(REFEREED RESEARCH)

EFFECTS OF FIBER CROSS-SECTIONAL SHAPES ON TENSILE AND TEARING PROPERTIES OF POLYESTER WOVEN FABRICS

LİF ENİNE KESİT ŞEKLİNİN POLİESTER DOKUMA KUMAŞLARIN ÇEKME VE YIRTILMA ÖZELLİKLERİ ÜZERİNE ETKİLERİ

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ABSTRACT

Breaking load and elongation, and tearing load properties of two type fabrics (plain and twill) woven from polyester fibers having round, hollow round, trilobal and hollow trilobal cross-sectional shapes were investigated. The fabrics produced from full fibers had higher breaking elongation and tearing load values but generally lower breaking load values than the fabrics produced from hollow fibers. The highest breaking load value was obtained in twill fabric woven from filaments having hollow round cross-sectional shape, while the highest tearing load value was obtained in twill fabric woven from filaments having round cross-sectional shape. The fabrics constituting filaments with round cross-sectional shapes had the highest breaking elongation values It was concluded that the effect of fiber cross-sectional shape on breaking strength and on tearing strength differed from each other.

Keywords: Fiber cross-sectional shape, Polyester, Woven fabric, Tensile and tearing properties.

ÖZET

İçi dolu ve içi boş dairesel ve trilobal enine kesite sahip poliester liflerden dokunmuş iki tip (bezayağı ve dimi) kumaşın kopma kuvveti, kopma uzaması ve yırtılma kuvveti özellikleri araştırılmıştır. İçi dolu liflerden üretilmiş kumaşlar içi boş liflerden üretilmiş kumaşlara göre daha yüksek kopma uzaması ve yırtılma kuvveti değerleri gösterirken, genellikle daha düşük kopma kuvveti değerleri göstermişlerdir. En yüksek kopma kuvveti değeri içi boş dairesel filamentlerden dokunmuş dimi kumaşta elde edilirken, en yüksek yırtılma kuvveti değeri içi dolu dairesel kesite sahip filamentlerden dokunmuş dimi kumaşta elde edilmiştir. Dairesel kesitli filamentlerden dokunmuş olan kumaşlar en yüksek kopma uzamasına sahiptir. Lif kesitinin kopma mukavemeti ile yırtılma mukavemeti üzerindeki etkisi birbirinden farklılık göstermektedir.

Anahtar Kelimeler: Lif kesit şekli, Poliester, Dokuma kumaş, Çekme ve yırtılma özellikleri.

1. INTRODUCTION

The usage of textile fibers with different cross-sectional shapes in textiles structures for some special needs, i.e. bulkiness, bending rigidity, abrasion resistance, handle, luster, dyeing, coefficient of friction, thermal comfort, liquid transfer, strength, and surface properties, has gained great importance recently. Cross-sectional shapes have a great influence on the surface and on the mechanical properties of fibers. The fiber cross-sectional shape and its related results also affect the properties of yarns and fabrics which are produced from them. The cross-sectional shape of a synthetic fiber produced by the melt spinning method can be easily varied by changing the spinneret hole shape. Besides the round cross-sectional shape, the trilobal cross-sectional shape is the mostly used one in textile applications, especially in the production of fabrics with handle similar to that of silk (1-5).

Hollow fibers with cross-sectional shapes of round, trilobal and square are the examples of fibers which their cross-sections differ from perfect round. These fibers are used commonly for artificial kidneys, cleaning and separation of various liquids and gases, carpets, garments and cushions (6-8). The characteristic properties of hollow fibers are; brightness, large volume, different appearance and heat insulation because of confinement of air. Hollow fibers are more rigid and exhibit more resistance to bending than full fibers in same fineness (9-12).

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Most of the studies performed on fiber cross-sectional shape have focused on its effects on fiber processing behavior and fiber properties (2, 3, 6, 7, 11, 13-19). Fewer researches have proven the effects of fiber cross-sectional shape on various fabric properties, such thermal comfort properties (20-23), microwave absorbing property (24), surface characteristics (1), moisture and liquid transfer properties (25), sound characteristics (26, 27), abrasion resistance (28), handle characteristics (29-31), wicking property (32), and luster characteristics (33). Matsudaira et al. (30) investigated the effects of different fiber cross-sectional shapes on mechanical properties of the woven fabrics composed of polyester continuous filaments.

The breaking strength of a fabric is popularly used both for quality control and as a performance standard. For industrial and other purposes where the fabric is subjected to tension, it is proper that breaking strength to be measured. Tearing strength is one of the most important properties of a fabric. Tearing can be described as the sequential breakage of yarns or groups of yarns along a line through a fabric. The tearing strength is often used to give a reasonably direct assessment of serviceability than the tensile strength and a fabric with low tearing strength is generally an inferior product. In the case of tensile loading, all the yarns in the direction of loading share the load; in tear loading only one, two or at most a few yarns share the load (34, 35). The breaking strength involves the force required to break a large number of yarns simultaneously, and is less affected from yarn and fabric parameters. However the tearing strength is considerably affected by changes in yarn and fabric structural characteristics (36, 37).

The purpose of this research is to investigate tensile and tearing properties of woven polyester fabrics in relation with fiber cross-sectional shapes.

2. MATERIALS AND METHODS

Polyester fabrics were produced from polyester filaments in the form of 150D/48f “Fully Drawn Yarn” that were produced by using the same production parameters other than nozzle hole shapes. Polyester filaments produced in round, hollow round, trilobal and hollow trilobal cross-sectional shapes were twisted at 300 turns/meter. Tensile properties of the yarns (Table 1) were measured by Instron Tensile Tester according to DIN 2062 at ten repeats.

Woven fabrics with two different weave patterns (plain and 2/1 twill) were produced from the twisted polyester filament yarns under the same weaving parameters.

After weaving, the woven fabrics were pre-treated under mill conditions and prepared for dyeing. The fabrics were heatset in a stenter (180°C for 60 s) and they were dyed as tied end-to-end in mill conditions in a sample jet dyeing machine with a black disperse dye (4% owf). After dyeing and reduction clearing, the samples were neutralized, warm and cold rinsed, and dried. The codes and constructional properties of the dyed fabric samples were given in Table 2.

The tests which were performed on dyed fabric samples were given as follows:

Tensile tests of the samples were carried out by using Instron Tensile Tester according to ISO 13934. The tests were performed both in warp and weft directions at five repeats and breaking load and breaking elongation values were determined.

Tear tests of the samples were carried out by SDL M350 Tensile Tester according to TS EN ISO 1397-2 (single rip method). The tests were performed both in warp and weft directions at five repeats and tearing load values were determined.

The means and standard deviations (SD) of data were calculated for all the tests. The results were evaluated statistically according to one-way variance analysis (ANOVA), and the factor was the fiber cross-sectional shape. The means were compared with each other according to the Student-Newman-Keuls (SNK) at 0.05 level.

Table 1. Tensile properties of the twisted polyester filament yarns (mean ± standard deviation).

Fiber cross-sectional shapes	Tenacity (cN/tex)	Breaking elongation (%)	Modulus (cN/tex)
Round	34.80 ± 0.51	46.45 ± 1.74	493.20 ± 8.50
Hollow round	35.70 ± 0.58	38.48 ± 1.96	526.90 ± 12.50
Trilobal	35.20 ± 0.60	41.39 ± 1.53	506.80 ± 7.10
Hollow trilobal	35.40 ± 0.64	34.33 ± 2.05	533.20 ± 15.40

Table 2. Codes and constructional properties of the dyed fabrics.

Fabric code	Fiber cross-sectional shapes	Weave pattern	Warp density (threads/cm)	Weft density (threads/cm)	Warp crimp (%)	Weft crimp (%)
R-P	Round	Plain	52	35	13.2	0.9
HR-P	Hollow round	Plain	52	36	19.9	1.0
T-P	Trilobal	Plain	52	35	13.2	1.0
HT-P	Hollow trilobal	Plain	52	36	15.6	1.0
R-T	Round	Twill 2/1	52	34	8.5	1.0
HR-T	Hollow round	Twill 2/1	52	35	11.4	1.4
T-T	Trilobal	Twill 2/1	52	33	9.4	0.8
HT-T	Hollow trilobal	Twill 2/1	52	35	9.9	0.9

3. RESULTS AND DISCUSSIONS

Tensile test results

Breaking load and breaking elongation results (means and standard deviations) obtained from tensile tests were presented in Figures 1 and 2. Variance analysis and SNK test results which were conducted to observe the effect of yarn cross-sectional shape on breaking load and breaking elongation in warp and weft directions of the weave patterns were presented in Table 3.

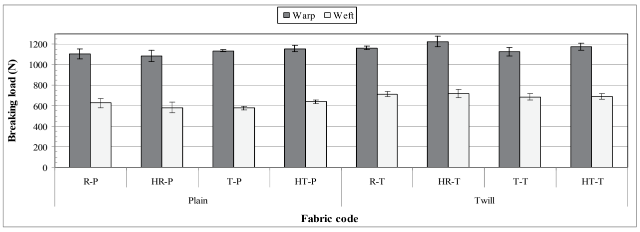

Figure 1. Breaking loads of the woven fabrics in warp and weft directions.

When all the fabric samples were considered, it was observed that the highest breaking load values both in warp and weft directions were obtained in twill fabric produced from hollow round fibers (HR-T).

When breaking load values in warp and weft directions were considered, it was observed that breaking load of plain fabrics were lower than that of twill fabrics. Only the values in warp direction of T-P and T-T did not suit this statement but the difference between them were considerably very small.

Tensile strength of fabrics change mainly due to strength and constructional properties (staple, continuous, etc.) of yarns which constitute the fabrics, and due to fabric constructional properties (pattern, yarn density, yarn count, etc.) (38).

Polyester yarns which were used in the experimental part were spun according to the same production parameters but their fiber cross-sectional shapes were different. For that reason, the differences between yarn strengths might only stem from the difference in fiber cross-sectional shapes. When the breaking strengths of yarns were considered, it was observed that generally all the results were almost the same (Table 1). However, the filament yarns which were produced from hollow fibers (HR and HT) had slightly higher breaking strength results than the filament yarns which were produced from full fibers (R and T). For any weave pattern, the differences in yarn breaking strengths would be expected to affect fabric breaking strengths. According to the variance analysis results of fabric breaking loads, fiber cross-sectional shape generally had a statistically meaningful effect on breaking load of fabrics. However, according to the SNK test results, breaking load values of fabrics produced from fibers having different cross-sectional shapes didn't show distinct clusters from each other. Also, for any weave pattern, significant relationships were not obtained between yarn and fabric strengths although yarn densities were almost at the same level. According to these results it could be stated that the small differences in breaking strengths of the yarns produced from fibers having different cross-sectional shapes did not cause important differences between the breaking strengths of the fabrics because of the interactions emerged from fabric constructional properties.

However, a different behavior was observed in fabrics which constituted hollow round fibers when breaking strengths of fabrics were considered. Although hollow round fibers had the highest breaking strength, the plain fabrics which constituted them had almost the lowest breaking strength. This unexpected behavior was not revealed in twill fabrics. The explanation could be made as follows: Plain fabrics have the highest number of yarn intersection points in unit fabric area. Moreover, hollow fibers have bigger cross-sectional areas. As a result of these two aspects, the fibers compress each other under the applied force during the tensile test and this could cause a decreasing effect on the load which the yarn could bear on the fabric plane axis. In the fabrics woven from other fibers, the cross-sectional areas of fibers are smaller and the probability of yarn flattening is higher. In these fabrics, the yarn compression effect would be expected to be lower. Even though the fabrics had the same yarn densities; the looser structure of twill fabrics together with the usage of yarns which constituted hollow fibers would let yarns to be flattened more during the tensile test. This flattening causes the above mentioned decreasing effect to be lower due to the compression of fibers. Finally, it could be stated that the high yarn strength resulted in high fabric strength in twill fabrics which constituted hollow round fibers.

It must be stated that all fabric samples were woven at the same warp and at almost the same weft densities for the consideration of breaking load values (Table 2). The only difference between the fabric samples was the weave pattern. Generally, fabric tensile strength decreases as number of intersection points in unit fabric area together with yarn crimp increase when yarns are composed of continuous filaments (38). This situation could be explained by the fact that the compressing forces in the radial direction at yarn intersection points do not contribute to the strength in the tensile direction (as fibers are continuous, slippage on each other can not be mentioned) but these forces cause the tension on fibers to increase which is opposite to the characteristics of staple fiber yarns.

When breaking elongation values of all the fabric types were considered, the highest value in warp direction was obtained in plain fabrics constituting full round fibers (R-P) and the highest value in weft direction was obtained in twill fabrics constituting full round fibers (R-T). It was observed in both weave patterns that breaking elongation of the fabrics which composed of round and trilobal full fibers were higher than the ones which composed of hollow fibers.

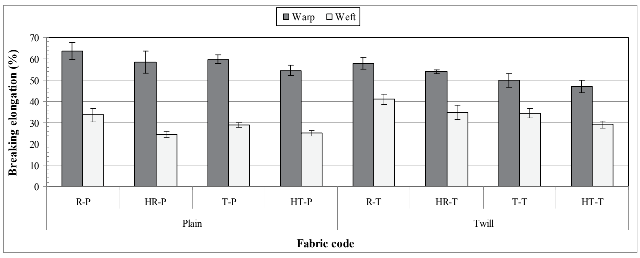

Figure 2. Breaking elongations of the woven fabrics in warp and weft directions.

Table 3. Statistical analysis (analysis of variance and SNK test) results for tensile properties.

Pattern	Direction	Breaking load		Breaking elongation	
		P / Significance	SNK ranges (high to low)	P / Significance	SNK ranges (high to low)
Plain	Warp	0.0485 / *	HT $^{(a)}$ T $^{(ab)}$ R $^{(ab)}$ HR $^{(b)}$	0.0101 / *	R $^{(a)}$ T $^{(ab)}$ HR $^{(ab)}$ HT $^{(b)}$
	Weft	0.0393 / *	HT$^{(a)}$ R $^{(ab)}$ HR $^{(b)}$ T $^{(b)}$	0.0000 / *	R $^{(a)}$ T $^{(b)}$ HT $^{(c)}$ HR $^{(c)}$
Twill	Warp	0.0111 / *	HR $^{(a)}$ HT $^{(ab)}$ R $^{(ab)}$ T $^{(b)}$	0.0000 / *	R $^{(a)}$ HR $^{(b)}$ T $^{(c)}$ HT $^{(c)}$
	Weft	0.3278 / ns	HR $^{(a)}$ R $^{(a)}$ HT $^{(a)}$ T $^{(a)}$	0.0000 / *	R $^{(a)}$ T $^{(b)}$ HR $^{(b)}$ HT $^{(c)}$

*: statistically significant ($P < 0.05$)

^{ns}: non-significant

(a), (b), (c) represent the statistical difference ranges according to SNK test.

According to the statistical analysis results, fiber cross-sectional shape had statistically meaningful effect on breaking elongation values in both weave patterns and in both yarn directions.

According to elongation mechanism of fabrics constituting continuous filament yarns under tensile load, deformation of crimp occurs at first, and then the elongation of the yarns takes place (35). Therefore, the increases in both yarn crimps and yarn breaking elongation values cause fabric breaking elongation values to increase.

When the elongations of the yarns were considered (Table 1), it was observed that yarns constituting full fibers had higher elongations than yarns constituting hollow fibers. This could be the reason why fabrics produced from full fibers had higher elongations than the ones produced from hollow fibers. However, the cross-sectional areas of the full fibers were smaller than that of the hollow ones so that the crimps of yarns which constituted them were lower in fabrics, which led to shorter fabric elongations. When the elongation differences between full and hollow filament yarns were considered in relation with yarn crimps differences in fabrics, it was revealed that the elongation differences were more effective than the crimp differences. Thus, it is an expected result that elongations of fabrics constituting different cross-sectional shape fibers were much more influenced from yarn elongations rather than yarn crimps.

As the yarn densities of the fabric samples were almost the same, it could be stated that for any fiber cross-sectional shape, the effect of fabric construction on fabric breaking elongation values were revealed by yarn crimps. The crimp values of plain patterned fabrics in warp direction were apparently higher than the crimp values of twill patterned fabrics in the same direction (Table 2). Depending on this result and adaptable to the above discussions which were made both on weave patterns and fiber cross-sectional shapes, it was an expected result to get the highest breaking elongation value in plain patterned fabrics which composed of round fibers (R-P). When the breaking elongation results in weft direction were discussed, it was observed that plain fabrics had lower values than twill ones. Considering the crimp values in weft direction, the crimps were almost the same in plain and twill fabrics. It could be stated that the observed values were just the opposite of the expected ones. The reason could be the thermal fixation process of the woven fabrics in a stenter which was conducted to bring the fabrics to the same width after fabric production, so that the tension applied in weft direction to obtain the same fabric width could have made an unexpected effect on elongation mechanism in weft direction during the tensile test. An explanation could be given so that plain fabrics had shorter fabric widths than the twill ones prior to thermal fixation (because of higher crimps of weft yarns) and in order to bring the fabric samples to the same width, the higher stretch applied on plain fabrics in weft direction caused a kind of mechanical conditioning effect that led to lower breaking elongations of them.

Tear test results

Tear test results of the fabrics (means and standard deviations) were presented in Figure 3. Variance analysis and SNK test results which were performed to explain the effect of fiber cross-sectional shape on tearing load of fabrics both in warp and weft directions were presented in Table 4.

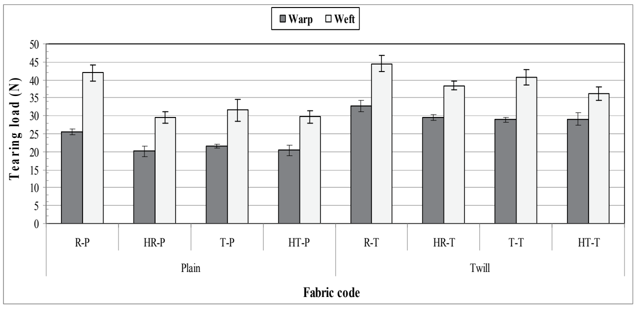

Figure 3. Tearing loads of the woven fabrics in warp and weft directions.

Table 4. Statistical analysis (analysis of variance and SNK test) results for tearing load.

Pattern	Direction	Tearing load	
		P / Significance	SNK ranges (high to low)
Plain	Warp	0.0000 / *	R $^{(a)}$ T $^{(b)}$ HT $^{(b)}$ HR $^{(b)}$
	Weft	0.0000 / *	R $^{(a)}$ T $^{(b)}$ HT $^{(b)}$ HR $^{(b)}$
Twill	Warp	0.0008 / *	R $^{(a)}$ HR $^{(b)}$ HT $^{(b)}$ T $^{(b)}$
	Weft	0.0000 / *	R $^{(a)}$ T $^{(b)}$ HR $^{(bc)}$ HT $^{(c)}$

*: statistically significant ($P < 0.05$)
(a), (b), (c) represent the statistical difference ranges according to SNK test

When all the fabric samples were considered, twill fabrics which were woven from yarns constituting round fibers (R-T) had the highest tearing load values both in warp and weft directions.

According to the statistical analysis results, fiber cross-sectional shape had statistically meaningful effect on tearing load values in both weave patterns and in both yarn directions.

In tear tests, the load which is needed to proceed the existing tear is measured rather than the load which is applied to begin a tear. Therefore, the constructional properties of fabrics have prime importance on the existing tear to proceed. During the test, the increasing force which is applied to the fabric causes first the slippage and then accumulation and tightening of the yarns which are cross to the tearing direction (34, 40). When the amounts of slippage and accumulation increase, tearing load also increases. Therefore, higher tearing load values are expected in twill fabrics when compared with plain ones because yarn intersection points in unit area of twill fabrics are lower than the ones in plain fabrics for the same constructional parameters. So, twill fabrics had easier yarn slippage and yarn accumulation than plain ones.

For fabrics of the same construction at equal yarn strength level, the higher the breaking elongation of yarns the higher will be the tearing strength and energy of fabrics (34). In the present study, the yarns which were produced from full and hollow fibers had almost the same breaking strengths. However, breaking elongations of full filament yarns were distinctly higher than that of hollow filament yarns. Therefore, tearing load of fabrics constituting full fibers were expected to be higher than tearing load of fabrics constituting hollow fibers. Also, the yarns constituting full fibers had smaller cross-sectional areas than the yarns constituting hollow fibers so that yarn slippage and accumulation of these yarns were much easier for the fabrics having the same yarn density and weave pattern.

When tearing load values of fabrics in warp and weft directions were considered, it was found that twill weave fabrics and fabrics constituting full fibers had higher tearing load results than plain weave fabrics and fabrics constituting hollow fibers respectively. These results were also consistent with the above-mentioned evaluations.

4. CONCLUSIONS

Tensile and tearing properties of plain and twill woven polyester fabrics produced from full and hollow, round and trilobal fibers were investigated under the same fabric constructional parameters such as yarn count and twist, yarn density and fabric pattern. The results of the research could be summarized as follows.

The highest breaking load values both in warp and weft directions were obtained in twill fabric produced from hollow round fibers (HR-T). Breaking load of plain fabrics was lower than that of twill fabrics. As it would be expected, breaking load values of filament yarns and twill fabrics which constituted them were consistent with each other. However, this consistence was not observed in plain fabrics. Although filament yarns constituting hollow round fibers had the highest breaking load, plain fabrics woven from them had the lowest breaking load. According to this statement, usage of hollow round fibers in tightly woven structures would not contribute to fabric breaking strength and would not be advantageous.

The highest breaking elongation value in warp direction was obtained in plain fabrics constituting full round fibers (R-P) and the highest value in weft direction was obtained in twill fabrics constituting full round fibers (R-T). It was observed in both weave patterns that breaking elongation of the fabrics which composed of round and trilobal full fibers were higher than the ones which composed of hollow fibers, similar to the breaking elongation values of filament yarns. Breaking elongation of the plain fabrics in warp direction was higher than that of the twill fabrics. However, breaking elongation of the plain fabrics in weft direction was lower than that of the twill fabrics because of the mechanical conditioning effect during stentering.

Twill fabrics which were woven from yarns constituting round fibers (R-T) had the highest tearing load values both in warp and weft directions. Twill fabrics and fabrics constituting full fibers had higher tearing load values than plain fabrics and fabrics constituting hollow fibers, respectively. Fiber cross-sectional shape had a more apparent effect on tearing strength of fabrics than on breaking strength.

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