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The Effect Of Recycled Polyester (rPET) Filament Fiber Properties On Various Woven Fabric Performance Properties

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ABSTRACT

In order to reduce the requirement of waste eliminating and environmental pollution, recycling seems to be a suitable solution. In this study, polyester fibers with three different number of filament and two fiber cross section form (round and plus) were spun from recycled polyethylene terephthalate (rPET) polymer and texturised on an industrial scale. rPET yarns were used as a weft yarn in woven fabric production. Fabric performance properties such as breaking, tearing and seam slippage resistance, weight, breaking elongation, abrasion resistance and air permeability were analysed and compared with that of virgin PET fabrics. As a result of this study, it was determined that virgin and rPET polymers provided almost similar fabric properties. Higher number of filaments gave lower fabric breaking elongation, seam strength, abrasion resistance and air permeability values while led to higher tearing strength. Except fabric weight and tensile properties, filament cross section had a significant affect on other studied fabric properties.

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KEYWORDS

Sustainability, textile waste, plastic wastes, recycle polyester, textured filament yarns, woven fabric properties

1. INTRODUCTION

Today, the production and consumption of packaged products (plastics, metal, glass, paper, cardboard etc.) increase with living standards and population growth. Packaging industry constitutes the biggest part of the world polyethylene terephthalate (PET) consumption with 29% share. PET products are disposed after usage, resulting in waste. PET packaging materials make up a large amount, such as 73% of environmental waste. As well as metal, glass, paper and cardboard, PET wastes are classified as solid waste. In our country, paper/cardboard and then PET wastes constitute the biggest share of solid wastes [1]. While most of these wastes are stored in regular storage facilities, the remaining part is disposed by methods such as burning, burying in the ground, and pouring into the stream. PET wastes, which are tried to be disposed by burying in the soil or storing, can remain for a very long time (up to 3000 years) without degrading. As a result of accumulation, incineration or burial of waste, many ecological problems arise. Reduction of suitable areas for the waste disposal, increased environmental pollution and high disposal costs have led to find new methods for optimum use of resources and waste reduction or utilization. Recycling or recovery seems to be the most likely solution for waste disposal. For this reason, recycling is carried out in order to transform the wastes into secondary raw materials and thus to be included in the production process again. PET can now be recycled by mechanical and chemical methods and in modern facilities. Polyester fibers can be obtained by recycling PET wastes and the resulting fibers are called recycled polyethylene terephthalate or rPET. Therefore, in present days, PET and rPET polymers have been used for polyester spun fiber production.

In this study, polyester fibers with different number of filament (filament fineness) and fiber cross section were produced from rPET polymer in order to investigate the

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possibility of different rPET polyester fibre production from PET wastes. Additionally, it was researched the effect rPET fiber properties on various performance properties of woven fabrics. On the other hand, rPET fibers have already been used for secondary textile products like as carpet bottoms, sleeping bags and insulation materials [2]. Therefore, the use of fibers in different areas needs to be explored and present study will contribute to the evaluation of plastic wastes for new usage areas.

In literature, Uyanık (2019) studied the usage of recycle polyester fiber (rPET) in different yarn count and blend ratio and so to determine which count and blend ratio is more suitable for rPET usage [3]. Qin et al. (2018) melt-spun five different poly (ethylene terephthalate) (PET) materials (two recycled and three virgin ones) into fibres using a capillary rheometer and aerodynamic stretching. In the study, surface smoothness, diameter and mechanical properties of the PET fibres were investigated [4]. Yuksekkaya et al. (2016) studied the properties of yarns and knitted fabrics produced by virgin PET, rPET, virgin and recycled cotton fibers [5]. Sanches et al. (2015) in their study compared the fabric properties knitted from two types 80/20% PET/rPET and 50/50% rPET/cotton yarns [6]. He et al. (2014) compared the surface morphology, mechanical properties, and internal fiber structure of recycled and virgin PET fibers [7]. Telli and Özdil (2015) analysed bursting strength, abrasion resistance, air permeability, surface friction, circular bending rigidity and dimensional stability properties of knitted fabrics produced from rPET and blends with PET and cotton fibers [2]. Koo et al. (2013) studied mechanical and chemical recycling processes and examined their effects on yarn properties such as tensile properties, thermal characteristics, hydrolysis and photo-degradation [8]. Kostov et al. (2013) established proper conditions for secondary polyethylene terephtalate (PET) fiber production. In the study, yarn linear density, breaking strength and elongation and thermal properties of the primary and secondary PET fibers were characterized [9]. Telli and Ozdil (2013) studied the performance of recycle polyester and virgin polyester blended yarns with cotton at different blend ratios (100%, 70/30%, 50/50%, and 30/70%) [10]. Lee et al. (2012) obtained recycled poly(ethylene terephthalate) (PET) chips from used water bottles and was extruded with virgin fiber-grade PET chips in blends of 20, 40, and 70 wt%. The mechanical properties of recycled PET/virgin PET blend fibers were analyzed using thermogravimetric analysis (TGA), differential scanning calorimetry (DSC), bi-refringence measurements, and tensile tests [11]. Abbasi et al. (2007) continuous filament yarns from virgin PET chips and used PET bottles were produced at the two take-up speeds and compared of optical bi-refringence, crystallinity, tenacity, breaking elongation, initial modulus, and shrinkage of yarns [12].

As given above, majority of the studies conducted in the literature focused on the analysis of rPET fiber spinning parameters and also yarn production from rPET staple fibers. However, there is not enough research on the effect of different rPET fiber properties on various fabric properties. The main objective of this research is to present a comparative analysis of breaking, tearing and seam slippage resistance, breaking elongation, abrasion resistance and air permeability properties of multifilament rPET fabrics having different number of filaments and cross-section shapes of a filament. In scope of the study, woven fabrics obtained from virgin and recycled PET polymers were also compared. Therefore, with this study, it will be presented many findings about the effect of polymer type, number of filament (filament fineness) and fiber cross section on woven fabric performance properties.

2. MATERIAL AND METHOD

2.1 Material

In the study, firstly, virgin polyester (PES) yarn with 125 denier filament fineness, 36 number of filament and round section form was produced from semi-matt polyethylene terephthalate (PET) polymer. And then, 125 denier filament fineness and 36-48-72 number of filaments recycled polyester (rPET) yarns were spun with round and plus cross section forms from the recycled polyethylene terephthalate (rPET) polymer. Physical properties of virgin polyethylene terephthalate (PET) and recycled polyethylene terephthalate (rPET) polymers are given in Table 1.

2.2 Method

Fibre production was realized under three stages as following:

- In the first part of the study, partially oriented polyester yarns (POY) were produced from virgin polyethylene terephthalate (PET) and recycled polyethylene terephthalate (rPET) polymers with the usage of the same fineness (125 denier), number of filament (36F) and fiber cross-section form (round), and the obtained yarns were texturized. The effect of polymer type on woven fabric properties was investigated. Virgin polyester yarns were named as PET-36R while recycled yarns were shown by rPET-36R.

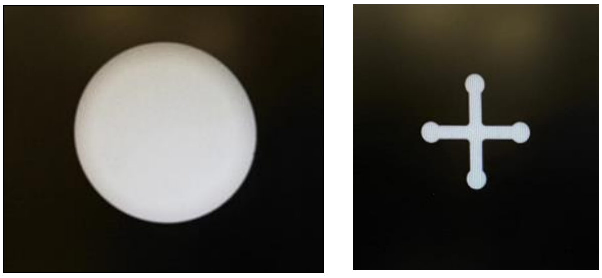
Table 1. Physical properties of virgin (PET) and recycled polyethylene terephthalate (rPET) polymers

PET	Colour	Ash (%)	Polymer Size (Chips/g)	Melting temperature (°C)	Viscosite (dL/g)
PET	Semi-dull	0.3	30	255	0.62
rPET	Semi- dull	0.3	35	253	0.65

- In the second part of the study, partially oriented polyester yarns (POY) having three different number of filaments (36F, 48F and 72F) were produced from rPET polymer with the usage of the same fineness (125 denier) and fiber cross-section form (round), and the obtained yarns were texturized. The effect of different filament fineness on woven fabric properties was examined. rPET-36R, rPET-48R and rPET-72R naming was used for 36, 48 and 72 number of filaments.
- In the third part of the study, round and plus form fiber cross sectional polyester yarns (POY) were produced from rPET polymer with the usage of the same fineness (125 denier) and number of filaments (48F), and the obtained yarns were texturized. In this section, the effect of different fiber cross-section form on woven fabric properties was researched. rPET-48R and rPET-48P naming was used for round and plus fiber cross section forms [13].

Partially oriented (POY) polyester filament yarn production

This study was realized at the polyester yarn production mill, and virgin and recycled polyester fibres were spun based on melt spinning method on an industrial scale. Polyethylene terephthalate (PET) and recycled polyethylene terephthalate (rPET) polymers with chips form were conveyed to silos and subjected to crystallization process. The crystallized polymers were delivered to the drying unit and then to the extruder. The extruder line used in the study has a 4-stage heating system by increasing the amount of heat at each stage. Since the pollution rate of the rPET polymer is higher than that of the original PET polymer, heater temperature in the extruder were increased by 2 degrees for rPET polymer in comparison to that of the PET polymer. Melt polymer was filtered and filter pore size was set as 20 micron. The filtered solution was translated to nozzle having 36, 48 and 72 number of holes, and circular and plus hole cross sections (Figure 1). Each spun polyester fiber was cooled with cold air flow at the exit of the nozzle holes and air flow rate for all yarns was 0.40 m/sec. The spin-finish oil (oil rate 0.4%) was applied to the yarn in order to remove the static load and to decrease the friction coefficient. In partially oriented yarn (POY) production, the draft ratio was close to 1. Virgin and recycled polyester (POY) spun yarn production parameters were given in Table 2. Cross-sectional images of some yarn samples were taken by Projectina DMM2000 model microscope (Figure 2).

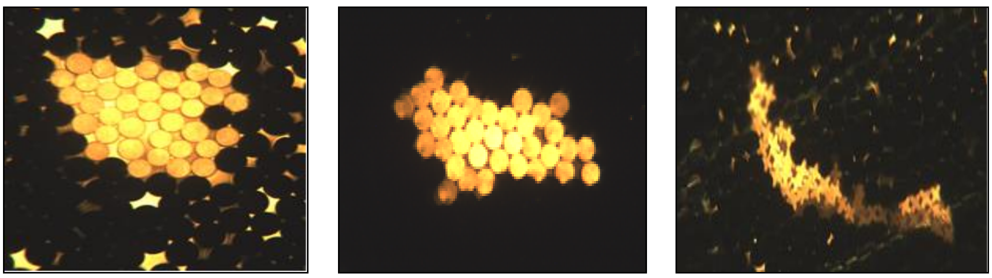


(a) (b)

Figure 1. Circular (a) and plus cross section form (b)

Table 2. Production parameters of the virgin (PET) and recycled polyethylene terephthalate (rPET) yarns

Parameters	Sample type				
	PET-36R	rPET-36R	rPET-48R	rPET-72R	rPET-48P
1st zone temperature of extruder (°C)	274	275	275	275	275
2nd zone temperature of extruder (°C)	279	280	280	280	280
3rd zone temperature of extruder (°C)	284	286	286	286	286
4th zone temperature of extruder (°C)	285	287	287	287	287
Winding speed (m/min)	3200	3200	2900	2900	2900
Godet 1 speed (m/min)	3239	3239	2937	2937	2937
Godet 2 speed (m/min)	3251	3251	2947	2947	2947
Pomp speed (rpm)	14.3	14.3	13	13	13



PET-36R rPET-36R rPET-48P

Figure 2. The optical microscope images of yarn samples

Texturing

Partially oriented (POY) yarns were textured by friction-disc texturing method and friction-disc texturing machine (Barmag). Before texturing, filament yarns were heated, cooled and then drafted between the Godet cylinders and heater. In the texturing process, polyurethane (PU) discs were used and the disc layout consisted of 1-5-1 combination. After the texturing, fixing was realized by second heating process and then cone oil was applied to the yarn. Textured yarn samples were produced on the same line and production parameters are given in Table 3.

Woven fabric production

Fabric samples were woven from all spun and texturized polyester yarn samples. Yarn samples were used as a weft yarn. Jacquard loom woven machine (Itema firm) and sateen weave type was used. During the weaving process, fully drawn polyester yarn (FDY) was used as a warp yarn for all woven samples. Warp yarns were kept constant to analyse the fabric properties. The parameters of woven fabric production are given in Table 4.

2.3. Test and analysis

Fabric weight of all woven fabrics was tested according to TS 251. Tensile and tearing strength, breaking elongation as well as the seam slippage are one of the properties determining the usage area of textile fabrics. Tensile strength and breaking elongation properties of woven fabrics obtained from all texturized polyester yarns were tested according to the strip method by Titan-Universal Strength Tester based on the EN ISO 13934-1 test standard. Tearing strength of woven fabrics was analysed on the Titan-Universal Strength Tester test device using the single-tonque method according to EN ISO 13937-2 test standard. Three samples were tested for each fabric type in the weft and warp direction for tensile properties of the fabrics. Seam slippage resistance is common test for the textile mill and therefore seam slippage resistance properties of woven fabrics were determined by Titan-Universal Strength Tester according to EN ISO 13936-2 (60 N) standard. In order to determine the abrasion resistance of woven fabrics, fabric samples were tested by Martindale abrasion tester according to EN ISO 12947-2 standard and number of abrasion cycles was determined when the first three yarn breaks occurred. Air permeability properties of the fabric samples were tested to evaluate the comfort-related properties of the fabrics according to TS 391 EN ISO 9237 standard by FX 3300 model air permeability.

All the tests were carried out on the same testers and test results were analysed statistically by SPSS 16.0 statistical software to determine any significant differences. ANOVA tests were used for two-way analysis of variance for the analysis of the production parameters, multiple-range test LSD method for the comparison of filament fineness and t-test for the comparison of polymer type and fiber cross section form and ANOVA analyses were performed for $\alpha=0.05$ significance level [13].

3. RESULTS AND DISCUSSION

Within the scope of the study, woven fabrics produced from virgin and recycle polyester filament yarns and their performance properties were examined. Sample codes are summarized in Table 5 and the results for warp and weft directions of woven fabrics were shown by WRP and WFT, respectively.

Table 3. Production parameters for texturing process

Parameters	Sample				
	PET-36R	rPET-36R	rPET-48R	rPET-72R	rPET-48P
Production speed (m/min)	650	600	600	600	600
Draft ratio	1.73	1.71	1.67	1.71	1.67
Disk speed (m/min)	1170	1100	1070	1100	1070
First heater temperature (°C)	180	140	175	140	175
Second heater temperature (°C)	160	130	150	130	150

Table 4. Woven fabric production parameters

Parameters	Value
Machine speed (rpm)	278
Weft density (yarn/cm)	50
Warp density (yarn/cm)	60
Weave type	Sateen (5:1)
Weft yarn	PET-36R, rPET-36R, rPET-48R, rPET-72R, rPET-48P
Warp yarn	30 denier, 12F, FDY circular fiber cross section, 1000 tpm (Z)

Table 5. Explanation for sample codes

Sample code	Polymer	Filamant fineness	Number of filament	Fiber cross-section
PET-36R	PET		36	Round (R)
rPET-36R	rPET		36	Round (R)
rPET-48R	rPET	125 denye	48	Round (R)
rPET-72R	rPET		72	Round (R)
rPET-72P	rPET		48	Plus (P)

3.1 Fabric weight

Fabric weight results of woven fabrics were given in Figure 3. When the results were examined, it was observed that different polymer (PET-36R and rPET-36R) and filament cross section types (rPET-48R and rPET-48P) had no significant effect on fabric weight. As to the effect of filament fineness (number of filament), all the fabrics (rPET-36R, rPET-48R and rPET-72R) had almost similar fabric weight values. However, fabric weight slightly decreased with the increase in the number of filaments and the lowest weight value was obtained in the highest filament number. In any case, as seen in Figure 3, all the fabrics had almost similar fabric weight values and there were not considerably differences in the fabric weight values. On the other hand, this study was realized in a mill and the firm planned to use the yarns for sport textiles. Finer warp yarns were used during the woven fabric production and produced yarn samples were used as a weft yarn. Due to finer warp yarns, the weight of fabric samples varied about 67-69 g/m^2.

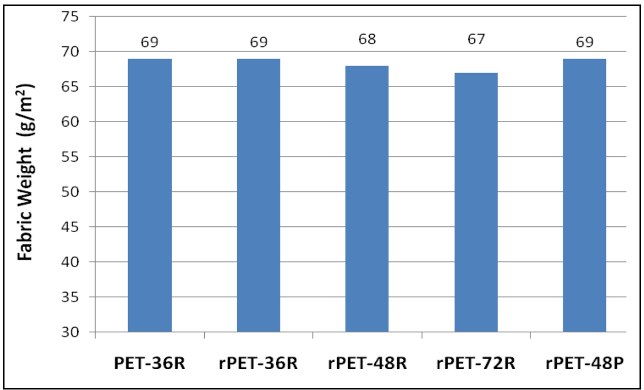


Figure 3. Fabric weight results

3.2. Breaking strength

In order to determine the effect of different polymer type, number of filament and fiber cross section on the mechanical properties of the fabrics, the breaking strength of woven fabrics was tested in the warp and weft directions. Particularly, in the weft direction, it was determined that all the fabrics have tensile strength values above 600 N and they exhibit similar behaviour. As to warp direction, it was observed different trends depending on fiber properties. The results are given in Figure 4 while ANOVA statistical analysis results were shown in Table 6-7.

When the effect of different polymer type on breaking strength of fabrics was examined, similar tensile strength values were determined for the fabrics (PET-36R and rPET-36R) obtained from virgin and recycled PET polymers. Additionally, the polymer type did not have statistically significant effect on the fabric tensile strength values (Table 6). Similar case was also observed for the effect of the number of filaments and filament cross section shape. There were not statistically significant differences in the rPET-36R, rPET-48R and rPET-72R fabrics (Table 7). Also, the differences between circular (rPET-48R) and plus (rPET-48P) fiber cross sections were found statistically insignificant at 5% level (Table 6).

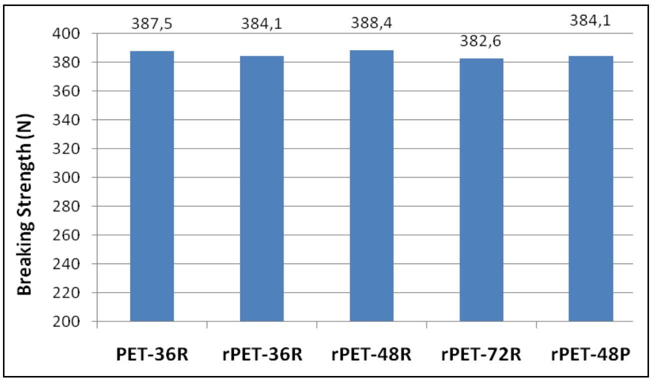


Figure 4. Breaking strength results of woven fabrics for warp direction

Actually, this result is not surprising and it was determined that texturized yarns produced from different polymer type (PET-36R and rPET-36R) and fiber cross section (rPET-48R and rPET-48P) had statistically similar yarn strength values [13]. Therefore, there was not statistically significant difference in breaking strength values of the fabrics woven from PET-36R and rPET-36R, or rPET-48R and rPET-48P yarns.

In literature, Koo et al. (2013) determined that tensile strains of mechanical and chemical recycled PET yarns are lower than that of virgin PET yarn [8]. However, He et al. (2014) indicated that recycled polyester fibers have a better tensile strength and breaking elongation than virgin ones and this result was explained by a bigger intermolecular force and thus, higher degree of crystallinity [7]. Therefore, the findings of virgin and recycled polyester fibers on yarn strength and breaking elongation do not show a single trend. Regarding the effect of filament cross section, Babaarslan and Haciogullari (2013) determined high tenacity and breaking elongation values in round cross sectional shaped POY yarns and reported that tensile properties of the yarns with multi-channelled cross-sectional shapes such as hexsa were low. This case was interpreted that multi-channelled structure makes the yarn less resistant to breaking due to the change in individual fiber tenacity [14]. In this study, it was also determined that the fabric obtained from circular cross section form had insignificantly higher fabric breaking strength values compared to plus cross-sectional shape. On the other hand, Behera and Singh (2014) determined that cross sectional shapes have minor influence on tensile behaviour of polyester fabric [15].

On the other hand, Özkan and Babaarslan (2010) determined that yarn strength values increase up to a certain number of filaments and then tend to decrease with the increase in the number of filaments [16]. This result was similar to the breaking strength of woven fabrics. In fact, they expected an increase in yarn strength and breaking elongation values as the number of filaments in the yarn section increased. However, an unexpected trend was observed and a reduction was determined in yarn strength and elongation values beyond certain number of filaments. The explanation for unexpected case was reported that the yarns with higher number of filaments are exposed to more friction effects during the false-twisted texturing process, and thus some weakening occurs in their structure. As a result, texturing process based on friction method realized in this study might be more effective on breaking strength of the fabrics rather than the effect of number of filaments and filament cross section form. As seen in Table 8, virgin PET polymer gave higher yarn strength values than recycled PET polymer. Additionally, 48F regarding number of filaments and round cross-section regarding filament cross-section form led to produce stronger yarns after texturing process [13]. As to woven fabric, the highest breaking strength values were obtained the woven fabrics having 48F and round cross section, and the lowest values were determined at 72F and plus cross-section.

Table 6. t-test results of fabric tensile strength values for warp direction

Parameter	Sig.
Polymer type	0.105
Cross section form	0.237

Table 7. ANOVA LSD test results of fabric tensile strength values for warp direction

Fabric type		Sig.
rPET-36R	rPET-48R	0.176
	rPET-72R	0.631
rPET-48R	rPET-72R	0.088

Table 8. Yarn strength results after texturing process

Yarn type	Strength (g/denier)
PET-36R	4.63
rPET-36R	4.48
rPET-48R	4.11
rPET-72R	4.00
rPET-48P	3.84

3.3. Breaking elongation

Breaking elongation results of woven fabrics are shown in Figure 5 and ANOVA statistical analysis results are given in Table 9-10.

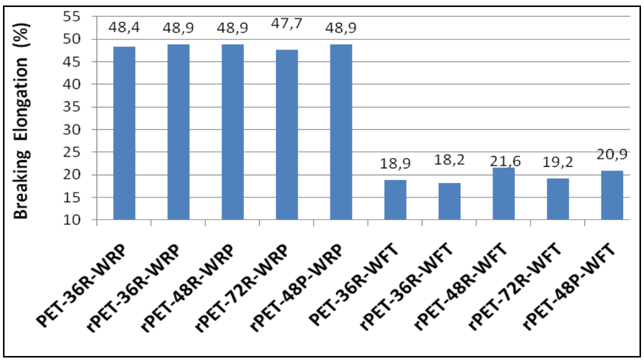


Figure 5. Breaking elongation results of woven fabrics for warp and weft directions

When the effect of the polymer type was examined, it was determined that the woven fabrics obtained from the virgin and recycled PET polymers had statistically similar breaking elongation values in the warp and weft directions (PET-36R and rPET-36R) (Table 9).

Regarding the effect of number of filaments (rPET-36R, rPET-48R and rPET-72R), it was observed different trends in the warp and weft directions. As the number of filament increased, breaking elongation of woven fabrics decreased in warp direction while the values of weft direction changed depending on number of filaments. In weft direction, breaking elongation increased up to a certain number of filaments (from 36 filaments to 48) and then decreased with the higher number of filaments (from 48 filaments to 72). When the results are evaluated statistically, it was determined that there were not statistically significant differences in breaking elongation values of warp direction (Table 10). Therefore, all filaments gave similar fabric breaking elongation values in warp direction. However, the differences in the weft direction was determined to be significant (Table 10) and number of filaments led to significantly different fabric breaking elongation values. As in yarn breaking elongation results after texturing process (Table 11), the highest elongation values were obtained in 48 filaments and the lowest in 36 filaments. In literature, Özkan and Babaarslan (2010) determined similar trend and reported that breaking elongation of texturized polyester yarns slightly increased when the number of filaments increased from 24 to 34. Then the elongation value decreased with the increase in the number of filaments [16]. This case was explained by the fact that POY yarns with high number of filaments exposed to more friction during texturing and the resulting lower breaking elongation due to less resistant structure. The effect of texturing process based on friction-disc method might be the reason for breaking elongation results of woven fabrics.

As to the effect of the filament cross sectional form, fabrics with round (rPET-48R) and plus cross-sections (rPET-48P) forms in the warp direction had statistically similar values (Table 9). In the weft direction, it has been determined that the round form (rPET-48R) gave insignificantly higher breaking elongation values compared to the plus cross section form (rPET-48P). In literature, Babaarslan and Haciogullari (2013) detected high tenacity and breaking elongation values in round cross sectional shaped yarns and tensile properties of multi-channelled cross-sectional shapes were low [14]. Varshney et al. (2011) and Babaarslan and Haciogullari (2013) explained the polyester yarn tenacity having different cross section shapes with the change in individual fiber tenacity [14, 17]. This case might be reason for lower breaking elongation values of woven fabrics obtained from plus cross section form. On the other hand, breaking elongation of the fabrics woven from plus cross sectional shape might be decreased as a result of subjecting more friction during texturing process due to higher surface area of the rPET-48P filament (Figure 2).

3.4. Tearing strength

Tearing strength results of woven fabrics are indicated in Figure 6 and ANOVA statistical analysis results for mean values are given in Table 12-13.

When the effect of polymer type on the tearing strength of fabrics (PET-36R and rPET-36R) was examined, different trends were observed in the weft and warp directions. Higher strength values were determined in the fabrics obtained from rPET (rPET-36R) polymer in the warp direction while PET polymer (PET-36R) gave better values in the weft direction. However, the differences in tearing strength values of warp direction were found statistically insignificant (Table 12). However, in weft direction, the differences in tearing strength of PET-36R and rPET-36R fabrics were statistically significant.

On the other hand, tearing strength values decreased slightly in warp direction while increased in weft direction with higher number of filaments (rPET-36R, rPET-48R and rPET-72R). In particular, the differences in tearing strength values of the warp direction were found statistically insignificant level for three different number of filament values. As to weft direction, all fabrics had almost statistically similar tearing strength values. However, difference in the fabrics between rPET-36R and rPET-48R was found statistically significant level (Table 13). rPET-48R and rPET-72R fabrics having higher number of filaments had similar fabric tearing strength values. In literature, tearing strength is defined as a function of the strength of the yarns in a fabric and the force required to make them slip over the crossing threads [18]. When the friction between the yarns in a fabric structure is increased, freedom of movement of the yarns decreases. Thus, the yarns do not slide over each other and this case lead to a reduction in tearing strength values. Hu and Chan (1998) reported that slack and exposed structures allow the yarns to transfer and group together, and thus the result in a great tearing strength in comparison to tight structures [19]. Thanikai Vimal et al. (2020) reported that fabrics with longer floats have higher tearing strength in comparison of the fabric having no floats like plain weave [20]. From these findings, it was thought that the increased surface area with higher number of filaments in the yarn cross section prevent the filament slippage during tearing and thus the fabrics having higher number of filaments give lower tearing strength values.

As the filament cross section form was circularized, it was determined that fabrics with round (rPET-48R) and plus cross section (rPET-48P) form in warp direction had statistically similar values. In the weft direction, as in breaking strength results, it was found that the round form gave higher tearing strength values and the difference was found statistically significant level (Table 12). In literature, Behera and Singh (2014) worked on the characterization of the effect of fibre cross-sectional shape on various structure–property relationship of fabric. In the study, mean frictional coefficient calculated twelve different cross-sectional shape filament yarns such as circular, octagonal, plus, square, dumble, trilobal etc. mean frictional coefficient was 0.127 for circular cross-section while it was 0.138 for plus one [21]. Therefore, as seen in Figure 2, higher surface area and friction characteristic of plus cross-section might be a reason for lower tearing strength of the fabrics produced with this cross-section.

Table 9. t-test results for fabric breakage elongation values

Parameter	Sig.	
	Warp direction	Weft direction
Polymer type	0.159	0.288
Cross section form	0.989	0.288

Table 10. ANOVA LSD test results for fabric breaking elongation values for warp and weft directions

Fabric type		Sig.	Fabric type		Sig.
rPET-36R-WRP	rPET-48R-WRP	10.000	rPET-36R-WFT	rPET-48R-WFT	0.000*
	rPET-72R-WRP	0.283		rPET-72R-WFT	0.017*
rPET-48R-WRP	rPET-72R-WRP	0.283	rPET-48R-WFT	rPET-72R-WFT	0.000*

*: The mean difference is significant at the 0.05 level.

Table 11. Yarn breaking elongation results after texturing process

Yarn type	Breaking elongation (%)
PET-36R	26.04
rPET-36R	23.93
rPET-48R	25.52
rPET-72R	25.00
rPET-48P	18.68

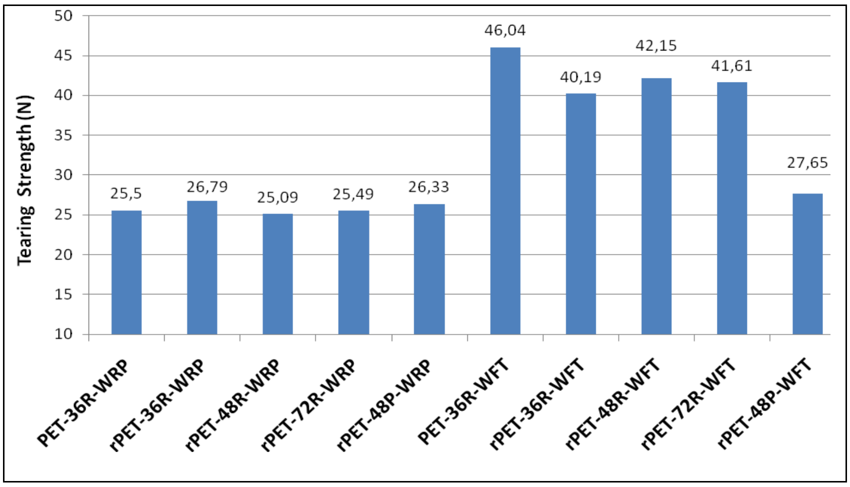


Figure 6. Tearing strength results of woven fabrics

3.5. Seam slippage resistance

Seam slippage resistance results of woven fabrics are shown in Table 14. The seam slippage resistance was given as the shear length and seam resistance to slippage and hence seam strength decreases as the shear length increases.

When the shear length results were examined, it was determined that the values of warp direction are similar in general, the polymer type, the number of filaments and the cross-sectional form have no significant effect on shear length values. As to weft direction, the results indicated that shear length values of the fabrics obtained from the rPET (rPET-36R) polymer was somewhat higher and therefore rPET-36R fabric had slightly lower seam slippage resistance than PET-36R. On the other hand, a clear trend was not observed in shear length values of rPET-36R, rPET-48R and rPET-72R fabrics, as the number of filaments increased. However, the highest shear length and hence the lowest seam slippage resistance was determined in rPET-72R having the highest number of filaments (72 filament). On the other hand, the highest seam slippage resistance values were obtained in rPET-48R fabric with 48 filaments. Actually, an improvement in seam slippage resistance values were expected from higher number of filaments due to increased surface area. However, in the study, rPET-72R woven fabric having higher number of filaments gave lower seam slippage resistance values. The decrease in filament strength given in Table 8 was thought to be more effective on lower seam slippage resistance rather than the increase in surface area against slip resistance. As a consequence, strength of the filament and hence resistance to seam slippage decreased as the number of filaments increased. Coarser filaments having lower number of filaments might give higher seam slippage resistance and seam strength values.

Regarding the effect of the filament cross section form, it was found that the slip length and therefore seam slippage resistance values in the weft direction (rPET-48R and rPET-48P) were the same. In warp direction, the fabrics with a circular (rPET-48R) section form had a higher shear length and hence a lower seam slippage resistance. This result meant that higher seam slippage resistance is obtained as the fiber cross section move away from circularity. Increased surface area with plus cross section form (mentioned in tearing strength results) might be a reason for better seam slippage resistance of plus cross section shape.

Table 12. t-test results of mean fabric tearing strength values of woven fabrics

Parameter	Sig.	
	Warp direction	**Weft direction**
Polymer type	0.604	0.039*
Cross section form	0.401	0.006*

*: The mean difference is significant at the 0.05 level.

Table 13. ANOVA LSD test results for mean fabric tearing strength values

Fabric type		Sig.	Fabric type		Sig.
rPET-36R-WRP	rPET-48R-WRP	0.064	rPET-36R-WFT	rPET-48R-WFT	0.027*
	rPET-72R-WRP	0.135		rPET-72R-WFT	0.148
rPET-48R-WRP	rPET-72R-WRP	0.611	rPET-48R-WFT	rPET-72R-WFT	0.254

*: The mean difference is significant at the 0.05 level.

Table 14. Seam length results of woven fabrics

Shear length (mm)	PET-36R	rPET-36R	rPET-48R	rPET-72R	rPET-48P
Warp direction	2	2	3	2	2
Weft direction	4.5	5	4	6	4

3.6. Abrasion resistance

Abrasion resistances of the textile materials are important features to determine using life of the fabrics. In addition, abrasion resistance is one of the most important mechanical properties that affect fabric appearance during and after use. In order to evaluate the abrasion resistance properties of woven fabrics, two samples of each fabric type were abraded between 8.000-50.000 rubbing cycles. Abrasion resistance of the fabrics were assessed according to the rubbing cycles which led to first three yarn breakages. As is known, the abrasion resistance of the woven fabrics increases with the increase in abrasion cycles where the yarn break is observed. According to the results given in Table 15, 1, 2 and 3 symbolizes the first, second and third yarn breakages, respectively. As seen, yarn breakages were observed at 40.000 and above rubbing cycles for the rPET-36R coded fabrics obtained from rPET polymer, while yarn breakages occurred between 25.000-32.000 rubbing cycles in PET-36R fabric obtained from PET polymer. Therefore, the fabrics woven from recycled polyester yarns represented a bit slight more resistance to abrasion than the fabrics with virgin polyester weft yarns.

Regarding the effect of number of filaments, yarn breakages were determined at lower rubbing cycles as the number of filaments increased. This case indicated that resistance to abrasion decreases with finer filaments. Yarn breakages were observed at 40.000 rubbing cycles for rPET-36R having the lowest number of filaments (36F) while it was 12.000-15.000 for rPET-72R having the highest number of filaments (72F). As similar to this result, Akgun (2014) reported that high number of filaments in yarn structure led to higher structural abrasion of the textured polyester woven fabric surfaces [22]. This case was explained that yarns with high number of filaments were more affected by abrasion and number of the pulled filaments from yarn surfaces increased as abrasion cycles increased. Lower abrasion resistance of the polyester yarns having higher number of filaments might be resulted from lower individual fiber tenacity of these yarns. As seen in Table 8, yarn tenacity decreased with higher number of filaments and this case led to lower resistance to abrasion for rPET-72R than that of the rPET-36R and rPET-48R.

On the other hand, effect of cross section form on abrasion resistance, the first three yarn breakages were observed in 22.000-28.000 rubbing cycles in rPET-48R fabric with round section form and in 8.000-10.000 cycles in rPET-48P fabric with plus cross section form. Abrasion resistance results indicated that rPET polyester filament yarns having lower number of filaments and round cross section form enhance the resistance to abrasion. Shape of filament cross section directly effects abrasion resistance. In literature, it was stated that woven fabrics with high surface roughness were affected more by abrasion. Plus filament cross section had higher surface areas than round cross section and therefore this case led to more abrasion. As stated in breaking strength results of woven fabrics, another reason might be higher fiber tenacity of round cross section form. In literature, it was stated that tenacity values of the two fibers with the same length and linear density values in the circular and trilobal cross-sectional shapes were different [14, 23]. On the other hand, Behera and Singh (2014) determined that yarn tenacity values of multifilament yarns are 2.52 g/denier for circular and 2.41 g/denier plus cross-sections [21]. In present study, it was also determined that yarn tenacity is 4.48 g/denier for round and 3.84 g/denier for plus cross-section (Table 8). As similar to this case, the higher fiber tenacity resulted from round cross section shape caused more resistance to yarn breakages.

3.7. Air permeability

Air permeability results of woven fabrics are shown in Figure 7 and ANOVA statistical analysis results are given in Table 16-17.

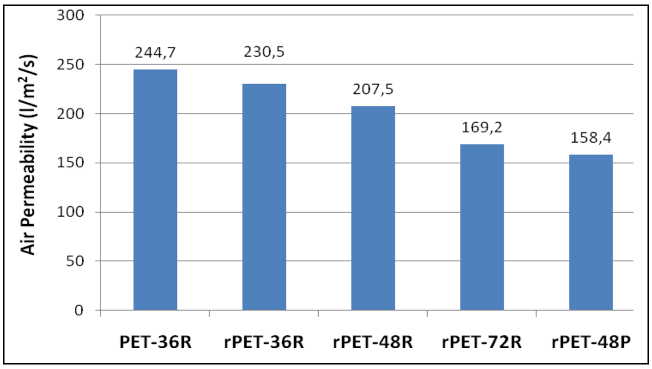


Figure 7. Air permeability results

When the effect of polymer properties on the air permeability of the fabrics was examined, it was determined that the PET-36R fabrics obtained from the PET polymer had significantly more air permeability values than the rPET-36R fabrics woven from rPET yarns (Table 16).

Table 15. Abrasion cycle results occurred the first three yarn breakages

Sample	Rubbing cycles (rpm)												
	8000	10000	12000	14000	15000	22000	25000	28000	30000	32000	40000	45000	50000
PET-36R (sample 1)	-	-	-	-	-	-	1	2	-	3	-	-	-
PET-36R (sample 2)	-	-	-	-	-	-	-	-	1	2	-	-	-
rPET-36R (sample 1)	-	-	-	-	-	-	-	-	-	-	1	2	3
rPET-36R (sample 2)	-	-	-	-	-	-	-	-	-	-	-	1	3
rPET-48R (sample 1)	-	-	-	-	-	1	2	3	-	-	-	-	-
rPET-48R (sample 2)	-	-	-	-	-	-	1	3	-	-	-	-	-
rPET-72R (sample 1)	-	-	1	2	3	-	-	-	-	-	-	-	-
rPET-72R (sample 2)	-	-	-	2	3	-	-	-	-	-	-	-	-
rPET-48P (sample 1)	2	3	-	-	-	-	-	-	-	-	-	-	-
rPET-48P (sample 2)	1	3	-	-	-	-	-	-	-	-	-	-	-

Regarding the effect of filament fineness, the air permeability values tended to decrease as the number of filaments increased in yarns with the same yarn fineness. It was determined that rPET-36R fabric with the lowest number of filaments (36 filament) had the highest air permeability while rPET-72R fabric having the highest number of filaments (72 filament) led to the lowest air permeability value. Additionally, the difference between the air permeability values of all three fabrics was found to be statistically significant (Table 17) and therefore it was concluded that number of filaments affected the air permeability of the fabrics significantly. As known, air permeability depends on porosity of textile materials and permeability improves with the increase in porosity. Behera and Singh (2014) stated that air permeability of the fabrics decreases with the increase of filament fineness as a consequence of higher specific surface area of the filament [15]. As seen in Figure 2, lower porosity resulted from higher number of filaments in yarn structure led to lower air passage from the fabric. Lower air permeability of the woven fabrics obtained from higher number of rPET filaments was agreed with this finding.

As to the effect of the filament cross section form, air permeability results of the woven fabrics indicated that round filament cross section (rPET-48R) gave significantly higher air permeability than plus cross section form (rPET-48P) (Table 16). In literature, a geometrical parameter of Shape Factor (SF) was defined that relates a closed curve path to its equivalent circle perimeter to express the irregularity of the cross-section. Various researchers have expressed this relationship in different ways. Neckar (1998) defined SF≈0 for circular cross-section [24]. SF and hence surface area of the fiber/filament increase with the irregularity of fibre cross-sectional shapes [15]. In consequence of higher specific surface area of each fiber/filament, space between the fibres in the fabric decrease and this case will increase higher drag resistance to air and result in low air and water vapour permeability for these fabrics. For plus cross section, it was stated that actual SF was 0.361 while theoretical SF was 0.52 [25]. Higher surface area of plus cross-section form might be a reason for lower air permeability of rPET woven fabrics comparing with that of the circular cross section

Table 16. t-test results of air permeability values of woven fabrics

Parameter	Sig.
Polymer type	0.805
Cross section form	0.000*

*: The mean difference is significant at the 0.05 level.

Table 17. ANOVA LSD test results for fabric air permeability values

Fabric type		Sig.
rPET-36R	rPET-48R	0.000*
	rPET-72R	0.000*
rPET-48R	rPET-72R	0.000*

*: The mean difference is significant at the 0.05 level.

4. CONCLUSION

In this study, it was studied the effect of virgin and recycled PET polymer, number of rPET filament and rPET filament cross section form on breaking, tearing and seam strength, breaking elongation, abrasion resistance and air permeability properties of woven fabrics. The results are as following:

- Regarding the effect of polymer type, it was not determined any significant differences in fabric weight, breaking strength and breaking elongation results. However, the fabrics obtained from virgin PET polymer gave better tearing strength, seam slippage resistance and air permeability while fabrics woven from recycled polyester yarns represented a bit slight more resistance to abrasion than the fabrics with virgin polyester yarns.
- Except fabric tearing strength results of weft direction, the differences in all analysed performance properties of the woven fabrics obtained from virgin and recycled PET polymer were not statistically significant and therefore both polymer types gave similar fabric properties.
- The results of warp direction were found statistically insignificant level due to the usage of FDY polyester yarn (30 denier and 12F) in warp direction of all woven fabrics.
- As to the effect of number of filaments, it was determined that woven fabrics having 36, 48 and 72 filaments had statistically similar fabric weight and breaking strength values. On the other hand, the results indicated that higher number of filaments gave lower fabric breaking elongation, seam slippage resistance, abrasion resistance and air permeability values while led to higher tearing strength.
- The effect of increased surface are with higher number of filaments might be the main reason for fabric breaking elongation, tearing strength and air permeability results. On the other hand, increased fiber fineness and hence lower fiber tenacity resulted from higher number of filaments in the same yarn cross section was thought to have affected on seam slippage resistance and abrasion resistance results.
- Except fabric weight and tensile properties, filament cross section shapes had a significant affect on other studied fabric properties. It was determined that circular cross section form gave higher fabric breaking strength and elongation, tearing strength, abrasion resistance and air permeability values while higher seam slippage resistance values were obtained with plus cross section form.
- Higher individual fiber tenacity of circular cross section form might be a reason for better tensile strength, breaking elongation, tearing strength and abrasion resistance values while increased surface area of plus cross section shape might be effective higher seam slippage resistance and lower air permeability results.

In recent years, recycled fibre usage has been attracting attention due to concerns about environment protection and increased raw material costs. This research makes several noteworthy contributions to production possibility of polyester yarns from polyethylene terephthalate (PET) wastes exhibiting comparable woven fabric properties with that of the virgin polyester yarns such as fabric strength and comfort. Additionally, this study showed that polyester yarns with different filament fineness and cross-sectional shapes can be produced from recycled PET polymer. Recycled polyester yarn could be used as an alternative to the virgin polyester yarns and this case enhances to benefit the low price and enviromentally friendly of the recycled material.

As reported, this study was realized at the polyester yarn production mill, and virgin and recycled polyester fibres were spun based on melt spinning method on an industrial scale. Due to limited yarn length, the current study has only examined the recycled polyester yarns as a weft yarn. The scope of this study was limited in terms of the analysis of usage of the recycled polyester yarns as a warp yarn and also fabric production parameters such as different weave types, warp/weft yarn densities (fabric weight), etc. and limited fabric properties. A future study investigating various woven fabric properties produced with different fabric production parameters would be very interesting. Considerably detailed work will need to be done to determine the tensile properties of the fabrics produced from recycled yarns and to compare with that of the virgin one. It is recommended that further research would be undertaken about knitted fabric properties.

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