highest values were observed in yarns with round cross-sectional shape. In addition, as a general distribution, it is seen that tenacity and breaking elongation values decline in all cross-sections when linear density values rise from 133 dtex to 283 dtex.

The second group of the study is composed of 47 filament and round, hexsa and octolobal cross-sectional shaped POY yarns. Results obtained by examining the effect of cross-sectional shapes and linear density values of these yarns on tenacity and breaking elongation have been interpreted with graphics (Figures 4 and 5). When results are examined, it is seen that POY yarns produced with hexsa cross-sectional shape in this group have the lowest tenacity and breaking elongation values while yarns with round and octolobal cross-sectional shapes have high tenacity and breaking elongation values. Similarly, tenacity and breaking elongation values of yarns in this group tend to fall with the increase in linear density. Also, as the significance level of the tenacity results was found as 0,000 and that of the breaking elongation results was found as 0,005 at a reliability level of $\alpha = 0,05$, it was concluded that the effect of cross-sectional shape variable on the tenacity and breaking elongation of POY filament yarn is statistically significant.

In both yarn groups used in the study, high tenacity and breaking elongation values were detected in round cross-sectional shaped yarns. It was seen that tenacity and breaking elongation values of yarns with multi-channelled cross-sectional shapes such as hexsa were low. Therefore, it can be argued that round cross-sectional shape is ideal for yarn with high tenacity and breaking elongation values. For features of yarn with hexsa cross-section, it can be interpreted that multi-channelled structure makes the yarn less resistant to breaking. In addition, the fact that octolobal cross-section structure is similar to round cross-section enabled octolobal cross-section to exhibit features that are close to round cross-sectional shaped yarns. It is known as a result of research carried out that the change of tenacity in the polyester yarns under the effect of cross-sectional shape factor results from the change in individual fiber tenacity. A study carried out

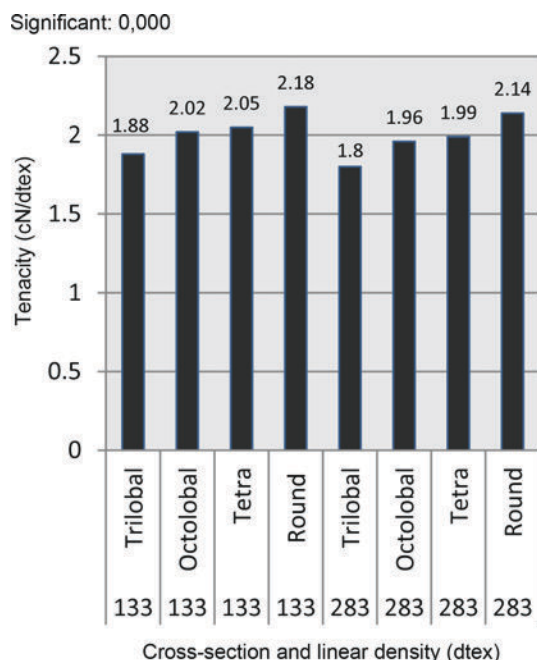


Figure 2. Effect of cross-section and yarn linear density on POY's tenacity.

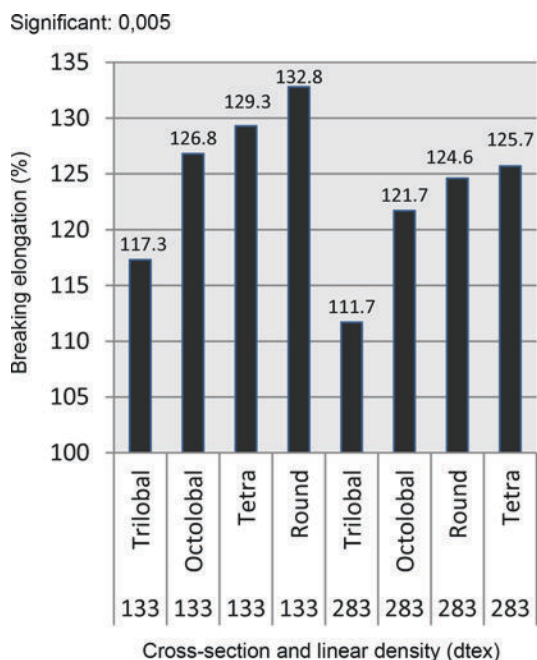


Figure 3. Effect of cross-section and yarn linear density on POY's breaking elongation.

by Varshney *et al.*, 2011, on this subject, it was concluded that fiber cross-sectional shape forming polyester yarn affects individual fiber tenacity value [7]. It was concluded that the tenacity values of the two fibers with the same length and linear density values in the circular and trilobal cross-sectional shapes used in the study were different. A

similar situation is also valid for scalloped oval and tetrakelion cross-sectional shapes. As a result of these investigations, it was concluded that the change in polyester yarn tenacity results from a change in individual fiber tenacity. It is also thought that the interaction among filaments affect yarn tenacity but no relevant tangible information has been yet reached. As the significance level of the tenacity results was

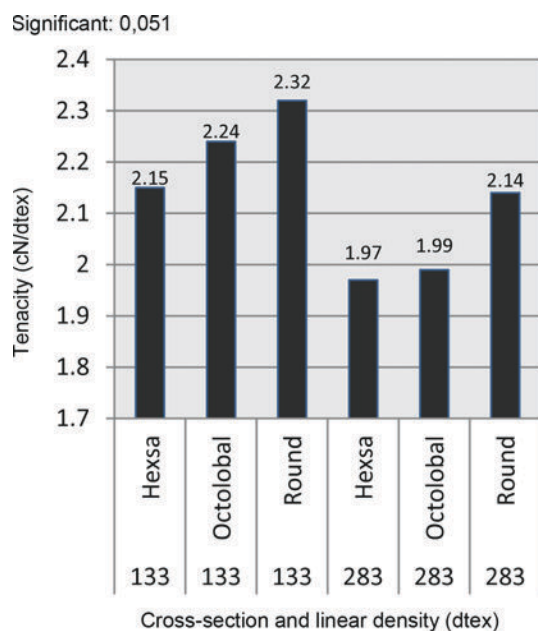


Figure 4. Effect of cross-section and yarn linear density on POY's tenacity.

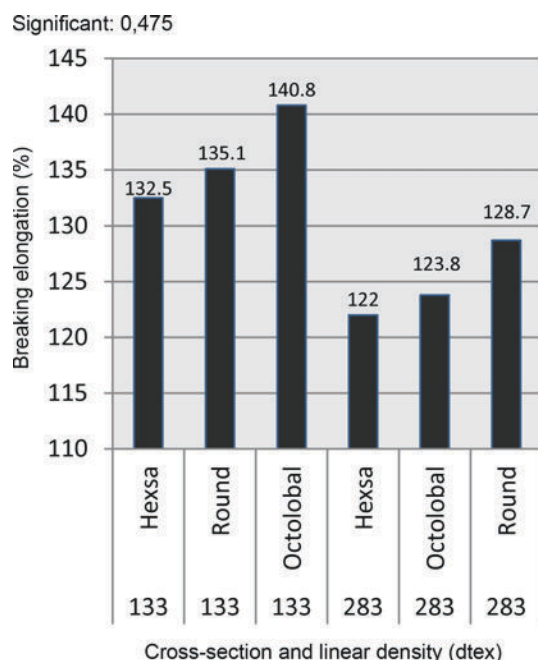


Figure 5. Effect of cross-section and yarn linear density on POY's breaking elongation.

found as 0,051 and that of the breaking elongation results was found as 0,475 at a reliability level of $\alpha=0,05$, it was concluded that the effect of cross-sectional shape variable on the tenacity and breaking elongation of POY filament yarn is not statistically significant.

It was seen that POY with 133 dtex had higher tenacity and breaking elongation values compared to thicker structured yarn. This can be explained with the fact that both quench air (cooling air) and drawing process affected the examined yarn more during POY production.

Unevenness

In the study, the effect of cross-sectional shape and linear density variables on the unevenness of yarns was also investigated. It was seen in the results obtained that round cross-sectional shape formed the most even and tetra cross-sectional shape formed the most uneven yarn structure (Figure 6). In addition to this, an increase in linear density levels helped the yarns to have a more even structure.

Unevenness test results of second group of yarns have been given in Figure 7. In the figure, it is seen that the structure with the best evenness is the round cross-sectional shaped yarn and the structure with the highest unevenness is the hexsa cross-sectional shaped yarn. Generally, it is seen that an increase in linear density value results in yarn structure with better evenness.

In both yarn groups, yarn structure with the best evenness was detected in round cross-sectional shaped yarn structure.

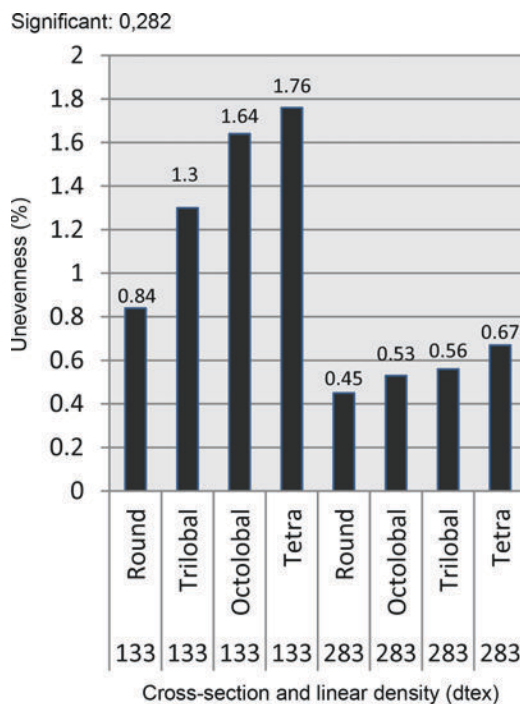


Figure 6. Effect of cross-section and yarn linear density on POY's unevenness.

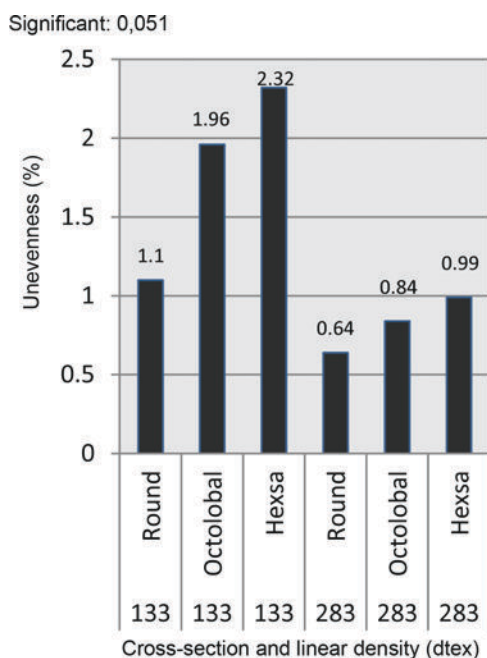


Figure 7. Effect of cross-section and yarn linear density on POY's unevenness.

It is seen that yarns with channelled cross-sectional shapes such as tetra and hexsa have high unevenness rates. Higher unevenness rates of yarn features with channelled cross-sections such as tetra and hexsa can be explained with the fact that adherence feature of filaments is weaker. In addition, the fact that yarn structures with better unevenness were obtained with the increase in linear density can be explained with the fact that thick monofilaments have better coexistence/adherence features. As the significance level of the first group of yarn was found as 0,282 and that of the second group of yarn was found as 0,051 at a reliability level of $\alpha=0,05$, it was concluded that the effect of cross-sectional shape variable on the unevenness of POY filament yarn is not statistically significant.

Conclusion

It is known that fibre cross-sectional shape, which is one of the structural parameters of synthetic fibres, has a significant effect on product features. This effect turns into a desired feature in the product and thus, innovative products can be obtained. For this reason, studies on the selection of parameters during the process of synthetic fibre production have gained speed today. In as it mentioned earlier this study, effect of selected cross-sectional shapes and two different linear density parameters on Polyester POY features have been examined. As a result of the study, it was seen that both parameters were effective on yarn features. Good

features such as high tenacity, high breaking elongation and low unevenness were obtained with round cross-sectional shaped yarns. Yarns with channelled and lobed cross-sectional shapes yielded lower tenacity and breaking elongation and higher unevenness rates. High unevenness rates were especially observed in yarns with hexsa cross-section due to its deep-channelled structure. It was also seen that an increase in the rate of linear density decreased the tenacity and breaking elongation rates of yarn and reduced yarn unevenness.

Acknowledgements

We extend our thanks to SASA Polyester San. A.Ş. Management and employees of related departments, who provided all the necessary opportunities for the carrying out of the tests and the production of the basic materials of this study, which was conducted with the cooperation of Çukurova University and SASA Polyester San. A.Ş. within the scope of "Academic Support Project" during the period of 2007-2010.

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