TEKSTİL VE MÜHENDİS

(Journal of Textiles and Engineer)

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A Comparative Study on Mechanic and Structural Properties of Recycled Pet (R-Pet) and Viscose Blended Yarns

Geri Dönüşümlü Pet (R-Pet) ve Viskon Karışımlı İpliklerin Mekanik ve Yapısal Özellikleri Üzerine Karşılaştırmalı Bir Çalışma

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Online Erişime Açıldığı Tarih (Available online):30 Eylül 2022 (30 September 2022)

Bu makaleye atıf yapmak için (To cite this article):

Murat DEMIR (2022): A Comparative Study on Mechanic and Structural Properties of Recycled Pet (R-Pet) and Viscose Blended Yarns, Tekstil ve Mühendis, 29: 127, 133- 139.

For online version of the article: https://doi.org/10.7216/1300759920222912703

TMMOB Tekstil Mühendisleri Odası
UCTEA Chamber of Textile Engineers
Tekstil ve Mühendis
Journal of Textiles and Engineer

Yıl (Year) : 2022/3
Cilt (Vol) : 29
Sayı (No) : 127

Araştırma Makalesi / Research Article

A COMPARATIVE STUDY ON MECHANIC AND STRUCTURAL PROPERTIES OF RECYCLED PET (R-PET) AND VISCOSE BLENDED YARNS

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Gönderilme Tarihi / Received: 25.04.2022
Kabul Tarihi / Accepted: 01.08.2022

ABSTRACT: Environmental pollution caused by plastic bottles is shown as one of the biggest environmental disasters of recent years. Not only in the form of plastic bottles, but the microplastics formed from these bottles threaten many areas of life such as soil and ocean pollution. Converting plastic bottle wastes into textile products is one of the effective methods that not only prevents environmental pollution caused by these materials but also ensures the reuse of raw materials. In this study, the properties of blended yarns produced using viscose fibers and recycled polyethylene terephthalate fibers (r-PET) obtained from recycling plastic bottles were investigated. Within the scope of the study, blended yarns at the ratios of 33-67%, 50-50%, 67%-33% r-PET/viscose fibers, and also 100% r-PET yarns were produced. The physical, mechanical, and structural properties and also cross-sectional images of the yarns examined. The results show that the blending ratio is statistically significant on the yarn properties in general. Among the measured properties, yarns containing 33% and 50% r-PET fibers generally show similar physical, structural and mechanical properties. It is revealed that blended yarns consisting of 67% r-PET have generally better properties in comparison with other types of blended yarns. Therefore, it is possible that higher r-Pet fiber fraction in yarn can create more positive effects on yarn properties and the results are comparable with 100% r-PET yarns.

Key Words: r-PET fibers, recycle, blended yarns, yarn properties, yarn cross section

GERİ DÖNÜŞÜMLÜ PET (R-PET) VE VİSKON KARIŞIMLI İPLİKLERİN MEKANİK VE YAPISAL ÖZELLİKLERİ ÜZERİNE KARŞILAŞTIRMALI BİR ÇALIŞMA

ÖZ: Plastik şişelerin sebep olduğu çevre kirliliği, son yılların en büyük çevre felaketlerinden biri olarak gösterilmektedir. Sadece plastik şişe formunda değil, bu şişelerden oluşan mikroplastikler toprak ve okyanus kirliliği gibi yaşamın birçok alanını tehdit etmektedir. Plastik şişe atıklarının, tekstil ürünlerine dönüştürülmesi, bu materyallerin sebep olduğu çevre kirliliğini önlemekle beraber, hammaddelerin yeniden kullanılmasını da sağlayan etkili yöntemlerden bir tanesidir. Bu çalışmada, plastik şişelerin geri dönüştürülmesinden elde edilen geri dönüştürülmüş polyester lifleri (r-PET) ve viskoz lifleri kullanılarak üretilen karışım ipliklerinin özellikleri incelenmiştir. Çalışma kapsamında, %33-67%, %50-50%, %67-%33 r-PET/viskoz liflerinden karışım iplikleri ve 100% r-PET iplikleri üretilmiştir. İpliklerin enine kesit görüntüleri, fiziksel, mekanik ve yapısal özellikleri karşılaştırmıştır. Sonuçlar, karışım oranının iplik özellikleri üzerinde istatiksel olarak anlamlı olduğunu göstermektedir. Ölçülen iplik özellikleri arasında, %33 ve %50 oranında r-PET lifleri içeren ipliklerin genelde benzer fiziksel, yapısal ve mekanik özellikler gösterdiği görülmektedir. %67 r-PET kullanılan karışım ipliklerinin ise genel olarak iplik özellikleri üzerine daha fazla olumlu etki ettiği ve sonuçların 100% r-PET ipliklerine benzer olduğu söylenebilir.

Anahtar Kelimeler: r-PET lifleri, geri dönüşüm, karışım iplikleri, iplik özellikleri, iplik enine kesiti

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***DOI:** https://doi.org/10.7216/1300759920222912703 www.tekstilvemuhendis.org.tr*

1. INTRODUCTION

Growing population, increasing market demand, fast fashion trends, developments in production technology etc. have led to a rapid increase in fiber consumption in recent years. According to the Preferred Fiber & Materials Market Report, in 2019 total fiber production was 119 million mt and it was doubled in the last 20 years. Besides, it is projected to grow another 30 % and reach 146 million mt in 2030. Polyethylene terephthalate (PET) has dominated the market alone and has approximately half of the market in the sum of fiber production. However, the share of recycled .polyethylene terephthalate in that amount (r-PET) is only 14% in 2019 [1].

Raising concern for environmental pollution, the desire to reach sustainability in the production process has accelerated the recycling of PET as a non-biodegradable material. Chen and Burns [2] claimed that recycling PET is significantly prevent environmental pollution as it compared to produce virgin PET from new raw material and estimate reduce 85% of air-pollution. Recycling PET bottles is also help to prevent ocean pollution [3]. The recycling process is grouped into four main categories primary, secondary, tertiary, and quaternary approaches ([4], as cited in [5]). Primary recycling is defined as converting recycling material to its original form. Secondary recycling is containing production of new material with different chemical, mechanical or physical properties. In the third group, recycled material is converted to chemicals and fuels while in quaternary recycling is the burning waste. The primary collecting, also called closed-loop recycling, is the process of converting post-consumer textile wastes to yarns. Secondary recycling, also known as open-loop recycling, converts recycling products to new products for the different application areas including converting plastic bottles to textiles ([4], as cited in [5]). Chemical, thermal, and mechanical processes are applied to recycle PET bottles and it is known that the recycling method and recycling processes affect the quality of the r-PET fibers [6]. Koo *et al*. [7] compared the mechanical and chemical recycled process on the r-PET fibers and concluded that chemically recycled fibers have higher tenacity values. For mechanical recycling, each production step including the opening and cleaning processes affects the quality of the fiber [8].

One of the most popular ways to recycle and reuse plastic bottles is to produce fiber from these mechanically recycled bottles. The use of r-PET in textiles has attracted the attention of researchers, and there are studies investigating the usage of r-PET in textiles. Sadeghi *et al*. [9] summarized the advantages and disadvantages of r-PET yarns. According to their study, decreasing thermal resistance, lower hairiness, lower tenacity, and interlocking fibers are the disadvantages of the r-PET yarns while easier heat stabilization, better crimp, and tensile properties, raising bending and shear rigidity, and good adhesion are the advantages of the r-PET yarns.

Blending recycled fibers with other virgin fibers is the popular way of the yarn production. Majumdar *et al*. [10] researched the properties of recycled fiber in the yarn and fabric structure. In the scope of the study cotton, PET, and r-PET fibers were blended at different ratios for yarn production. Comparing results showed that virgin PET yarns have higher tenacity values than r-PET yarns and it was explained by the crystallinity of recycled fibers that related to ester bonds.R-PET fibers recycled from a plastic bottle have gone through melting processes twice, first for the production of bottle manufacturing and second for fiber manufacturing and as the result of this repetitive process, ester bonds could be damaged and cause lower tenacity values. However, elongation of the r-PET was found higher than virgin PET. Lower tenacity values of the r-PET than virgin PET yarns was also reported in the paper of Sarıoğlu [11]. Nohut *et al.* [12] produced cotton/r-PET and viscose/r-PET yarns at 70/30 % and 50/50 % blend ratios in ring spinning system. In addition, cotton-virgin PET and viscose-virgin PET yarns at the same blend ratios were also produced. Comparing yarn properties showed that, viscose blended yarns have greater tenacity than cotton blended yarn due to regular fiber distribution in the yarn cross-section. In contrary to the related literature, r-PET fibers have greater tenacity values than virgin PET (v-PET) fibers and it was related to the improvements in the recycling process. The positive relation between better fiber distribution and yarn tenacity is also mentioned in the study of Özdil and Telli[13]. In the study, properties of different ratios of cotton, r-PET, and v-Pet yarns were compared. It was stated that despite the r-PET fibers having lower tenacity values than cotton fibers, the increasing blend ratio of r-PET fibers in the yarns showed a positive correlation to the tenacity values of the yarns thanks to the better fiber orientation. Besides, 100% PET and 50% PET- 50% r-PET yarns displayed similar elongation values and increasing the r-PET ratio in the yarn resulted in higher hairiness values than 100% v-PET yarns.

The optimum blend ratio of r-PET can display desired results for the specific application area. Uyanık [14] compared the properties of cotton/r-PET yarns at different linear densities and concluded the optimum blend ratio as up to 65% for Ne 30 yarns according to the yarn properties. In another study, 50% r-PET/ 50% cotton blended OE yarns display similar results comparing the same ratio of cotton and virgin PET yarns and suggested as an eco-friendly yarn production [15].

Thermal comfort properties of the fabrics made of r-PET blended yarns were also investigated in the literature. Kumar and Raja [16] studied the thermal properties of the socks made from r-PET/virgin cotton and its blends. In the scope of the study, socks were made from 100 % r-PET, 100 % virgin cotton, 70%-30%, 50%-50%, and 30%-70%, cotton/r-PET blend yarns. Results showed that r-PET yarns possess lower thermal conductivity than virgin cotton. The increasing blend ratio of r-PET fibers resulted in greater thermal resistance, air permeability, water and vapour permeability also decreasing the thermal conductivity. Therefore r-PET blended socks achieve higher thermal resistance than cotton yarns. Majumdar *et al*. [10] also stated that greater r-PET proportion than v-PET in the cotton, v-PET and r-PET blended yarns reduces the thermal resistance of woven fabrics and it was related to higher molecular weight and intrinsic viscosity of r-PET than those of v-PET. The fabric properties made of the r-PET/cotton blended yarns having same linear densities of showed that the increasing r-PET ratio resulted in thinner, lighter, and more porous fabrics with higher thermal conductivity, air permeability, and lesser thermal resistance [17].

The recent trend of converting plastic bottles to fibers meets the demand of preventing environmental pollution caused by plastic wastes and efficient ways of reusing raw materials. This study focuses on the properties of r-PET/viscose blended yarns and the effects of blend ratio on the yarn properties. For this purpose at 33%/67%, 50%/50%, 67%/33% blend ratios of r-PET/viscose yarns were produced at same linear densities. In addition, 100% r-PET yarns were also produced. In order to visually analyze the fiber position in the blended yarn structure as well as evaluate the blending process in blended yarn homogeneity, yarn cross-sectional images were also presented. The structural, mechanical and physical properties of the yarns were tested and statistically analyzed at the confidence level of 95%.

2. MATERIAL AND METHODS

2.1 Materials

In the scope of the study, recycled PET and viscose blended yarns were produced. Mechanically recycled r-PET fibers were used from REPREVE which is a commercial trademark of UNIFI. Viscose fibers were used from Lenzing. Details of fiber properties are given in Table 1.

2.2 Method

All slivers used in the study were produced with Rieter B34 Bale opener, Rieter A81 UniBlend, Rieter A79 UniStore and Rieter C60. Rieter SBD-45 draw frame was used for drawing process at 100m/min production speed and Ne 0.120 slivers were produced. Marzoli FTSDN was used for roving production. Total draft was 7.5 in the roving frame and Ne 0.90 rovings were produced. Pinter Merlin laboratory type spinning machine was used for all yarn production. The spindle speed is 11950 rpm/min. The theoretically calculated total draft is 33.3 but after checking yarn count, total draft is set as 36.2. Linear densities of roving and yarn and twist coefficients for all blended yarn types are presented in Table 2.

2.2.1 Preparation of Yarn Samples for Sectioning

The hard sectioning method is used for yarn cross section samples. Each sample of the yarn firs placed in the circular specimen (Figure 1a) and then embedded in the mould with historesin (Leica Historesin Embedding Kit) as it was described in the study of Demir [18] (Figure 1b). Leica Rotary microtome (RM2125RT) was used for the sectioning and the cross-section images of yarns were acquired with camera integrated Olympus BX43 microscope at 100X zoom.

Figure 1. **a.** Yarn samples in circular specimen **b.** Prepared sample for sectioning [18]

2.2.2 Tests Performed

Unevenness (% CVm), optical unevenness (% CV2D 8mm), thin places (-%50/km), thick places (+%50/km), neps (+%200/km) properties of the yarns were measured according to the TS 2394 ISO 2649 standard with USTER Tester 6 S800 at 400 m/min production speed for 2.5 minutes [12]. Hairiness (H, S3) diameter (2DØ mm), density (g/cm^3) values of the yarns were also measured with USTER Tester 6 S800 at 400 m/min test speed for 2.5 minutes. Breaking force (cN) and breaking elongation (%) values of yarns were measured according to the TS EN ISO 2062 by Uster Tensorapid 4. Every test was performed at 400 m/min strain rate and 500 mm gauge length [12]. For each of the yarn samples, 5 different bobbins were produced and average values of each sample were used for statistical analysis.

Table1. Fiber properties [12]

	Linear Density (dtex)	Length (mm)	Tenacity (cN/tex)	Elongation (%)
Viscose	1.3	39	25	19
r-PET	1.2	38	60	22

Table 2. Yarn production parameters

<table>
<tr><th>Yarn Sample Code</th><th>Blend Ratios (%)
(r-PET-Viscose)</th><th>Linear Density of Roving
(Ne)</th><th>Linear Density of Yarn
(Ne)</th><th>Twist Coefficient
(α_e)</th></tr>
<tr><td>I</td><td>33:67</td><td rowspan="4">0.90</td><td rowspan="4">30</td><td rowspan="4">4.20</td></tr>
<tr><td>II</td><td>50:50</td></tr>
<tr><td>III</td><td>67:33</td></tr>
<tr><td>IV</td><td>100:0</td></tr>
</table>

3. RESULTS AND DISCUSSION

3.1 Cross Section Images of the Yarns

Gray scale cross-sectional images of r-PET/viscose ring spun yarns were illustrated in Figure 2. Different cross-sectional views of the r-PET and viscose fibers can be clearly observed in Figure 2. From Figure 2, it is seen that a homogenous blending was achieved for blended yarn samples. Assuming dividing yarn structure into the circular layers from the yarn center to the outwards, both the fibers types can be seen in each layer. It is also seen that all yarns are in a circular cross-section shape and the number of the r-PET and viscose fibers changes depending on the blend ratio.

3.2 Yarn Properties

Mean values of the physical, structural and mechanical properties of the blended yarns were given in the Table 3 and ANOVA analysis of these results were listed in Table 4. It is understood from Table 4 that, blend ratios of the r-PET/viscose yarns are statistically significant on the yarn properties. Only for the breaking elongation values, blend ratio is not statistically significant on the yarn properties (α_e=0.891>0.05).

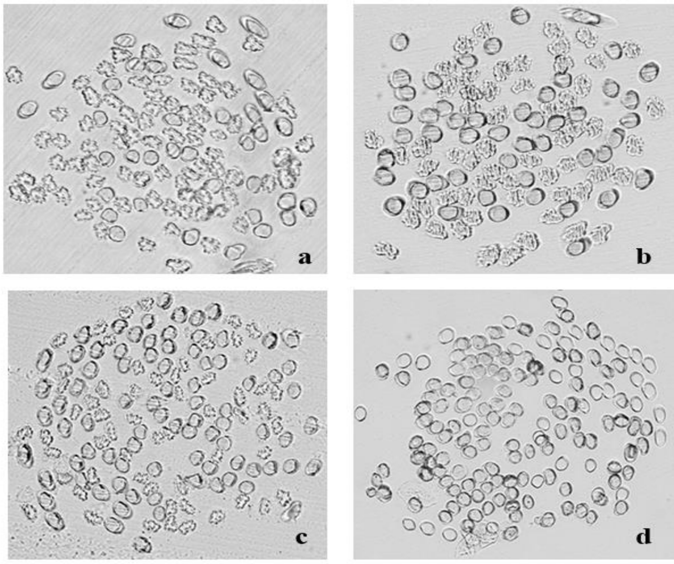

Figure 2. Cross-sectional images of blended yarns **a.** 33% r-PET -67% viscose, **b.** 50% r-PET -50% viscose, **c.** 67% r-PET -33% viscose, **d.**100% r-PET

Table 3. Mean values of the physical, structural and mechanical values of the blended yarns

Yarn Properties	Blend Ratio			
	33% r-PET / 67% viscose	50% r-PET / 50% viscose	67% r-PET / 33% viscose	100% r-PET
H	5.458	5.46	5.332	5.198
S3	8126.2	8166.2	6184.4	6297
CVm (%)	14.84	15.102	11.882	12.466
CV2D 8 mm (%)	10.536	10.624	8.828	9.196
Breaking Strength (cN)	402.76	442.26	520.6	624.5
Breaking Elongation (%)	12.306	12.282	12.188	12.13
Thin Places (-50%/km)	15.4	17.8	0.4	1.6
Thick Places (+50%/km)	12	20.4	11.8	19.6
Neps (+200%/km)	11.2	12.6	19.4	18.8
Density (g/cm^3)	0.678	0.682	0.702	0.722
Diameter (2DØ mm)	0.1922	0.1912	0.189	0.1862

Table 4. ANOVA results of yarn properties

Yarn Properties	Type III Sum of Squares	df	Mean Square	F	Sig.
H	0.233	3	0.078	7.200	0.003
S3	18190348.150	3	6063449.383	34.005	0.000
CVm (%)	40.140	3	13.380	210.486	0.000
CV2D 8 mm (%)	12.651	3	4.217	103.257	0.000
Breaking Strength (%)	143448.658	3	47816.219	106.242	0.000
Breaking Elongation (%)	0.101	3	0.034	0.206	0.891
Thin Places (-50%/km)	1234.800	3	411.600	55.622	0.000
Thick Places (+50%/km)	329.750	3	109.917	6.485	0.004
Neps (+200%/km)	265.000	3	88.333	4.649	0.016
Density (g/cm^3)	0.006	3	0.002	29.333	0.000
Diameter (2DØ mm)	0.000	3	3.538E-5	34.520	0.000

In order to observe effect of each blending ratios on the yarn properties, 95% of confidence interval graph for measured yarn properties were also presented. Figure 3 represents the 95% confidence interval graph for the breaking strength (cN) and breaking elongation (%) values of the produced yarns. It is seen from Table 3 and Figure 3 that, 33% r-PET / 67% viscose yarns have the least breaking strength value and each of the blend ratio is statistically significant on the breaking strength values. It was also observed that the increasing r-PET ratio in the yarn structures has led the greater breaking strength between the blended yarns and 100 % r-PET yarns have the greatest breaking strength values. Since all yarns are produced with the same production parameters, it has been observed that the strength of individual fibers is more decisive in the total yarn breaking strength, and higher strength of r-PET fibers than viscose fibres provide higher yarn breaking strength [12,17]. For the breaking elongation values, there is not a statistically significant difference at 95% confidence level and similar results were reported in the paper of Nohut *et al*. [12] (α_e>0.05).

Confidence interval graph at 95% confidence level for unevenness (CVm%) and optical unevenness (CV2D 8mm%) values of the produced yarns are presented in Figure 4. It is determined from Figure 4 as well as the Table 3 that, both of the unevenness parameters (CVm and CV 2D) display similar tendencies. For both of the unevenness parameters, 33% r-PET / %67 viscose and 50% r-PET / 50% viscose yarns are more uneven structures than those yarns with contain higher proportion of r-PET value. Nohut et.al., [12] also found similar unevenness values of the r-PET blended yarns that contain 30% and 50% r-PET fibers. Kilic ve Okur [19] also reported that increasing fiber proportion with fewer mean linear density decreases the unevenness values in the blended yarns and it is lower than those yarns with 100% single fibers.

Figure 5 presents the confidence interval graph for imperfection values. It is realized from Figure 5 and Table 4 that blend ratio is statistically significant on the yarn imperfection values. It is also seen that increasing the ratio of r-PET fibers in the yarn structure decrease the number of thin places (-%50/km) in the yarn structure and similar results were recorded by Uyanık [14]. On the other hand, yarns with greater proportion of r-PET fibers have the tendency to contain a greater number of neps (+200%/km) values

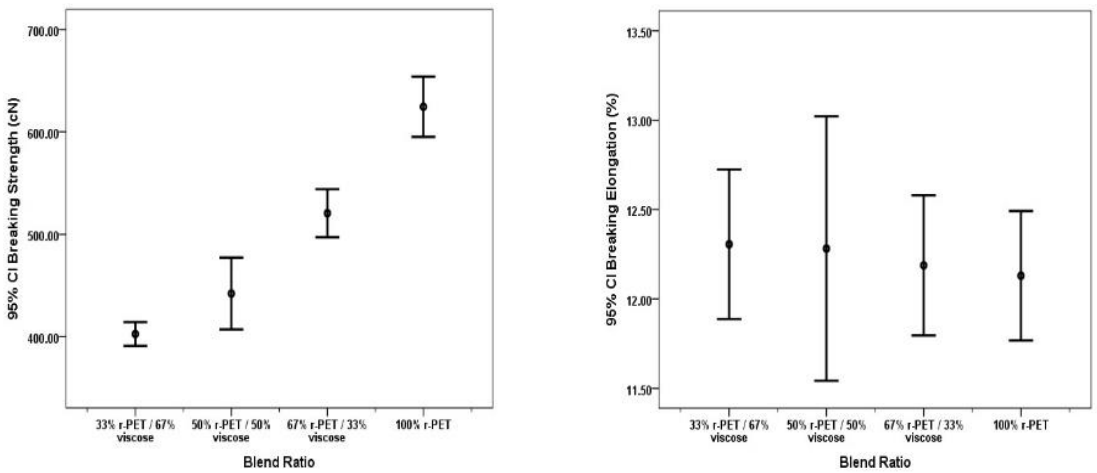

Figure 3. a. Breaking Strength (cN) for yarns, **b.** Breaking Elongation (%) for yarns

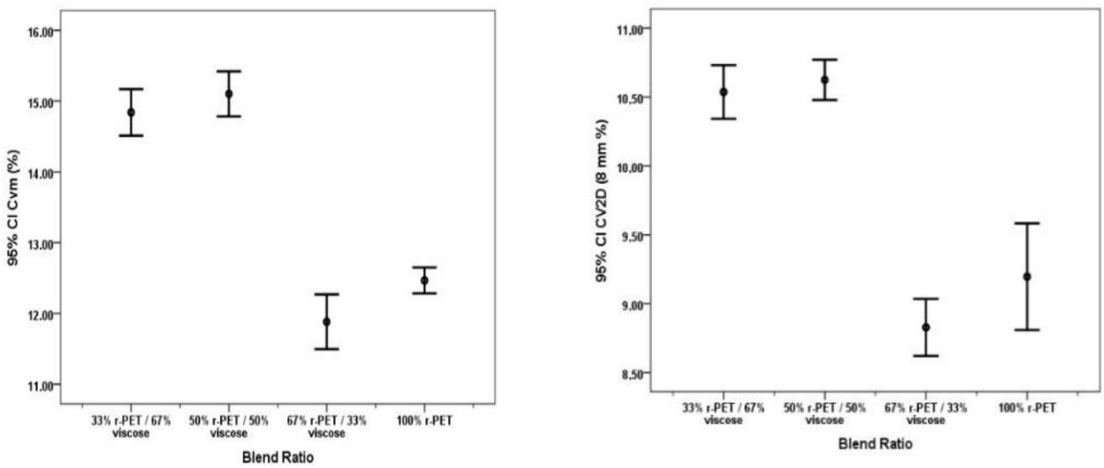

Figure 4. a. Unevenness (Cvm %) **b.** Optical Unevenness (CV2D 8 mm %)

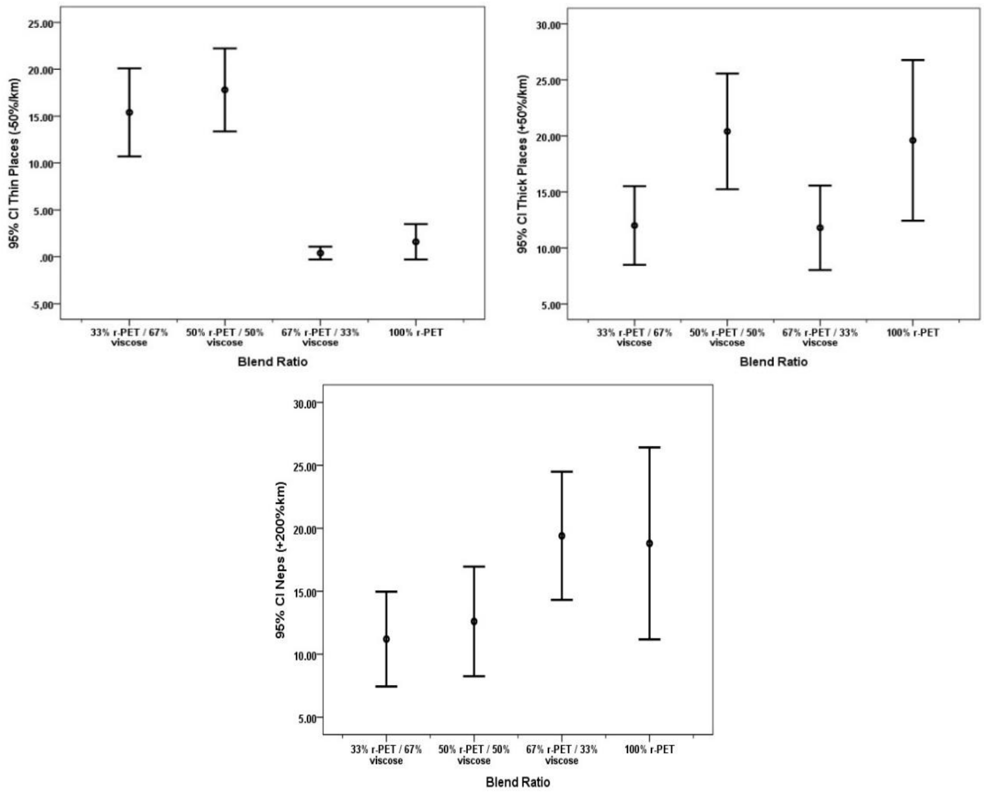

Figure 5. Thin places (-%50/km), thick places (+%50/km) and neps (+200%/km) values

Density (g/cm^3) and diameter (2DØ mm) values of the yarns were also measured as structural parameters and 95 % confidence interval graph of those values were presented in Figure 6. Between the yarns produced in the same parameters, yarns with larger diameter values have lower density values. It should be also noted that, blended yarns display poor fiber arrangement in the yarn cross section and thus display poor density values [19]. It is seen from Figure 5 that, yarns with greater proportion of r-PET have the lower diameter and higher density values and blend ratio is statistically significant on the density and diameter values.

According to the above-given Table 3, the effect of blend ratio is statistically significant on both of the hairiness parameters which is also illustrated in the confidence interval graphs in Figure 7. It is seen from Figure 7 that, 100 % r-PET yarns have the lowest values for both hairiness parameters. Compared to blended yarns, 100% yarns display better hairiness values as reported in numerous studies [14, 19]. It is also seen that, yarns with increasing amount of r-PET fibers reduce the H values and differences were found statistically significant (α_e<0.05). It could be attributed to better fiber orientation that prevents protruding fiber ends. For the S3 values, yarns with more than 50% of r-PET fibers display similar results and differences are not found statistically significant (α_e= 0.679).

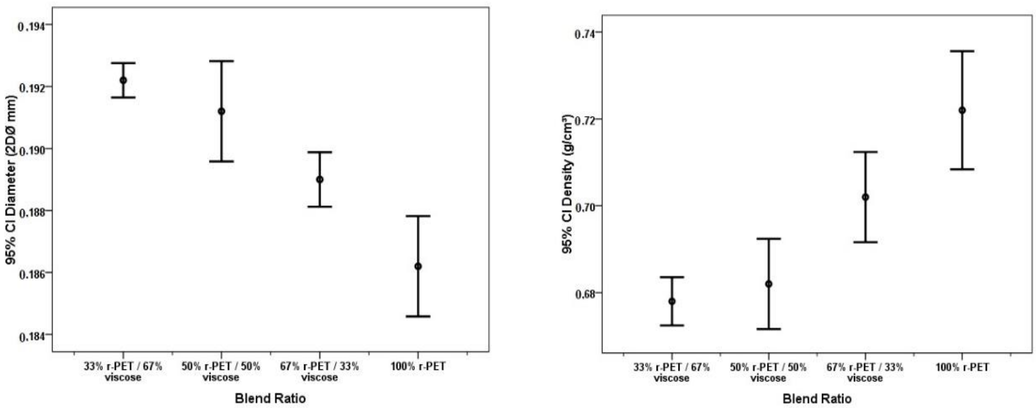

Figure 6. Diameter (2DØ mm) and density (g/cm^3) values of the yarns

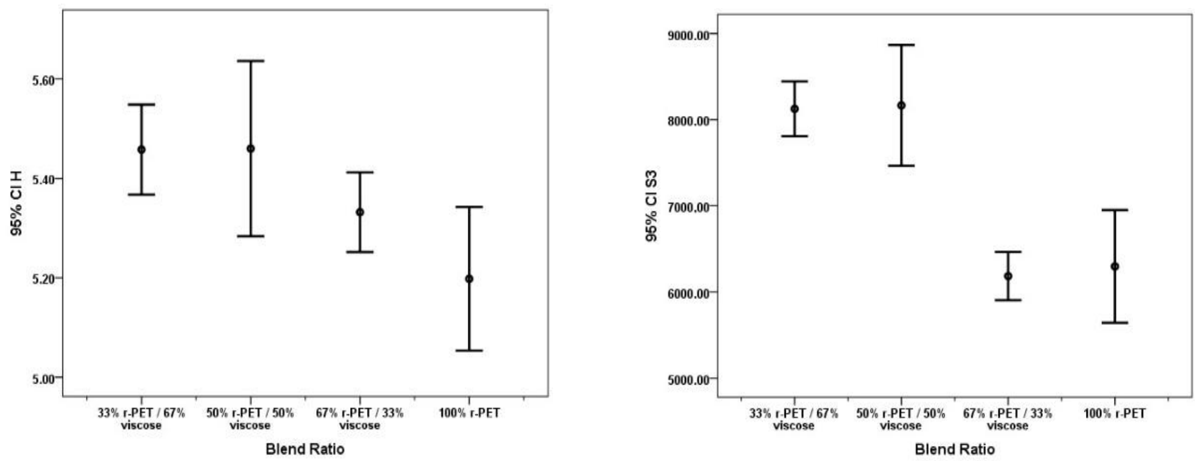

Figure 7. Hairiness values of the yarns

4. CONCLUSIONS

Recycling plastic bottles, as a non-biodegradable material, for textile products is one of the most popular and effective ways to reuse these wastes for sustainability in the production chain and reducing the environmental pollution. This study investigates the properties of r-PET/viscose blended yarns. For this purpose, 33%/67%, 50%/50%, 67%/33% r-PET/viscose blended yarns, and 100% r-PET yarns were produced at the same linear densities. Comparing yarn properties shows that, greater breaking strength of the yarns was obtained for the yarns consisting higher amount of r-PET ratio. However, a similar effect was not observed for the breaking elongation values. Besides, yarns with a greater proportion of r-PET fibers have better unevenness and hairiness values and are also in more compact structures. In addition to the yarn properties, fabric properties depending on consumer preferences related to application area should be investigated in future studies.

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