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Influence of Cross-Sectional Shape on the Tensile Properties of Fiber, Yarn, and Fabric

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Abstract

The cross-sectional shape is one of the effective parameters influencing the characteristics of fiber, yarn, and fabric. Today, fibers are produced with different cross-sections to create specific characteristics in fiber, yarn, and fabric. In this study, two fibers were produced: the first is a polyester fiber with two different cross-sections, named trilobal and round; while the second is polypropylene fibers with three different cross-sections, named trilobal hollow, trilobal, and octalobal. The same condition was applied to produce all the fibers. Then, the produced fibers were used to produce yarn and fabric. Fabrics with three weave designs, named plain, satin, and twill, were woven from the produced yarn by completely applying the same conditions. The tensile properties of the fibers, yarns, and fabrics produced were investigated according to available standards in light of elongation and modulus. The statistical analyses of the results showed a significant difference in the characteristics of the fibers, yarns, and fabrics. to create hollow conditions fibers, yarns, and fabrics that were produced were investigated according to available standards in the light of elongation and modulus. The statistical analyses of the results showed the existence of a significant difference in the characteristics of the fibers, yarns, and fabrics as a result of their different cross-sections.

Keywords: Fiber, Cross-Sectional, Polyester, Polypropylene, Tensile

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1. Introduction

Synthetic fibers with a round cross-section are the most commonly produced industrially [1]. However, fibers with other cross-sectional shapes are also manufactured for various reasons such as performance, comfort, pilling propensity, bulkiness, tactility, and processing [1-3]. The cross-sectional shape of the fiber significantly influences the physical properties of yarns and fabrics [4, 5]. It can be concluded that fibers with a round cross-sectional shape have the highest tenacity-breaking elongation value and the most even structures, Fiber cross-sectional shapes play a critical role in deciding the surface geometry of fabrics [6]. Characteristics such as bulkiness, crease recovery, flexural rigidity, abrasion resistance, luster, handle, pilling, and dyeing are considered by consumers when making decisions on garment selection [1, 4, 7, 8]. One significant advantage of using fibers with modified cross-sections is their improved flexural stiffness. Fiber cross-section significantly impacts the degrees of fabric softness, drape, crispness, and stiffness [8-10]. In the 1960s, the development of melt-spun fibers began with noncircular cross-sections [2, 11]. in deciding Characteristics that the initial study was on the gloss of expensive silk fiber, a function of altering the cross-section into a trilobal shape, which provided functionality and aesthetics to synthetic fiber by developing different types of non-circular fibers. Fibers with a trilobal cross-section are widely used to produce silk-like fabrics [2, 11, 12]. The cross-section's shape varies by changing the shape of the spinneret hole during the melt-spinning synthetic process. [11, 12]. The properties of fibers with a non-circular cross-section differ from those with a circular cross-section. These properties include bending stiffness, coefficient of friction, softness, luster, comfort, pilling, bulkiness, handle, and performance [1, 9, 13, and 14]. Matsudaria, et al. (1993) evaluated the effect of fiber cross-section on the physical properties of fabric. The impact of eight different cross-sections on the mechanical properties of fabrics (such as tensile strength and shearing strength) was tested. The results revealed that cross-section shape and fiber fineness significantly impact the mechanical properties of fabrics [15].

Alston et al. (2002) studied the effect of polyester fibers with non-circular cross-sections on the rotor spinning of polyester and polyester/cotton yarns [7]. Fibers with hollow, trilobal, oval, ribbon, peanut, and scalloped oval cross-sections were selected. Polyester fibers (i.e., oval, ribbon, peanut, and scalloped oval shapes) with aspect ratios greater than 1 had fewer yarn breaks than the stiffer polyester fibers (i.e., round, hollow, and trilobal shapes) with an aspect ratio of 1. Peanut and scalloped oval fibers, which combined a multi lobular character with an aspect ratio greater than 1, recorded the fewest yarn breaks. The superior rotor spinning of these non-circular fibers was due to the enhanced twist propagation because of the reduced torsional rigidity and lower fiber-to-surface contact. Cross-sections, Karaca and Ozcelik (2006), investigated the effects of fiber cross-sectional shape on the structure and properties of polyester fibers [2]. The result showed that the difference in cross-sectional shapes of fibers influenced modulus, maximum strain, yield stress, and shrinkage in boiling water. They also showed a difference between the strain-stress curves of full and hollow fibers. However, the strain-stress curves of round and trilobal fibers were the same, but the only difference was in the yield stress. Compared to full fibers, hollow fibers recorded a higher yield stress. Dhamija et al. (2011) investigated the effects of polyester fiber fineness and cross-sectional shape on the physical characteristics of yarns. It was observed that all the non-circular fibers had yarn variations higher than the corresponding circular ones. The trend on the yarn packing fraction decreased with the linear density of the constituent fiber. Compared to the circular fibers, the degree of yarn packing in the non-circular fibers was lower [4]. More recently, Babaarsian and Haciogullari reported that round, tetra, and octagonal cross-sectional shapes have resulted in the production of polyester partially oriented yarn (POY) with high tenacity and breaking elongation. However, trilobal and hexes cross-sectional shapes led to yarn production with low tenacity [3]. In addition, due to its deep-channeled structure, the Hexa cross-sectional shape led to a POY structure with a high unevenness rate. It was also shown that an increase in the rate of linear density decreased the tenacity and breaking elongation rates of yarn and reduced POY unevenness. Considering the earlier reviewed literature, it could be concluded that there is no organized and systematic research relating the mechanical properties of fiber with different cross-sectional shapes and yarns to the mechanical properties of fabrics. Therefore, in this study, the researchers systematically investigated the effect of fiber cross-sectional shape on the tensile properties of fibers, yarns, and fabrics. At first, polyester and polypropylene fibers with five different cross-sectional shapes were produced. Then, yarns and fabrics were produced from the obtained fibers using the same condition. The tensile properties (tenacity, elongation, initial modulus) of the fibers, yarns, and fabrics were characterized and studied using statistical analyses. Singh et al., (2021) investigated the effect of fiber cross-sectional shapes on the bending behavior of continuous multifilament polyethylene terephthalate (PET) yarns and corresponding fabrics [16]. Fibers with circular, trilobal, rectangular, plus, double flange dumbly shape, octagonal, hexagonal, square, and trilobal plus or Y-shape cross-sections were selected for the study. The yarn bending behavior was compared with fabric bending behavior to study the effect of cross-sectional shapes on bending behavior.

2. Experimental apparatus

2.1. Materials and Method

Polypropylene chips (PP 512P, SABIC Co.) a controlled rheology grade with medium molecular weight distribution for fiber extrusion had a melt flow rate of 25 g/10 min (230°C, 2.16 kg) and a density of 0.905 g/cm³ (23°C). Semi-dull polyethylene terephthalate chips (PET-TG641, Tondgooyan Petrochemical Co., Iran) had an intrinsic viscosity of 0.64 dl/g and a titanium dioxide content of 0.3 ± 0.05 wt. %. Square, trilobal plus, and Y-shape cross-sections were selected to compare yarn and fabric bending behavior, examining the effect of cross-sectional shapes on bending.

2.2. Fiber production

The melt-spinning process of NEUMAG is used to produce PP fibers. Three different spinnerets were applied to produce fibers with trilobal, trilobal hallow, and octagonal cross-sectional shapes. To investigate only the effect of the fiber's cross-sectional shape on fiber properties, various processing parameters such as viscosity, mass throughput rate, spinning temperature, take-up speed, and quenching conditions that affect the final properties of melt-spun fibers were kept constant. This approach meant that the polymer's throughput and take-up speed were constant for each sample. The spinning speed was set at 3000 m/min. The melt spinning of the Pacific was used to produce the PET fiber. All the included parameters were kept constant, except for the cross-sectional factor of the fiber. Two different spinnerets were applied to produce fibers with round and trilobal cross-sectional shapes. Here, as in the case of the PP fibers, all the spinning parameters were kept constant, except for the cross-sectional shapes of the spinnerets. The spinning speed was set at 2200 m/min. The fiber area and perimeter were measured using an image processing technique. These quantities were measured for five different filaments in the bundle and the average was obtained. These values were used to calculate the "non-roundness" factor k defined as follows (Table 1.):

$$k = \frac{C_f}{2\sqrt{\pi S}} \qquad (1)$$

where k is the non-roundness factor (dimensionless); Cf is the fiber circumference (m); and S is the fiber cross- sectional area (m^2) [1].

2.3. Yarn production

The produced PP yarns consisted of a full-drawn yarn (FDY) of 136 filaments with a linear density of 1690 dtex. PET yarns consisted of 384 filaments with a linear density of 1800 dtex.

Table 1. Shape Factor of Fibres

Fibre	Cross Section	K
Polyester	T	1.174
	R	1.0628
PP	Oc	1.36
	TH	1.38
	T	1.326

T: Trilobal, TH: Trilobal Hallow, Oc: Octalobal, R: Round

2.4. Fabric production

Five different fabrics were woven in three different weaving patterns (plain, 2/1 Z twill, and satin) using the Sulzer G6300 weaving loom under the same conditions. Warp yarns of polyester and five types of weft yarns were applied to produce the fabrics. Table II shows the characteristics of the fabrics obtained under ASTM D3776 and ASTM D1777 standards.

Table 2. Characteristics of The Fabrics

			Ends/cm	Picks/cm	Thickness mm	Weight gr/cm^2
Polyester	Plain	T	14.4	9.2	0.746	0.0291
		R	14.4	9.2	0.708	0.0322
	Twill	T	14.4	9.2	0.658	0.0286
		R	14.4	9.2	0.622	0.0312
	Satin	T	14.4	8.8	0.830	0.0266
		R	14.4	8.8	0.790	0.0318
PP	Plain	Oc	15.5	9	0.788	0.0222
		TH	15.5	9	0.862	0.0193
		T	15.5	9	0.784	0.0221
	Twill	Oc	16	9.3	1.014	0.0227
		TH	16	9.3	1.1	0.0238
		T	16	9.3	1.04	0.0258
	Satin	Oc	16	9.5	0.654	0.0213
		TH	16	9.5	0.744	0.0217
		T	16	9.5	0.760	0.0237

2.5. Characterization

Optical microscopy (Lelica Metallovert) was used to determine the area diameter of the filaments. To perform these tests, the filaments were embedded in epoxy resin matrix, followed by curing at ambient temperature. The specimens were polished perpendicularly to the fiber axis.

After being cleaned in water and dried, the polished samples were analyzed using an optical microscope.

The single fiber tenacity measurement was conducted for at least 30 single fibers using a force transducer instrument, Sdl Atlas, equipped with a 100 cN force cell. With ASTM D 3822, the cross-head velocity was 1010 mm/min while the gauge length was 20 mm. The linear density of the yarns was measured according to ASTM D 1907. For mean and standard deviation determination, five measurements were made.

Yarn tensile tests were carried out according to ASTM D 2256 using a Mesdan Lab tensile tester with an accuracy of about 0.01 N. Samples with 250 mm yarn length were used. The testing speed was set at 200 mm/min. The tensile force versus deformation was recorded, and 30 measurements were made to get the force average value for each type of yam. Breaking force is a measure of the steady force that is necessary for the breaking of a fiber and is experimentally given by the maximum load developed in a tensile test.

With the standard test method of ASTM D 5034, the tensile strength and elongation of the fabrics were evaluated using a Mesdan Lab instrument. A constant cross-head speed of 50 mm/min was used throughout the experiments. The measurements were performed in the warp and weft directions of the fabrics (20 × 5 cm), and the average values were determined from the measurements of five samples. Thereafter, the experimental results were statistically analyzed by the SPSS software using ANOVA, T-test, and Duncan methods.

3. Results and Discussion

3.1. Fabric Characterization

Figures 1 and 2 show the respective microscopy photographs of the obtained PP and PET filaments. The PP and PET filaments with different cross-sectional shapes were successfully produced and used for the making of yarns and fabrics.

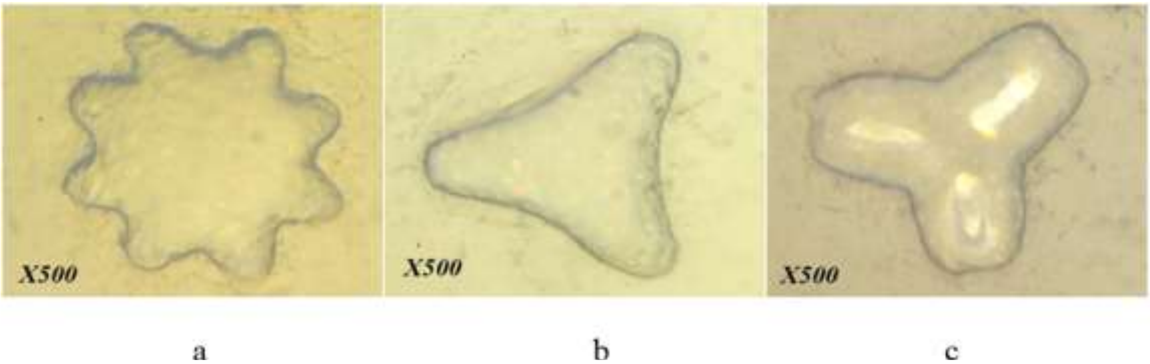

Figure 1. Microscopy photographs of the produced PP filaments: (a) Octalobal, (b) Trilobal and (c) Trilobal hollow

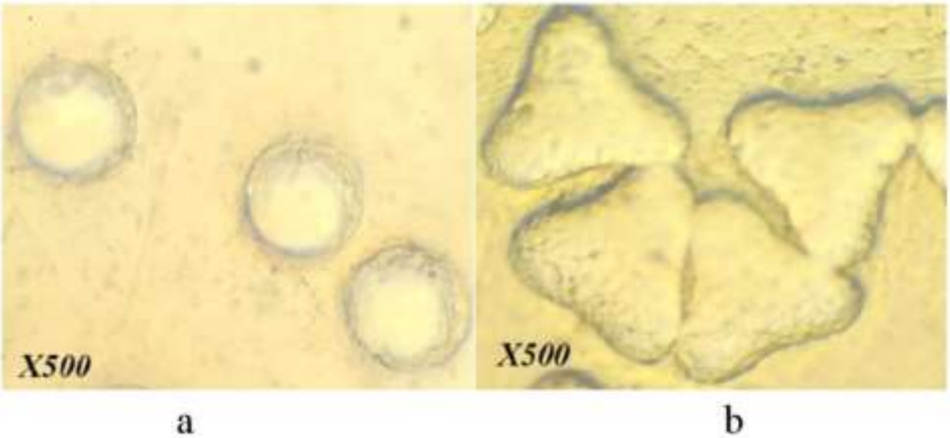

Figure 2. Microscopy photographs of the produced PET filaments: (a) round and (b) trilobal.

Table 3. Statistical Results of Tensile Properties of the Fibers

			N	Mean	Std.D	T	Sig
polyester	Tenacity (cN/Tex)	Trilobal	30	27.827	1.304	-5.894	0.00
		Round	30	31.39	1.732		
	Elongation (%)	Trilobal	30	41.325	5.053	-6.632	0.00
		Round	30	55.136	7.336		
	Modulus (N/Tex)	Trilobal	30	41.325	0.627	2.004	0.088
		Round	30	55.136	0.201		
						F	Sig
PP	Tenacity (cN/Tex)	Octalobal	30	37.050 a	2.156	3.373	0.038
		Trilobal Hallow	30	39.627b	1.898		
		Trilobal	30	38.553b	3.125		
	Elongation (%)	Octalobal	30	48.853	15.542	0.079	0.925
		Trilobal Hallow	30	48.041	16.963		
		Trilobal	30	47.302	15.552		
	Modulus (N/Tex)	Octalobal	30	1.828	0.113	2.155	0.122
		Trilobal Hallow	30	1.918	0.127		
		Trilobal	30	1.828	0.142		

a, b, c means differences between the values and indicate meaningful variations in this case.

Table 3. presents the average tensile properties of the fibers. Polyester fibers exhibited a significant variation in tenacity and elongation, with round cross-sections displaying superior tenacity and elongation. Among PP fibers, tenacity varied significantly, with trilobal hollow fibers demonstrating the highest tenacity. Notably, tenacity did not differ significantly between trilobal hollow and trilobal PP fibers. Elongation showed no

statistically significant difference across all PP fibers. Initial modulus was calculated from the slope of the linear portion of the stress-strain curve.

3.2. Properties of yarns

Table 4 shows the statistical results of the tensile properties of PP and PET yarns. In the case of PET yarns, the results showed a meaningful difference between the tenacity and elongation of yarns. Yarns with a round cross-sectional shape had the highest tenacity values. In the case of PP yarns, the results showed that there was a significant difference between tenacity and elongation values. Yarns with an Octalobal cross-sectional shape had the highest tenacity; however, there was no significant difference between the tenacity values of trilobal and trilobal hollow cross-sectional shapes. For all the PP fibers, the elongation values had no statistically significant difference. The initial modulus was determined by the slope of the initial part of the stress-strain curve, which means the tangent of the linear part of the curve, as shown in Figure 3.

Table 4. Statistical Result of Tensile Properties of the Yarns

			N	Mean	Std. D	T	Sig
polyester	Tenacity (cN/Tex)	Trilobal	30	25.887	1.07	-14.192	0.00
		Round	30	29.635	0.968		
	Elongation (%)	Trilobal	30	42.989	3.144	8.736	0.00
		Round	30	36.294	2.762		
	Modoulus (N/Tex)	Trilobal	30	1.159	1.720	1.80	0.088
		Round	30	.874	2.370		
						F	Sig
PP	Tenacity (cN/Tex)	Octalobal	30	26.503b	0.379	14.084	0.00
		Trilobal Hallow	30	25.708a	0.525		
		Trilobal	30	25.417a	0.821		
	Elongation (%)	Octalobal	30	39.927b	3.782	9.555	0.00
		Trilobal Hallow	30	36.428a	2.395		
		Trilobal	30	40.491c	2.675		
	Modoulus (N/Tex)	Octalobal	30	1.219	0.916	2.155	0.122
		Trilobal Hallow	30	1.279	0.930		
		Trilobal	30	1.219	0.860		

a, b, c means differences between the values and indicates meaningful variations in this case.

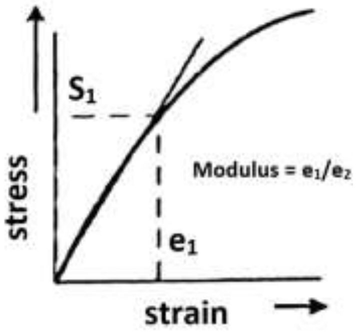

Figure 3. Stress-strain curve

3.3. Properties of PET fabrics

The results of the strength, elongation, tenacity, and initial modulus of the PET fabrics in both the warp and weft directions, and also for three weaving patterns, were statistically investigated and are shown in Tables 5 and 6. The results showed that in warp and weft directions, the different cross-sectional shapes influenced all parameters of the fabrics. In all the weavings, except twill, strength variations are meaningful in the direction of warp, but elongation variations are meaningful in all the weavings. In the direction of weft, elongation is meaningful only in satin weaving. The variation in initial modulus in both warp and weft directions is meaningful, but in the weft direction, it is only meaningful for satin.

3.4. Properties of PP fabrics

Tables 7 and 8 show the results of the tensile properties of PP fabrics in both the warp and weft directions, and also for the three weaving patterns. In all the weavings except twill, strength variations are meaningful in the direction of warp, but elongation variations are meaningful in all the weavings in warp direction. In the weft direction, elongation is meaningful in satin weaving. Variations in the initial modulus in both the warp and weft directions are meaningful. Cross-sectional shape does not have a meaningful impact on the fibers and yarns, but has a meaningful effect on the fabrics. Hence, it could be concluded that the weaving structure has a more important effect on the initial modulus.

Table 5. Statistical Results of Tensile Properties of Pet Fabric in the Warp Direction

		Cross section	N	Mean	Std.D	T	Sig
Plain	Strength (N)	T	5	596.705	7.223	11.227	<0.001
		R	5	517.429	14.039		
	Elongation (%)	T	5	27.200	0.844	-3.22	0.012
		R	5	28.785	0.704		
	Initial modulus (N/Tex)	T	5	2.960	0.406	6.894	<0.001
		R	5	1.799	2.058		

Twill	Strength (N)	T	5	524.992	31.593	-1.763	0.116
		R	5	555.406	22.121		
	Elongation (%)	T	5	22.600	0.224	12.016	<0.001
		R	5	18.600	0.709		
	Initial modulus (N/Tex)	T	5	2.524	-2.174	1.742	0.061
		R	5	3.272	0.612		
Satin	Strength (N)	T	5	643.810	31.046	5.775	<0.001
		R	5	529.668	31.450		
	Elongation (%)	T	5	20.900	1.714	-5.43	0.001
		R	5	25.432	0.737		
	Initial modulus (N/Tex)	T	5	5.702	3.063	1.991	0.082
		R	5	2.963	0.290		

Table 6. Statistical Results of Tensile Properties of Pet Fabric in the Weft Direction

		Cross section	**N**	**Mean**	**Std.D**	**T**	**Sig**
plain	Strength (N)	Trilobal	5	1620.93260	40.360547	-8.431	0.000
		Round	5	1790.40380	19.779474		
	Elongation (%)	Trilobal	5	43.66850	1.950955	12.14	0.001
		Round	5	30.69290	1.380142		
	Initial modulus (N/Tex)	Trilobal	5	31.226400	4.6532970	-7.344	0.000
		Round	5	52.290200	4.4131048		
Twill	Strength (N)	Trilobal	5	1548.10640	55.841774	-4.400	0.002
		Round	5	1671.50740	28.538201		
	Elongation (%)	Trilobal	5	37.36760	2.187716	5.335	0.001
		Round	5	29.50020	2.467091		
	Initial modulus (N/Tex)	Trilobal	5	48.031600	4.2787869	095 5	0.349
		Round	5	45.510600	3.7156758		
Satin	Strength (N)	Trilobal	5	1824.33320	41.834080	13.421	0.000
		Round	5	1502.98100	33.412410		
	Elongation	Trilobal	5	29.32860	3.470270	0.184	0.859

	(%)	Round	5	29.77370	4.161712		
	Initial modulus	Trilobal	5	65.845300	2.5444453	43.61	0.000
	(N/Tex)	Round	5	19.985200	.8365828		

a,b,c means differences between the values and indicates meaningful variations in this case.

Table 7. Statistical Results of Tensile Properties of Polypropylene Fabric in the Warp Direction

		Cross section	N	Mean	Std. D.	F	Sig
Plain	Strength (N)	Octalobal	5	5.427 b	21.355	7.809	**.007**
		Trilobal Hallow	5	5 a	18.149		
		Trilobal	5	5.18 a,b	8.214		
	Elongation (%)	Octalobal	5	36.67 c	0.833	40.50	**.000**
		Trilobal Hallow	5	28.38 a	1.981		
		Trilobal	5	33.01 b	1.335		
	Initial modulus (N/Tex)	Octalobal	5	1.11 a	0.137	48.74	**00**
		Trilobal Hallow	5	3.18 b	0.512		
		Trilobal	5	1.72 a	0.222		
twill	Strength (N)	Octalobal	5	5	64.631	3.78	**.053**
		Trilobal Hallow	5	5	34.899		
		Trilobal	5	5.6	18.209		
	Elongation (%)	Octalobal	5	21.39 a	3.189	8.94	**.004**
		Trilobal Hallow	5	26.71 b	1.473		
		Trilobal	5	25.81 b	1.119		
	Initial modulus (N/Tex)	Octalobal	5	4.05 b	0.906	6.398	**.013**
		Trilobal Hallow	5	3.18 a,b	0.172		
		Trilobal	5	2.81 a	0.296		
satin	Strength (N)	Octalobal	5	5.7 b	19.562	10.61	**.002**
		Trilobal Hallow	5	5.3 a	31.450		
		Trilobal	5	5.9 b	18.633		
	Elongation (%)	Octalobal	5	22.903 a	1.140	6.777	**.011**
		Trilobal Hallow	5	25.432 b	0.737		
		Trilobal	5	22.828 a	1.737		
	Initial modulus (N/Tex)	Octalobal	5	6.303 b	0.830	44.96	**.000**
		Trilobal Hallow	5	2.963 a	0.290		
		Trilobal	5	2.813 a	0.724		

Table 8. Statistical Results of Tensile Properties of Polypropylene Fabric in The Weft Direction

pp * weft			N	Mean	Std.D	F	Sig
Plain	Strength (N)	Octalobal	5	43 c	19.603	556.349	**.000**
		Trilobal Hallow	5	27 a	40.966		
		Trilobal	5	32 b	18.814		
	Elongation (%)	Octalobal	5	28.871	1.785	3.149	**.080**
		Trilobal Hallow	5	26.669	1.416		
		Trilobal	5	28.987	1.712		

	Initial modulus (N/Tex)	Octalobal	5	25.614 b	1.725	124.419	**.000**
		Trilobal Hallow	5	19.674 a	1.427		
		Trilobal	5	32.899 c	0.523		
twill	Strength (N)	Octalobal	5	43 c	38.000	71.583	**.000**
		Trilobal Hallow	5	39 b	62.948		
		Trilobal	5	31a	65.527		
	Elongation (%)	Octalobal	5	31.447 c	2.238	19.337	**.000**
		Trilobal Hallow	5	28.291 b	1.914		
		Trilobal	5	24.403 a	0.989		
	Initial modulus (N/Tex)	Octalobal	5	24.230 b	3.543	17.913	**.000**
		Trilobal Hallow	5	23.746 b	1.617		
		Trilobal	5	16.362 a	1.053		
satin	Strength (N)	Octalobal	5	36 b	77.477	34.209	**.000**
		Trilobal Hallow	5	40 c	41.237		
		Trilobal	5	31 a	46.439		
	Elongation (%)	Octalobal	5	27.338	3.071	2.844	**.098**
		Trilobal Hallow	5	29.773	4.161		
		Trilobal	5	25.137	1.268		
	Initial modulus (N/Tex)	Octalobal	5	11.283 a	1.122	145.572	**.000**
		Trilobal Hallow	5	19.985 c	0.836		
		Trilobal	5	13.074 b	0.414		

a,b,c means differences between the values and indicates meaningful variations in this case.

The results of the present study are in full agreement with the results of other works [1,5] that investigated the effects of different cross-sectional shapes (i.e., round, trilobal, tetra, hexsa, and octalobal) on the tensile properties of the polyester fibers and showed that the tensile strength of fibers with round cross-sectional shape was higher than those with other cross-sectional shapes, regardless of the fiber density.

4. Conclusions

The cross-sectional shapes of the filaments were shown to have a substantial influence on the properties of fibers, yarns, and fabrics. For both PP and PET, and by varying the cross-sectional shapes of the filaments, significant differences were observed among the values of tenacity, elongation, and modulus of the products.

There were significant differences in the tenacity and elongation of polyester fibers, but there was no difference in their initial modulus. The tenacity and elongation in fibers with a round cross section were higher than those of trilobal fibers. However, there was only a significant difference in the tenacity of polypropylene fibers, while fibers with a trilobal hollow cross-section had the highest level of tenacity.

There were significant differences in the tenacity and elongation of PET and PP yarns, while the initial modulus did not change. PET yarns containing fibers with round cross-section had the highest tenacity, and yarns containing fibers with trilobal cross-section had the highest elongation. PP yarns containing fibers with Octalobal cross section had the highest tenacity, while yarns with trilobal cross section had the highest elongation.

In all the weavings of PET fabrics, except for twill, strength variations were significant in the warp direction, whereas elongation variations were significant in all weavings. In the weft direction, elongation was only significant in satin weaving. Both the warp and weft directions showed meaningful variation in the initial modulus, but in the weft direction, it was only significant for satin.

In all the weavings in PP fabrics, except twill, strength variations were meaningful in the warp direction, but elongation variations were meaningful in all the weavings in the warp direction. In the weft direction, elongation was meaningful in satin weaving. In both warp and weft directions, variation in initial modulus was meaningful. Cross-sectional shape did not have a meaningful effect on the fibers and yarns, but there was a meaningful effect on the fabrics. Hence, it could be concluded that the weaving structure had a more important effect on the initial modulus.

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