Araştırma Makalesi / Research Article

Properties investigation of polyester yarns with different cross-sections

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Abstract
In this work, the properties of polyester filaments with different cross-sectional shapes were investigated. Trilobal, flat and hollow shaped polyester filaments, having the same count, were produced by following the same route and production parameters. Properties, such as tensile strength, elongation, breaking load, unevenness etc., were investigated. Comparative evaluations of the test results with regard to the cross-sectional shapes were carried out. The results showed that cross-sectional shape of the filaments directly affected the yarn properties and trilobal filament containing polyester yarns showed better properties as compared to yarns containing filaments with a cross-sectional shape of hollow and flat.

Keywords: Polyester, Cross-sectional shape, Melt extrusion, Fully drawn yarn.

Farklı enine kesitlere sahip polyester ipliklerin özelliklerinin incelenmesi

Öz
Bu çalışmada, farklı enine kesit şekillerine sahip polyester filamentlerin özellikleri araştırılmıştır. Aynı numaraya sahip olan trilobal, yassı ve hollow (içi boş) polyester filamentler, aynı yol ve üretim parametreleri izlenerek üretilmiştir. Çekme mukavemeti, uzama, kopma yükü, düzgünsüzlük vb. özellikler incelenmiştir. Enine kesit şekillerine göre test sonuçlarının karşılaştırmalı değerlendirmeleri yapılmıştır. Sonuçlar, filamentlerin enine kesit şeklinin iplik özelliklerini doğrudan etkilediğini ve trilobal filament içeren polyester ipliğin, içi boş ve yassı enine kesitli filamentleri içeren ipliklere kıyasla daha iyi özellikler gösterdiğini göstermiştir.

Anahtar kelimeler: Poliester, Enine kesit şekli, Eriyikten çekim, Tam çekilmiş iplik.

1. Introduction

The cross-section of the textile fibers is one of the most significant morphological features. In other words, it is possible to modify the various properties of the yarn and fabric by changing the shape of the fiber cross-section [1]. In the early stages of fiber extrusion from molten polymers, produced fibers mostly had circular cross-section. After 1960’s, attempts to produce fibers with various types of non-circular cross-sections increased to impart aesthetic and functional properties to the fibers. Nakajima et al. [2] tried to mimic the gloss of silk fiber by producing synthetic fibers with a triangle-like cross-section. Producing hollow fibers was another attempt of synthetic fibers with non-circular cross-sections [3].

Polyester fibers with different cross-sectional shapes are obtained by changing the shape of the holes in the nozzle in a melt extruder. The cross-sectional shapes of the synthetic fibers produced according to the melt-extrusion process can easily be varied by changing the nozzle. The fibers having different cross-sectional shapes obtained in this manner are also referred in the literature as “profiled fibers”, “non-circular fibers” or “modified cross-section fibers” [4-5].

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Tyagi and Madhusoodhanan investigated the effect of circular and trilobal cross-sectional polyester filaments on handle properties of fabrics produced from polyester/viscose and polyester/cotton blend yarns. Blended yarns were produced via a ring and a Murata air-jet spinners. The polyester content in the yarn structure was either 48% or 65%. They produced twelve plain woven fabrics and the properties of produced fabrics were tested. They stated that the trilobal polyester fiber containing fabric showed higher formability and shear rigidity as compared to circular polyester fiber containing structures fabric [6].

The effects of cross-sectional shape on tensile, thermal, and thermo-mechanical properties of polyester filaments were investigated by Hasan et al. [4]. Two different cross-sectional shapes of the polyester filaments that they produced via spin winding process were in round and plus shaped. They found that both tenacity and elongation values measured for polyester yarn having filaments with plus-shaped cross-section were lower than that of yarn having filaments with round-shaped cross-section. When they compared the crystallinity degrees of these two yarns, they stated that polyester yarn having filaments with plus-shaped cross-section had slightly higher degree of crystallinity while the maximum crystallinities were very similar. Their concluded as that the effect of the shape of cross-sections on the crystallinity degree of undrawn PET filament yarn was not significant.

Omeroglu et al. studied the effect of yarn twist on the tensile strength and elongation of FDY polyester yarns [7]. They used 167/48 dtex polyester produced in four different cross-sectional shapes; round, trilobal, round-hollow and trilobal-hollow. They applied six different amount of twist; 300, 600, 900, 1200, 1500 and 1800 tpm. The overall view of the study was that twist had an effect on the tensile properties of the yarn. However, they also concluded that a similar study could be done to examine the effect of the amount of twist less than 300 tpm. Karaca and Ozcelik investigated the effect of cross-sectional shape of polyester filaments on the physical properties of the produced yarns [8]. They produced and investigated the physical properties of polyester yarns with four different cross-sectional shapes (round, trilobal, round-hollow and trilobal-hollow). It was stated that maximum strain values of yarns consisting of hollow filaments were lower as compared to yarns consisting of full filaments. On the other hand, some other properties, such as the modulus, yield stress, take-up stress, and shrinkage in boiling water of hollow filament containing yarns were higher than that of full filaments containing yarns. The highest unevenness was observed on round-hollow filaments containing yarns. Dhamija et al. [9] investigated the physical characteristics of the yarns with different cross-sectional shapes (circular, trilobal, scalloped oval and tetrakelion) and fiber fineness. Their general conclusion was supportive to the literature that the cross-sectional shape had an effect on the properties.

This work focuses on the effects of cross-sectional shape of the filaments on the yarn properties. Polyester yarns (167/48 dtex) consisting of trilobal, flat or hollow filaments were produced by a melt extrusion process. In order to have comparable materials, polyester chips were melt extruded through three different nozzles (trilobal, flat and round-hollow), and the process conditions were kept the same for each production. Although there have been studies in the literature examining the effects of filaments with different cross-sectional shapes on yarn properties, no comparative study of these three cross-sections were found.

2. Materials and Methods

2.1. Materials

Polyester granules used in this study were obtained from Thailand and Adana. These granules were turned into yarn by using melt-extrusion machines in the real production environment of a mill.

2.2. Production parameters for FDY

Moisture is one of the undesirable factors in polyester yarn production. Therefore, the moisture in the polyester granules that come to production is tried to be reduced to the range of 0.3-0.4% by means of dryers until it reaches the extruder. The purpose of the drying process is to dry polyester granules until the moisture is between 15 and 25 ppm, which means 15-25 g water in 1 tone polyester granules. To achieve this moisture content, polyester granules are dried at 170ºC for about 5 hours. The feeding of the polymer was 1.8% while the pump worked with 21.60 l/dk. The granules were heated up gradually through the heating zone, and the temperature at the die was around 285ºC. The filaments went through the cooling zone where the temperature falls dramatically to 30-35ºC. The filaments then came to the lubrication zone. The main objectives of lubrication is to keep the filaments together, to help cooling, to reduce static electricity, and to reduce friction. Take up speed was 4600 m/min.

2.3. Test Methods

Yarn properties, such as tensile strength, elongation, breaking load, unevenness, and shrinkage in boiling water, were studied. In order to be able to investigate the effect of cross-sectional shape on yarn parameters, all three samples (trilobal, flat and hollow) had the same yarn count which was 167/48 dtex.

The cross-sectional shapes of the yarns were analyzed under microscope. In order to examine the effect of different cross-sections on the yarn properties, we produced and examined the yarns having the same count but the different cross-sections. To assess the yarn count, a spinning-wheel with a diameter of 1 m was used to calculate the yarn count according to BS EN ISO 2060. This was repeated 10 times and the average value was taken as the count of related yarn.

Some of the physical properties, such as yarn strength, elongation and breaking load of polyester yarns were obtained from a Statimat Me Tensile Test Equipment, according to DIN 2062 test standard. Measurements were repeated 10 times and the average values were recorded. Unevenness of the yarns was measured by using Uster Tester 3 according to DIN 53817-1 test standard. Shrinkage of the produced polyester yarns with different cross-sections were measured by using a Texturmat Me. The shrinkage test was performed according to DIN 53840 test standard. Two samples were used for each measurement. The initial length of the yarn was measured automatically by the equipment. Second measurement is done after the samples were subjected to 190ºC for 15 mins. in a drying oven.

3. Results and Discussion

Microscopic view of cross-sectional shapes of the yarns are given in Figure 1. Images are taken from the same device but there are colour differences due to the brightness of the filaments. The results obtained are collected and given in Table 1 while the effect of cross-sectional shape on each studied yarn property is discussed individually.

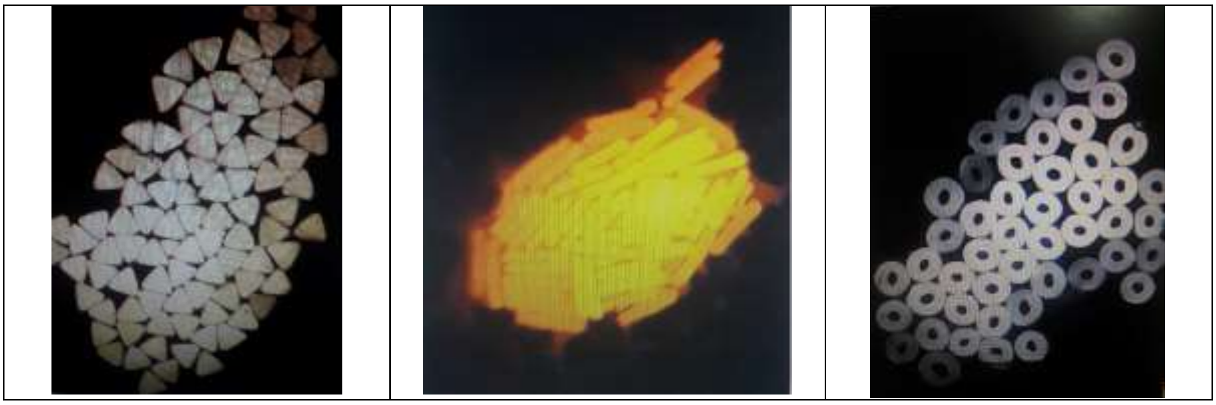

Figure 1. Cross-sectional view of produced polyester fibers: (a) trilobal, (b) flat, and (c) hollow captured with a magnification of 1000X

Table 1. Properties of produced polyester yarns

Cross-secion	Tensile strength (cN/dtex)	Elongation (%)	Breaking load (cN)	Unevenness (%)	Shrinkage in boiling water (%)	Lubricant (%)
Trilobal	3.87	36.79	622.80	1.11	10.10	1.34
Flat	2.70	39.40	451.40	3.96	34.10	1.00
Hollow	2.80	55.10	467.80	0.93	5.30	0.68

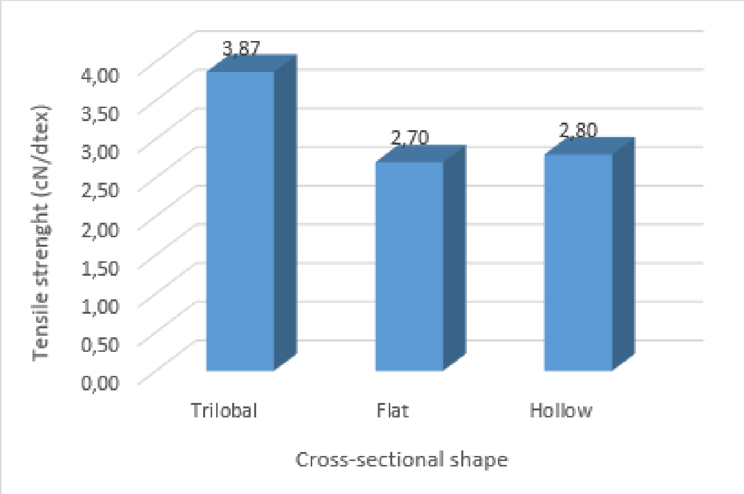

Figure 2. Tensile strength (cN/dtex) of produced polyester yarns

The tensile strengths of trilobal, flat, and hollow polyester filaments are given in Figure 2. It was observed that polyester yarn having a-trilobal cross-section showed the highest tensile strength among polyesters yarns studied. It is possible to say that trilobal cross-section has a positive effect on the yarn strength. This can be explained as that the ability of trilobal cross-sectional filaments to cling together is better than that of flat and hollow filaments.

Babaarslan et al. [10] investigated the effects of cross-sectional shape polyester yarn properties. They worked on five different cross- sectional shapes: round, trilobal, tetra, hexsa and octolobal, and studied their effects on tenacity-elongation. It was stated that the yarns with cross-sections of round, tetra and octolobal influenced tensile strengths and breaking elongation while other two yarns with trilobal and hexsa cross-sections had low tensile strengths. Varshney et al. [11] were another research group worked on the effect of cross-sectional shape. They stated that individual fibers, taken from two yarns with different cross-sections, having the same length and linear density showed different tensile strengths values. This was concluded as the effect of the individual fiber tensile strength and cross-section on the tensile strength of the yarns.

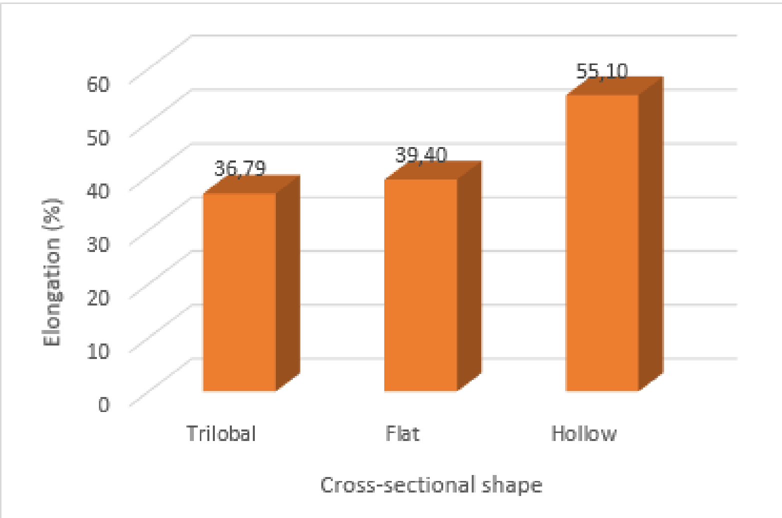

Figure 3. Elongation (%) of produced polyester yarns

Elongation of produced polyester yarns are given in Figure 3. In contrast to tensile strength values, the highest elongation value of 55.10% was observed on hollow filament containing yarn. The elongation values of yarns with trilobal and flat cross-sections were close to each other, 36.79% and 39.40%, respectively. If we consider the inverse proportionality with the elongation in normal conditions, we can clearly see how important the different sections are on the yarn. Babaarslan et al.

argued the effect of cross-sectional shape on elongation of the yarns with five different cross-sections [10]. Flat shaped cross-sectional yarn was not in these 5 yarns. However, their study included trilobal and round shaped cross-sections. It was found that the elongation (%) of the yarns with a round cross-sectional shape was higher as compared to the yarns with a trilobal cross-sectional shape. Their general conclusion was that yarns with multi-channelled cross-sectional shapes showed low elongation (%) values while the yarn having a round shaped cross-section had the higher elongation (%) before broken. This supports our elongation (%) test results.

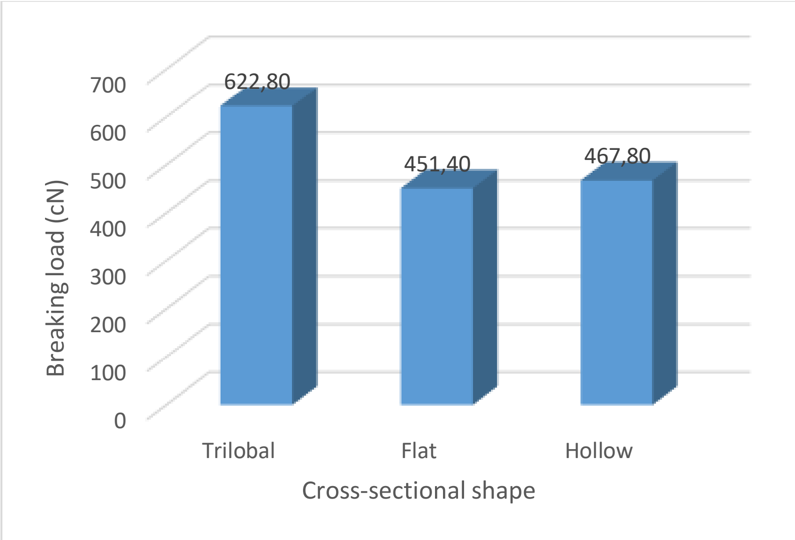

Figure 4. Breaking Load (cN) of produced polyester yarns with different cross-sectional shapes

The information on the breaking loads of the produced polyester yarns are given in Figure 4. As can be seen, the load needed to break the yarn having a trilobal cross-section is higher than the others. This can be explained as that filaments with a trilobal cross-section are easier to have a good contact to each other in the yarn structure, and constitute a more robust structure. Breaking load of polyester yarns consisting of flat or hollow filaments were lower since the ability of filaments to hold each other in the yarn structure is less than the filaments having a trilobal cross-section. Therefore, it is possible to say that the cross-sectional shapes of the filaments, forming the yarn, affect the tensile properties of the yarn. This is an agreement with Karaca and Ozcelik, who drew a similar conclusion for their experiments conducted on polyester yarns with 4 different cross-sectional shapes [8].

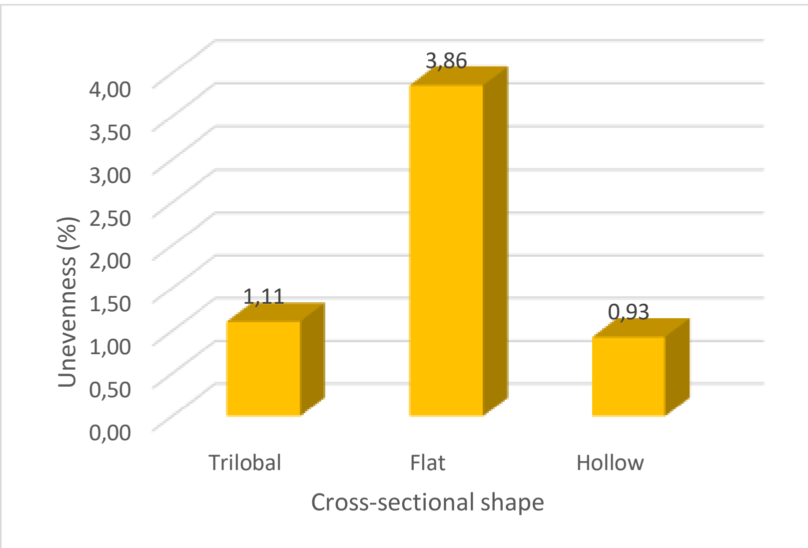

Figure 5. Unevenness (%) of produced polyester yarns with different cross-sectional shapes

Unevenness percentage of studied yarns are given in Figure 5. The highest unevenness (3.86%) was observed on yarn having flat-shaped cross-sectional filaments. While unevenness values of yarns having filaments with trilobal cross-sectional shape, and hollow filaments were similar; 1.11% and 0.93% respectively. In the work of Karaca and Ozcelik, the unevenness values of trilobal cross-sectional polyester and round-hollow cross-sectional polyester were vice versa [8]. Their hollow polyester filaments had slightly higher unevenness value as compared to trilobal polyester filaments. This may be an effect of process parameters. The reason for the unevenness in the yarn with a flat cross-section may be that the air-friction forces applied on the filament surface may probably be differs according to the different cross-sections that also affects the cooling behavior of filaments.

It is believed that the air friction forces in contact with the surface of the filament during cooling of the filaments may differ in different cross-sections, which is also influenced by the cooling behavior of the filaments. Therefore, the yarn with a flat cross-section may not fully take up the air after it has come out that may lead unevenness. This remark is an agreement with literature [8, 12].

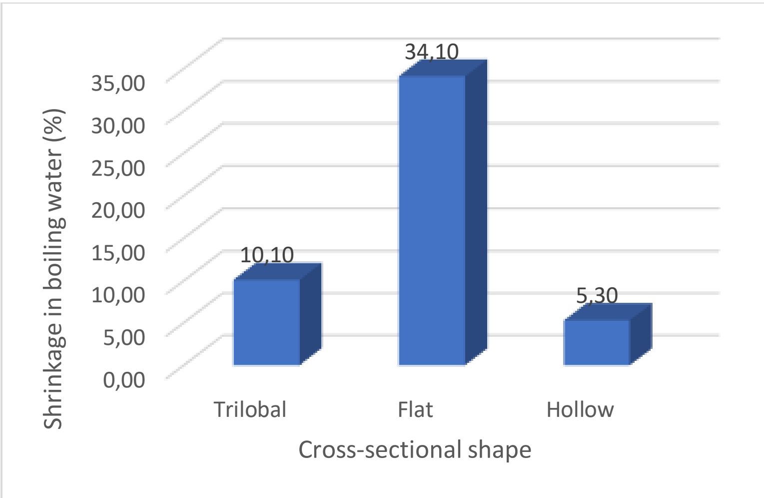

Figure 6. Shrinkage (%) of produced polyester yarns with different cross-sectional shapes

The shrinkage in boiling water properties according to the cross-sectional shape of the filaments were also investigated and the results are presented in Figure 6. As can be seen that the filaments with flat-shaped cross-section had greater shrinkage values in boiling water as compared to trilobal and hollow shaped filaments. Therefore, it is possible to say that the shape of the cross-section of the filaments had an effect on the yarn properties. Hacıoğulları et al. [13] studied the shrinkage of polyester yarns with different cross-sectional shapes along with other properties. They stated that yarns having round cross-sectional filaments showed lower shrinkage that the yarns with -lobal cross-sections: trilobal, tetra and octolobal. This is an agreement with our shrinkage test results for hollow and trilobal yarns as seen in Figure 6. On the other hand, the yarn with a flat cross-sectional shape showed highest shrinkage and this was associated to its high unevenness.

4. Conclusions

Properties of polyester yarns with different cross-sectional shapes were investigated in this study. The yarn with trilobal cross-sectional shape showed the highest tensile strength therefore needed higher load before breaking and this was associated to better clinging ability of trilobal cross-sectional filaments in the yarn structure than that flat and hollow filaments. Elongation values were in agreement with the literature. The yarn with flat cross-sectional shape showed highest unevenness and shrinkage as compared to other two. The unevenness was related to the air-friction forces applied on the filament surface which also affects the cooling behavior of filaments. The high shrinkage of the yarns consisting of filaments with flat cross-sections was associated to high unevenness.

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Author's Contributions

Yasin TOYDEMİR performed all filament productions and tests. Derman VATANSEVER BAYRAMOL supervised the work; prepared the draft and final version of the manuscript.

Statement of Conflicts of Interest

No potential conflict of interest was reported by the authors.

Statement of Research and Publication Ethics

The authors declare that this study complies with Research and Publication Ethics.

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