We are IntechOpen, the world's leading publisher of Open Access books Built by scientists, for scientists

6,900
Open access books available

186,000
International authors and editors

200M
Downloads

154
Countries delivered to

Our authors are among the

TOP 1%
most cited scientists

12.2%
Contributors from top 500 universities

CLARIVATE ANALYTICS
BOOK CITATION INDEX
INDEXED

WEB OF SCIENCE™

Selection of our books indexed in the Book Citation Index
in Web of Science™ Core Collection (BKCI)

Interested in publishing with us?
Contact book.department@intechopen.com

Numbers displayed above are based on latest data collected.
For more information visit www.intechopen.com

PET Bottle Recycling for Sustainable Textiles

Esin Sarioğlu and Hatice Kübra Kaynak

Additional information is available at the end of the chapter

Abstract

Polyethylene terephthalate (PET), as the most favorable packaging material, is owing to its transparent color, lightweight, strength, food safe, inexpensive price, fully recyclability, etc. In addition to all these advantages, PET as a waste material takes up considerable space in nature and needs to be recycled for the disposal of these wastes. In this regard, recycling enables conserving raw materials, reducing energy use in order to produce virgin PET, and reducing greenhouse gas emissions. Today, PET is the most widely recycled plastic in the world. Eco-friendly products obtained by recycling of PET are mainly used as textile fibers. In addition, both brands and consumers are seen to be enthusiastic in order to minimize the environmental effects of PET wastes. This study is concerned with the use of textile fiber from recycled PET (r-PET) bottles to produce a cotton blended ring and compact yarns. Undoubtedly, the study also includes comparison of cotton blended virgin polyester fiber (v-PET) with r-PET fiber to determine the advantages and disadvantages of r-PET fiber. The reason for choosing cotton fiber is the most preferred fiber blending with PET commercially.

Keywords: r-PET, recycle, PET bottle, ring spinning system, compact spinning system, virgin PET

1. Introduction

Economic and population growth and industrialization in the world together cause an increase in the amount of waste. As a consequence of all these, while the more intensive use of natural resources is inevitable, the wastes created by the ever-increasing consumption tendency have reached the huge amounts that threaten the environment and human health due to their quantity and harmful contents. For this purpose, waste policies should be developed and waste management studies should also be carried out, especially in the field of recycling these wastes, because of long decomposition time of these wastes in the environment causing landfill problem [1, 2].

Waste management system enables collection, categorization, reduction, recycling, and reuse of waste. At present, countries' intensive efforts on waste management are striking. Waste management, which has an important place among environmental protection policies, should prevent the rapid depletion of natural resources and minimize the potential risks of the wastes to the environment and human health [3].

Polyethylene terephthalate (PET) is a versatile material and has a wide range of applications such as clothing, acoustic panels, sportswear, agricultural nets, nonwovens, sheets and films, straps, engineering resins, food and beverage bottles, bottles, packaging materials, reinforcement in building construction, etc. Among these products, bottle grade PET is generally used for water and beverage packaging due to its lightweight, inexpensive price, resistance to microorganisms, and light [4–6]. Bottles of water, soft drinks, and other beverages constitute 83–84% of global PET resin requirement [7]. Furthermore, the projected demand for PET packaging materials is forecasted to reach 20 million tons by 2019 with an annual increase of 4.6% [8].

With the widespread application of PET, large quantities of PET waste were inevitably created. PET has no side effects on the human body and does not pose a direct threat to the environment. On the other hand, it is regarded as a harmful material because of its high volumetric fraction in the waste stream and high resistance to atmospheric and biological agents [9].

Due to poor biodegradation of PET, it is difficult to remove waste. It is possible to suggest two acceptable solutions; burning and recycling. Burning method arises releasing toxic fumes into the atmosphere, causing environmental pollution and health risks [4, 10]. As an acceptable solution, the recycling of PET bottles enables the conservation of natural sources such as fossil fuels and energy, solving landfill problem, reducing greenhouse gas emission, lowering carbon footprint, creating new business opportunities as well as a contribution to the national economy [7, 11–14]. In addition, recycling processes are the best way to economically reduce PET waste [15]. With both reduced energy costs and raw material costs, recycling fiber production has become a form of production with a significant economic advantage [16]. Two forms of PET bottle recycling can be distinguished as a closed loop and open loop recycling. Closed loop recycling or bottle-to-bottle refers to a product system that recycles post-consumer waste within the same system. Open loop recycling denotes the utilization of recycled material in another product system such as bottle-to-fiber recycling [16–18]. **Figure 1** displays the process of bottle-to-fiber recycling.

PET flakes are obtained from PET bottle wastes after a series of procedures such as sorting, washing, grinding, drying, etc. [19]. Most of the recycled PET flakes produced worldwide are utilized for staple fiber applications in textile sector (**Figure 2**) [8, 20, 21]. Because of environmental reasons initially, the recycling of PET bottles to textile fibers has now become commercially attractive [22]. Furthermore, as petroleum prices increase, recycling of PET becomes more financially feasible rather than a virgin PET. It is expected that the recycling of the PET bottle will be estimated up to annually 13 million tons in 2018 and up to 15 million tons in 2020 [21].

The fiber obtained from PET flakes has dominant proportion among end users as 44% of total market share in 2016. These fiber materials are generally called as recycled PET (r-PET) and especially used in carpets, blankets, clothing, and other textile applications [12, 14, 23]. However,
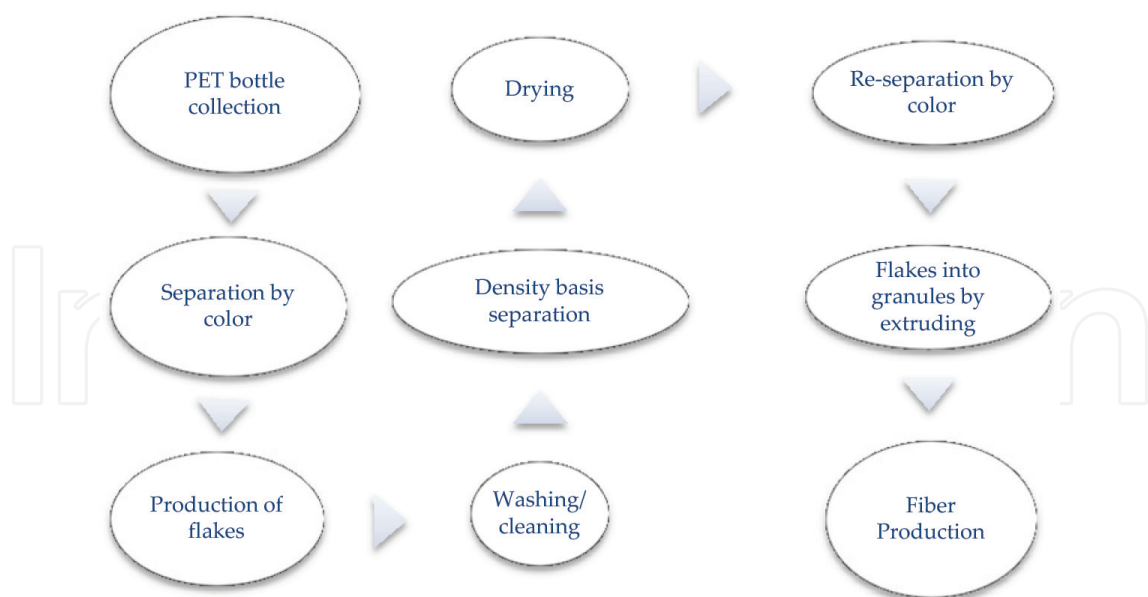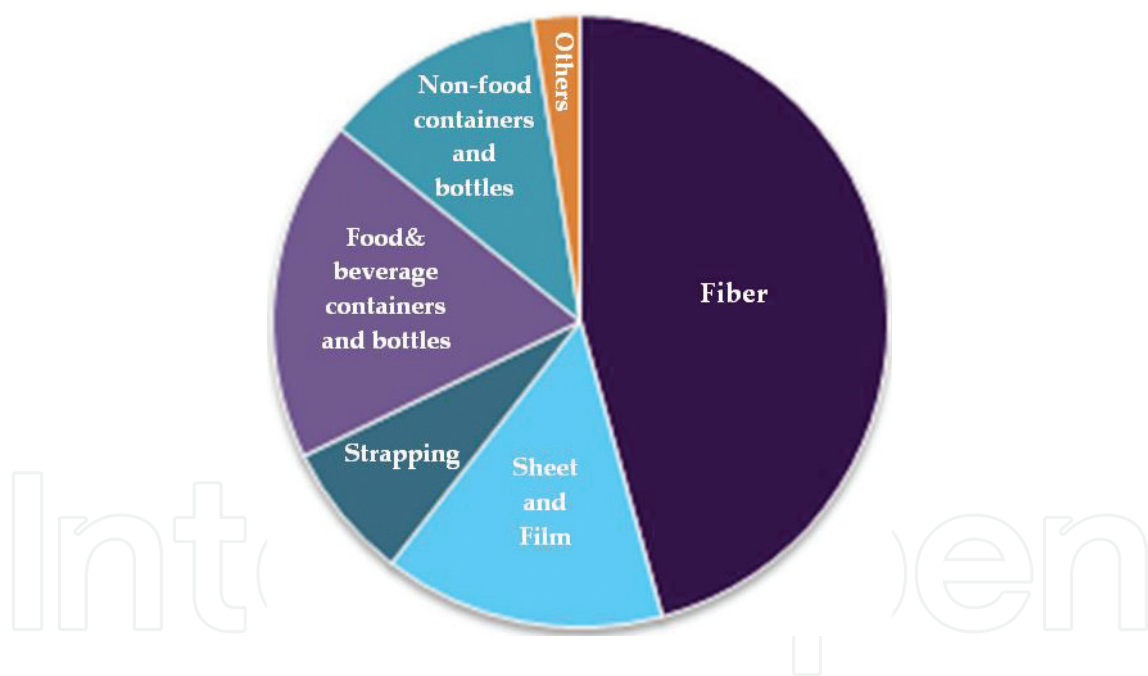
Figure 1. Bottle-to-fiber recycling.

Figure 2. Global annual r-PET market volume by end-use in 2016 [23].

properly sorting PET bottle wastes and carefully removing impurities are essential so as to obtain similar recycled fiber quality as virgin ones [24]. Furthermore, there are significant limitations in the use of r-PET for the production of partially oriented yarn (POY), drawn textured yarn (DTY) and fully drawn yarn (FDY) type textile yarns, microfilaments, tire cord or high quality biaxial films [21].

Converting of PET flakes into PET fibers can be carried out by two main processes, such as chemical recycling and mechanical recycling. The chemical recycling method provides value-added

products from PET bottle wastes, and depolymerization of PET by hydrolysis, methanolysis, and glycolysis is used to re-use regenerated raw materials as monomers for new polymerization processes [10, 12, 16, 25–27]. The chemical recycling technique produces superior quality materials, but this method is highly labor and power-intensive, so it requires high processing costs [4, 12, 15, 21].The mechanical recycling method involves sorting and separation of waste, washing for removal of dirt and contaminants, grinding in order to obtain flakes, cleaning, separating, dehydrating, drying, and re-melting [10, 16, 21, 25, 27]. Mechanical recycling is preferred due to a significant reduction in processing costs, global warming potential, non-renewable energy use, abiotic exhaustion, acidification, eutrophication, human toxicity, and water toxicity [4].

As such, studies on the use of r-PET staple fiber in the field of textile applications have established the focus of researchers. Yüksekkaya *et al.* investigated the properties of yarns and knitted fabrics produced by virgin PET and r-PET and cotton fibers as virgin and recycled. Yarns were produced as 100% virgin, 100% recycled, and 50%/50% virgin/recycled proportion by using rotor spinning machine. They stated that yarns produced from recycled fibers had better yarn unevenness, lower number of yarn imperfections, and better yarn quality index value. In addition, yarn tensile strength and knitted fabric burst strength were found to be lower for recycled yarns and fabrics when compared to virgin ones [28].

Another study was conducted on the performance and durability of woven fabrics made from r-PET with different ratios by Mari and Shinji. Commercially available plain and twill woven samples were collected and categorized according to the recycling content. They observed that more fatigue action occurred for fabrics including r-PET than virgin PET after washing. It was found that fabrics with r-PET exhibited higher stiffness with increasing r-PET content [29]. Rajamanickam and Vasudevan studied on the antibacterial activities of 19.7 tex ring spun yarns including lyocell and r-PET at different blending ratios (100% r-PET, 70%/30%, 50%/50% lyocell/r-PET, and 100% lyocell). Before the antibacterial activities, yarns were treated with chitosan finish. In this study, it was suggested that the yarns can be used as hospital textiles and blended yarn samples exhibited better antimicrobial activity. Furthermore, "blends of lyocell & r-PET yarns" were found to be suitable in the field of hospital textiles due to having higher tenacity and elongation property [30].

Telli and Özdil studied the performance of r-PET and v-PET blended yarns with cotton at different blend ratios (100%, 70%/30%, 50%/50%, and 30%/70%). In that respect, 30 tex yarn samples were manufactured by means of ring spinning system and tensile properties, unevenness, imperfection index (IPI), and hairiness of these yarns were determined. In this study, it is suggested to encourage the consumption of the lower cost r-PET fibers having current quality standards in this field [31]. Another study of the authors is related to the knitted fabric performance made from these yarns. It was found that knitted fabrics including virgin PET had better performance specifications than that of r-PET. According to the test results, they offered to use blends of r-PET fibers in suitable proportions according to usage area in order to prevent the decrease in fabric performance instead of using virgin PET fiber [19].

In order to contribute the use of r-PET staple fiber in the textile sector, producers should be encouraged and some legislation should be implemented. Since recycling of PET bottles is an

important value-added sector; it prevents the consumption of limited fuel source and energy so it helps to protect the environmental pollution and decreases the landfilling problem. There are various attempts of big textile brands about using of r-PET fibers in their products such as Zara, H&M, Nike, Adidas, and Lewis® etc. to fulfill their social responsibilities to nature. With this study, we aimed to determine the performance of r-PET containing yarns produced with different spinning systems at the same production conditions. For this purpose, r-PET fibers obtained from PET flakes by mechanical recycling methods were used and blended with cotton fiber at different ratios. The yarn samples with the same blend ratios were produced with v-PET fiber instead of r-PET, in order to compare the performance of recycled and virgin fibers. Two spinning systems were selected as ring and compact which are commercially used in industry. Tensile properties, unevenness, IPI, hairiness of these yarns were determined and compared. IBM® SPSS® 20 statistical package program was used to determine the statistical significance of the effects of raw material, spinning system and blend ratio on yarn performance characteristics.

2. Materials and methods

2.1. Materials

In this research, authors cooperated with Gama Recycle Textile Company in Gaziantep/Turkey. PET flakes were manufactured by collecting, rating, washing and grinding, drying and the size of PET bottle wastes. Then, PET flakes were converted into r-PET fiber by a mechanical process. The most commercially preferred r-PET fiber was chosen among the productions of the company. r-PET ,v-PET, and cotton (Co) fibers were used as raw materials for yarn production (**Table 1**).

Fibers were weighted and blended with sandwich blend method at the beginning of the blowroom. In the yarn production stage, blowroom, carding, three passage drawframe, and roving processes were achieved. In addition, 19.7 tex ring and compact spun yarns were produced with α_e = 3.39 (730 TPM) twist level at different blend ratios (70%/30%, 50%/50%, and 30%/70%) of r-PET and v-PET with cotton fiber, separately. The spindle speed was constant at 13,500 rpm. The 100% r-PET and 100% v-PET ring and compact yarns were also produced with the same production parameters to compare and evaluate the differences in yarn properties systematically. Nevertheless, the production of the 100% Co ring and compact yarns were conducted with α_e = 3.71 (800 TPM) twist level at the same spindle speed, owing to the necessity of producing all yarn samples at optimum process parameters [32]. Since the

	r-PET	v-PET	Co
Fiber linear density (dtex)	1.30	1.30	1.70*
Length (mm)	38	32	32

*4.32 Micronaire (dtex Cotton = Micronaire*0.394).

Table 1. Raw material properties.

higher twist was necessary to hold the fibers together and to obtain required cohesion forces between fibers in the production of the 100% Co ring and compact yarns.

2.2. Methods

Yarn samples were conditioned in standard atmosphere conditions at $20 \pm 2°C$ temperature and $65 \pm 4\%$ relative humidity for 24 hours [33]. Tensile properties were carried out by Uster® Tensorapid-4 according to the related standard with 10 measurements from every four bobbins [34]. Five tests from each four bobbins were carried out in order to determine unevenness, IPI, and hairiness of yarn samples with Uster® Tester 4 in accordance with ISO standard [35].

In statistical analysis, multivariate analysis of variance (MANOVA) was achieved at 95% confidence interval by means of IBM® SPSS® 22.0 package program to compare whether there is statistically significant effect of the independent parameters as raw material (r-PET and v-PET), blend ratio (100%, 70%/30%, 50%/50%, 30%/70% and 0%), and yarn type (ring and compact) on yarn unevenness, IPI, hairiness and tensile properties. In addition, multiple comparison tests were obtained to determine the difference between two groups via pair wise comparison at a 0.05 significance level.

3. Experimental results

3.1. Unevenness

CVm% is defined as unevenness of yarn samples and is shown in **Figure 3**. When the raw material is considered, lower CVm % values are observed for pure v-PET yarn samples for both yarn types.

On the other hand, the maximum CVm % was recorded for 100% Co ring spun yarn. There is a tendency of increasing in unevenness from 100% pure synthetic yarn to 100% Co yarn. It is
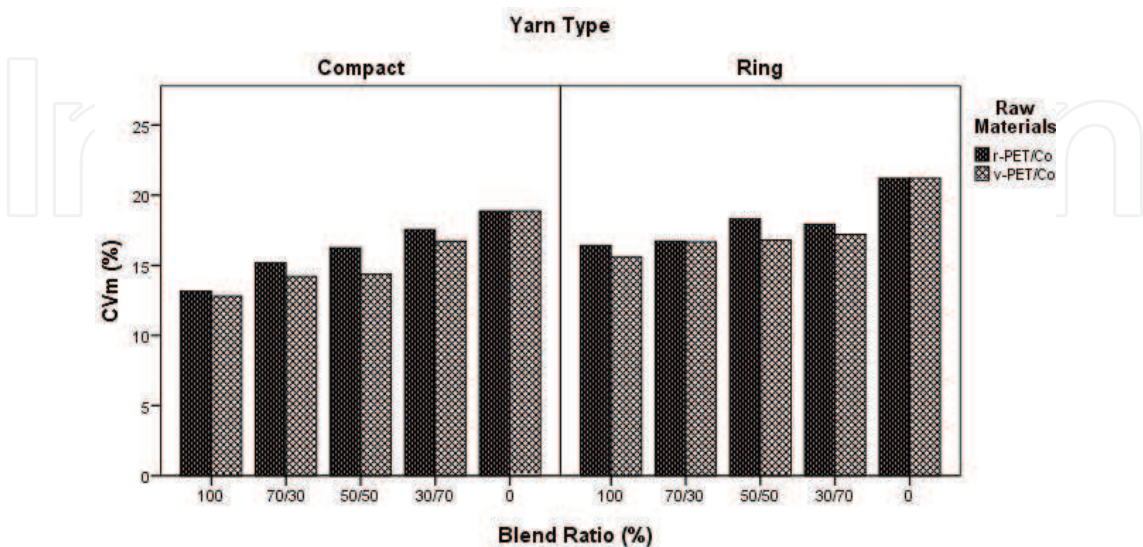

Figure 3. CVm % of yarn samples.

probable that the incorporation of synthetic fibers having a more uniform fiber structure than the Co fiber in the yarn cross-section reduced the unevenness. Comparison in between the ring and compact yarn types, ring spun yarns for all samples have higher unevenness owing to the higher number of protruding fiber ends from yarn body. When results are examined generally, r-PET raw material cause higher yarn unevenness than v-PET. It should also be noted that higher yarn unevenness will cause lower tensile strength and higher IPI. Consequently, it is preferable to use 70%/30% blend ratio and compact spinning system for a better yarn unevenness, aiming using the r-PET raw material.

3.2. IPI

Imperfections are referred to as frequently occurring yarn faults as percentage. Imperfection index in the yarn refers to the total number of thin places (−50%), thick places (+50%) and neps (+200%) of yarn in kilometer. IPI values of yarn samples are given in **Figure 4**.

According to IPI values, it is seen that v-PET blended yarns have lower values than that of r-PET ones. On the other hand, for all blended samples, it is seen that increasing PET content cause a decrease in IPI values. Furthermore, 100% r-PET yarn samples exhibit similar IPI values with 100% v-PET samples. Compact spinning technology has a decreasing effect on IPI for all samples. Consequently, it can be concluded that higher IPI values of r-PET blended yarns may be a result of low compatibility of r-PET fibers with Co fiber. Higher IPI values of r-PET blended yarns should be compensated by using higher PET ratio and preferring compact spinning technology.

3.3. Hairiness

From **Figure 5**, lower hairiness values of compact spun yarn samples than that of ring ones are obvious. Since in the compact spinning system, it is aimed to provide a less hairy yarn by contributing the protruding fiber ends into yarn body via reforming the spinning triangle. On the other hand, it is seen that r-PET samples have slightly higher hairiness values than that of v-PET samples for ring spun yarns, whereas there is almost no difference between r-PET and
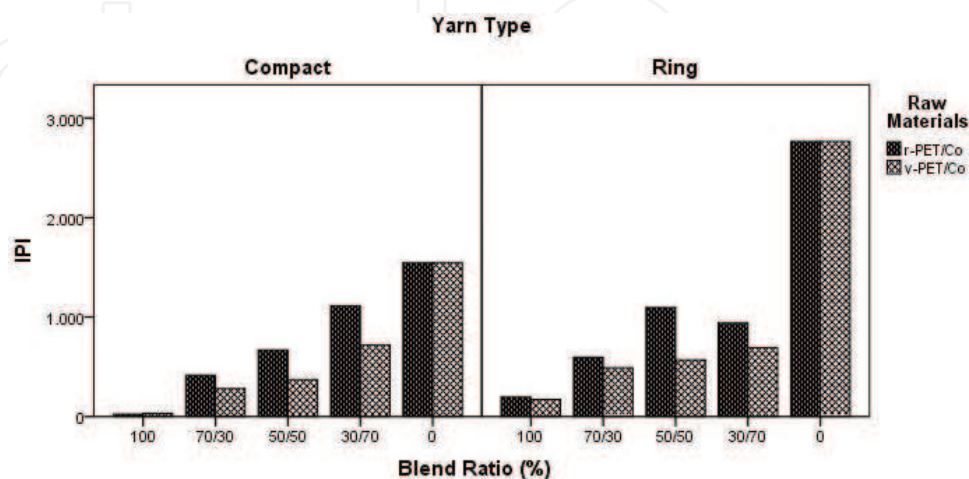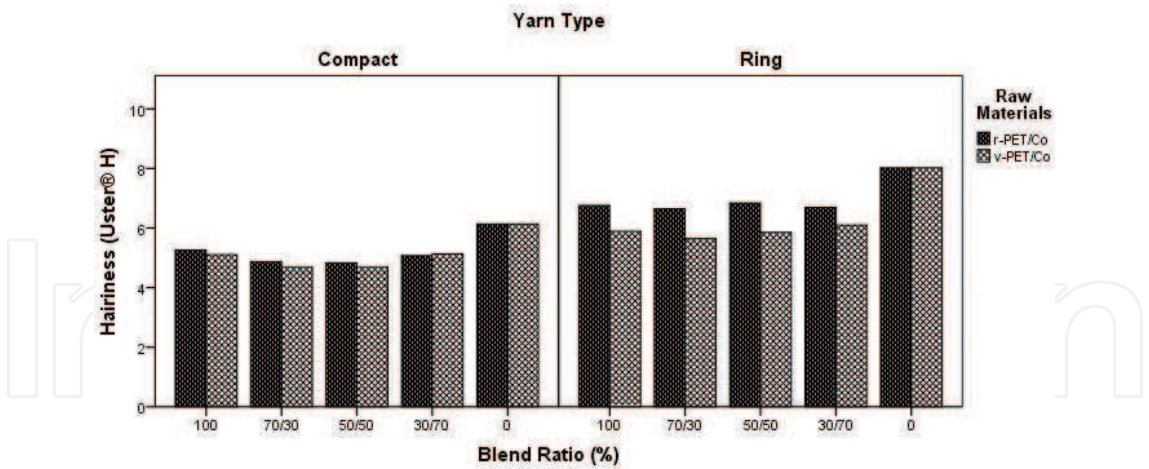

Figure 4. IPI of yarn samples.

Figure 5. Hairiness of yarn samples.

v-PET for compact spun yarns. Among blended yarn samples of both r-PET and v-PET fiber types, it is clear that the lowest yarn hairiness is obtained with 50%/50% blend ratio.

3.4. Tensile properties

Figure 6 displays tensile strength values of r-PET/Co and v-PET/Co ring and compact yarns at different blend ratios. It is obviously seen that v-PET containing yarns have higher tensile strength than that of r-PET ones and 100% v-PET compact yarn has the highest strength. This is an expected situation owing to the fact that r-PET fiber has lower fiber strength due to recycling. On the other hand, for ring spun yarn type, 100% v-PET yarn has higher strength value than that of 100% r-PET yarn about 28% at same production parameters. 100% v-PET compact spun yarn has higher tensile strength with the value of 39% than 100% r-PET compact yarn. This is an obvious positive effect of the compact spinning system on yarn strength. But also it should be considered that the magnitude of this effect is lower for PET fibers than v-PET.
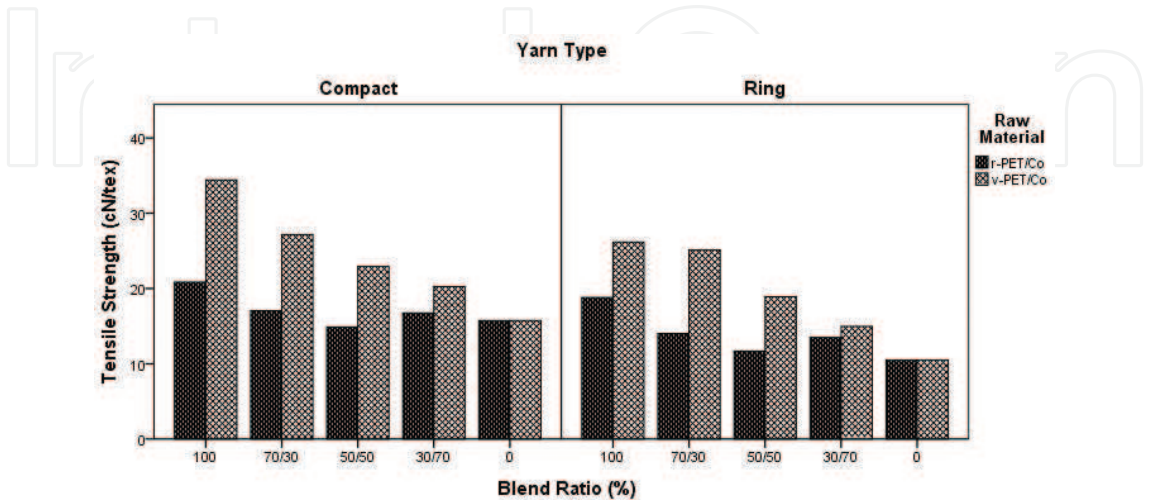

Figure 6. Tensile strength of yarn samples.

Having higher tensile strength is an important issue for both fabrication processes and fabric performance during use life. So that, 70%/30% blend ratio and compact spinning technology should be preferred for a higher yarn strength. When yarn type is taken into consideration, as an expected result is that the tensile strength of the compact spun yarns are higher than that of conventional ring yarns [36–41]. Since compact spinning technology contributes yarn evenness by increasing the number of protruding fiber ends into yarn body. This reforming in yarn body also contributes yarn tenacity by increasing the number of fibers in yarn cross-section that withstand against tensile force. On the other hand, it is also clearly seen that r-PET and v-PET presence contribute yarn tensile strength with respect to the Co content. The bar graphs for elongation of yarn samples are illustrated in **Figure 7**.

Pure r-PET ring and compact spun yarns exhibit a higher elongation at break than a pure v-PET ring and compact yarns, it may be probably due to the fact that higher elongation of r-PET fiber than that of v-PET. It is determined that both the compact and the ring spun yarns elongation at break decrease with increasing Co fiber ratio.

3.5. Statistical analysis

MANOVA analysis was carried out to determine the significance of the effects of raw material, yarn type and blend ratio on tensile properties, unevenness, imperfections and hairiness of yarn samples (**Table 2**). Results show that yarn type, raw material, and blend ratio has significant effects on all response variables at 0.05 level, except the insignificant effect of the raw material on yarn elongation. Furthermore, there is no statistically significant difference between raw materials in elongation of r-PET or v-PET containing ring and compact yarns. R^2 value is defined as the magnitude of the effect of the independent variables on the response variables in percent. The strength of the relationship between independent variables and response variables are explained in the range of 0-100%. The higher the R^2 means the better the model fits your data.
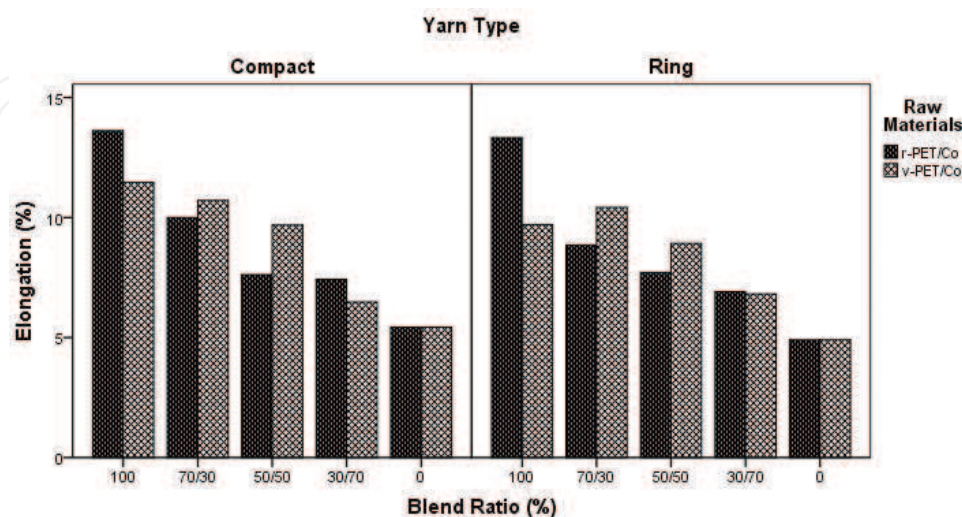

Figure 7. Elongation of yarn samples.

Source	Dependent variable	Sum of squares	df	Mean square	F	Sig.
Corrected model	Tensile strength	2904.574 **(a)**	19	152.872	75.864	**0.000***
	Elongation	499.457 **(b)**	19	26.287	57.934	**0.000***
	CVm	344.032 **(c)**	19	18.107	63.940	**0.000***
	IPI	35363708.784 **(d)**	19	1861247.831	50.887	**0.000***
	Hairiness	87.003 **(e)**	19	4.579	165.571	**0.000***
Intercept	Tensile strength	27369.271	1	27369.271	13582.285	**0.000***
	Elongation	5916.800	1	5916.800	13039.899	**0.000***
	CVm	22291.832	1	22291.832	78717.571	**0.000***
	IPI	50949906.153	1	50949906.153	1392.992	**0.000***
	Hairiness	2812.836	1	2812.836	101707.072	**0.000***
Yarn type (A)	Tensile strength	347.403	1	347.403	172.402	**0.000***
	Elongation	9.884	1	9.884	21.784	**0.000***
	CVm	72.048	1	72.048	254.418	**0.000***
	IPI	1781597.278	1	1781597.278	48.710	**0.000***
	Hairiness	46.772	1	46.772	1691.195	**0.000***
Raw material (B)	Tensile strength	777.442	1	777.442	385.814	**0.000***
	Elongation	0.030	1	0.030	.065	0.799
	CVm	9.099	1	9.099	32.131	**0.000***
	IPI	553363.278	1	553363.278	15.129	**0.000***
	Hairiness	2.915	1	2.915	105.389	**0.000***
Blend ratio (C)	Tensile strength	1347.936	4	336.984	167.232	**0.000***
	Elongation	434.549	4	108.637	239.423	**0.000***
	CVm	240.446	4	60.111	212.267	**0.000***
	IPI	29589733.206	4	7397433.302	202.249	**0.000***
	Hairiness	30.965	4	7.741	279.912	**0.000***
A * B	Tensile strength	13.082	1	13.082	6.492	**0.013***
	Elongation	0.964	1	0.964	2.124	0.150
	CVm	0.364	1	0.364	1.287	0.261
	IPI	1432.278	1	1432.278	.039	0.844
	Hairiness	1.821	1	1.821	65.846	**0.000***
A * C	Tensile strength	20.552	4	5.138	2.550	**0.048***
	Elongation	1.206	4	0.301	.664	0.619
	CVm	14.704	4	3.676	12.981	**0.000***
	IPI	2797362.394	4	699340.598	19.120	**0.000***
	Hairiness	3.086	4	0.772	27.900	**0.000***
B * C	Tensile strength	367.084	4	91.771	45.542	**0.000***

Source	Dependent variable	Sum of squares	df	Mean square	F	Sig.
	Elongation	49.650	4	12.413	27.356	**0.000***
	CVm	6.047	4	1.512	5.339	**0.001***
	IPI	557862.644	4	139465.661	3.813	**0.008***
	Hairiness	0.959	4	0.240	8.669	**0.000***
A * B * C	Tensile strength	31.075	4	7.769	3.855	**0.007***
	Elongation	3.175	4	0.794	1.749	0.151
	CVm	1.323	4	0.331	1.168	0.334
	IPI	82357.706	4	20589.427	.563	0.690
	Hairiness	0.484	4	0.121	4.374	**0.004***
Error	Tensile strength	120.904	60	2.015		
	Elongation	27.225	60	0.454		
	CVm	16.991	60	0.283		
	IPI	2194552.313	60	36575.872		
	Hairiness	1.659	60	0.028		
Total	Tensile strength	30394.749	80			
	Elongation	6443.482	80			
	CVm	22652.855	80			
	IPI	88508167.250	80			
	Hairiness	2901.498	80			
Corrected total	Tensile strength	3025.478	79			
	Elongation	526.682	79			
	CVm	361.023	79			
	IPI	37558261.097	79			
	Hairiness	88.662	79			

(a) $R^2 = 96$ (Adjusted $R^2 = 94.7$), (b) $R^2 = 94.8$ (Adjusted $R^2 = 93.2$), (c) $R^2 = 95.3$ (Adjusted $R^2 = 93.8$), (d) $R^2 = 94.2$ (Adjusted $R^2 = 92.3$), and (e) $R^2 = 98.1$ (Adjusted $R^2 = 97.5$). *The mean difference is significant at 0.05 level.

Table 2. Multivariate analysis of variance (MANOVA) statistical analysis results.

Multiple comparison results provide to analyze the differences between two samples differently from MANOVA providing to see only if there is a statistically significant difference among sample groups. The results in **Table 3** involve r-PET and v-PET samples to focus on the effect of blend ratio for all samples. According to multiple comparison tests, it is seen that the difference between sample groups are generally important (α at 0.05 significance level). For tensile strength, it is seen that 70%/30% and 50%/50% yarn samples provide statistically similar results. In other words, these two samples compose a group regarding the tensile strength. Also, the rest of the samples have statistically different strength results among each other. On the other hand, all of the samples have statistically different yarn elongation, CVm % and IPI

		Dependent variable				
		p Value				
Blend ratio	**Blend ratio**	**Tensile strength (cN/tex)**	**Elongation (%)**	**CVm (%)**	**IPI (%)**	**Hairiness (Uster® H)**
0	100	0.000*	0.000*	0.000*	0.000*	0.000*
	30/70	0.000*	0.000*	0.000*	0.000*	0.000*
	50/50	0.000*	0.000*	0.000*	0.000*	0.000*
	70/30	0.000*	0.000*	0.000*	0.000*	0.000*
100	0	0.000*	0.000*	0.000*	0.000*	0.000*
	30/70	0.000*	0.000*	0.000*	0.000*	0.930
	50/50	0.000*	0.000*	0.000*	0.000*	0.004*
	70/30	0.000*	0.000*	0.000*	0.000*	0.000*
30/70	0	0.000*	0.000*	0.000*	0.000*	0.000*
	100	0.000*	0.000*	0.000*	0.000*	0.930
	50/50	0.593	0.000*	0.000*	0.041*	0.041*
	70/30	0.000*	0.000*	0.000*	0.000*	0.001*
50/50	0	0.000*	0.000*	0.000*	0.000*	0.000*
	100	0.000*	0.000*	0.000*	0.000*	0.004*
	30/70	0.593	0.000*	0.000*	0.041*	0.041*
	70/30	0.000*	0.000*	0.008*	0.013*	0.668
70/30	0	0.000*	0.000*	0.000*	0.000*	0.000*
	100	0.000*	0.000*	0.000*	0.000*	0.000*
	30/70	0.000*	0.000*	0.000*	0.000*	0.001*
	50/50	0.000*	0.000*	0.008*	0.013*	0.668

*The mean difference is significant at 0.05 level.

Table 3. Multiple comparison test results of yarn properties via blend ratio.

values among each other. With respect to yarn hairiness, 30%/70% samples and 100% samples have statistically similar values and on the other hand, 50%/50% samples have similar values with 70%/30% samples.

4. Conclusion

As a conclusion, it can be stated that r-PET fiber has enough contribution to be used with cotton fiber as a blended yarn component. IPI, unevenness, hairiness, and elongation performances of the r-PET yarn are at acceptable levels when they are compared with the v-PET yarns. The lower strength of the r-PET yarn may seem to be a disadvantage. But it must be

encouraged as a social responsibility to use r-PET fiber in textile products in a certain proportion to maintain the nature, to recycle and to reuse PET bottle wastes in different application areas. Thus, it enables for reducing the volume of the landfill pollution, natural resources consumption, and extra energy costs required for virgin product handling.

Studies on the use of r-PET fibers are generally on the comparison of this fiber with r-PET fibers and using r-PET fibers in the blends with v-PET and Co fibers. The researchers emphasized the importance of using r-PET fiber in the textile industry as a result of these studies. However, some quality parameters require improvement in fiber properties. In systems that enable to recycle the PET bottle waste entered our lives as a part of waste management, mechanical and chemical works should be done for a better r-PET production with very close quality values with v-PET. Separate collection of PET bottles, proper categorization, and separation are required to capture sustainable r-PET fiber quality. In Turkey, while production of short fibers from PET flakes are intensive, with technological developments are now showing that providing filament from PET flakes production is also starting as investments.

In general, we can summarize the results as follows:

- v-PET containing yarns have higher tensile strength than that of r-PET ones and 100% v-PET compact yarn has the highest strength. This situation is expected since r-PET fiber has lower strength due to recycling and reforming processes.

- IPI and unevenness quality parameters are also very important in order to reason the usability of the yarn as a textile product. When the unevenness test results are evaluated, it is seen that the lowest CVm % values are obtained with pure v-PET yarn for both yarn spinning technologies. It should also be considered that higher yarn unevenness values caused higher IPI and lower tenacity.

- As a result of MANOVA analysis, yarn spinning technology, raw material and blend ratio generally have significant effects on response variables.

Acknowledgements

Author details

Esin Sarioğlu* and Hatice Kübra Kaynak

*Address all correspondence to: sarioglu@gantep.edu.tr

Department of Textile Engineering, Faculty of Engineering, Gaziantep University, Gaziantep, Turkey

References

[1] Tayyar AE, Üstün S. Usage of recycled PET. Pamukkale University. Journal of Engineering Sciences. 2010;**16**:53-62

[2] European Commission DG ENV. Plastic waste in the environment [Internet]. 2011. Available from: http://ec.europa.eu/environment/waste/studies/pdf/plastics.pdf [Accessed: October 8, 2017]

[3] Turkish Republic Ministry of Science, Industry and Technology General Directorate of Industry. National recycling strategy document and action plan 2014–2017. [Internet]. 2015. Available from: http://www.sanayi.gov.tr/DokumanGetHandler.ashx? Dokuman Id=19b39a64-ed35-4485-89df-aefea5bc21ea [Accessed: September 18, 2017]

[4] Barman NK, Bhattacharya SS, Mandot A. Mechanical properties of melt-spun monofilaments produced from virgin and recycled poly(ethylene terephthalate) blends. International Journal of Recent Scientific Research. 2015;**6**:4517-4525

[5] Luijsterburg BJ. Mechanical recycling of plastic packaging waste. Eindhoven: Technische Universiteit Eindhoven [thesis]; 2015. DOI: 10.6100/IR783771

[6] Shafique U, Zaman W, Anwar J, Munawar MA, Salman M, Dar A, Rehman R, Ashraf U, Ahmad S. A rapid, economical, and eco-friendly method to recycle terephthalic acid from waste poly (ethylene terphthalate) bottles. International Journal of Polymeric Materials. 2011;**60**:1147-1151. DOI: 10.1080/00914037.2011.557802

[7] Zhang H, Wen ZG. The consumption and recycling collection system of PET bottles: A case study of Beijing, China. Waste Management. 2014;**34**:987-998

[8] Sangalang A, Seok S, Kim DH. Practical design of green catalysts for PET recycling and energy conversion. In: Norena LE, Wang JA, editors. Advanced Catalytic Materials—Photocatalysis and Other Current Trends. Croatia: Intech; 2016. p. 141-166. DOI:10.5772/62041.ch.6

[9] Bartolome L, Imran M, Cho BG, Al-Masry WA, Kim DH. Recent developments in the chemical recycling of PET. In: Achilias DS, editors. Material Recycling—Trends and Perspectives. Croatia: Intech; 2012. p. 65-84. DOI: 10.5772/33800

[10] Park SH, Kim SH. Poly (ethylene terephthalate) recycling for high value added textiles. Fashion and Textiles. 2014;**1**:1-17

[11] Shen L, Nieuwlaar E, Worrell E, Patel MK. Life cycle energy and GHG emissions of PET recycling: Change-oriented effects. International Journal of Life Cycle Assessment. 2011;**16**:522-536. DOI: 10.1007/s11367-011-0296-4

[12] Dutt K, Soni RKA. Review on synthesis of value added products from polyethylene terephthalate (PET) waste. Polymer Science. 2013;**55**:430-452

[13] Hopewell J, Dvorak R, Kosior E. Plastics recycling: Challenges and opportunities. Philosophical Transactions of the Royal Society B. 2009;**364**:2115-2126. DOI: 10.1098/rstb.2008.0311

[14] Greene JP. Sustainable Plastics with Reduced Carbon Footprint & Reduced Waste [Internet]. Available from:http://www.sustainablegreenproducts.org/files/sustn-plastics.pdf [Accessed: October 1, 2017]

[15] Awaja F, Pavel D. Recycling of PET. European Polymer Journal. 2005;**41**:1453-1477

[16] Telli A, Özdil N, Babaarslan O. Usage of PET bottle wastes in textile industry and contribution to sustainability. Journal of Textiles and Engineer. 2012;**19**:49-55. DOI: 10.7216/130075992012198607

[17] Kuczenski B, Geyer R. Life Cycle Assessment of Polyethylene Terephthalate (PET) Beverage Bottles Consumed in the State of California [Internet]. 2014. Available from: http://www.calrecycle.ca.gov/publications/Documents/1487/20141487.pdf [Accessed: August 16, 2017]

[18] Plastics – the Facts 2014/2015 [Internet]. 2015. Available from: http://www.plasticseurope.org/documents/document/20150227150049final_plastics_the facts_2014_2015_260215.pdf [Accessed: October 10, 2017]

[19] Telli A, Özdil N. Effect of recycled PET fibers on the performance properties of knitted fabrics. Journal of Engineered Fibers and Fabrics. 2015;**10**:47-60

[20] Leonas KK. The use of recycled fibers in fashion and home products. In: Senthilkannan MS, editor. Textiles and Clothing Sustainability Recycled and Upcycled Textiles and Fashion. 1st ed. Singapore: Springer; 2017. pp. 55-77. DOI: 10.1007/978-981-10-2146-6_2

[21] Aizenshtein EM. Bottle wastes − to textile yarns. Fibre Chemistry. 2016;**47**:343-347. DOI: 10.1007/s10692-016-9691-8

[22] Upasani PS, Jain AK, Save N, Agarwal US, Kelkar AK. Chemical recycling of PET flakes into yarn. Journal of Applied Polymer Science. 2011;**123**:520-525. DOI: 10.1002/app.34503

[23] Recycled polyethylene terephthalate (PET) market analysis by product type (clear, colored), by end-use (fiber, sheet & film, strapping, f&b containers, bottles, non-food containers), and segment forecasts, 2014–2025 [Internet]. 2017. Available from: http://www.grandviewresearch.com/industry-analysis/recycled-polyethylene-terephthalate-pet-market [Accessed: October 16, 2017]

[24] Shen L, Worrell E, Patel MK. Open-loop recycling: A LCA case study of PET bottle-to-fibre recycling. Resources, Conservation and Recycling. 2010:1-19. DOI: 10.1016/j.resconrec.2010.06.014

[25] Lee JH, Lim KS, Hahm WG, Kim SH. Properties of recycled and virgin poly(ethylene terephthalate) blend fibers. Journal of Applied Polymer Science. 2013:1250-1256. DOI: 10.1002/APP.38502

[26] Elamri A, Lallam A, Harzallah O, Bencheikh L. Mechanical characterization of melt spun fibers from recycled and virgin PET blends. Journal of Materials Science. 2007;**42**:8271-8278. DOI: 10.1007/s10853-007-1590-1

[27] Koo HJ, Chang GS, Kim SH, Hahm WG, Park SY. Effects of recycling processes on physical, mechanical and degradation properties of PET yarns. Fibers and Polymers. 2013;**14**:2083-2087. DOI: 10.1007/s12221-013-2083-2

[28] Yüksekkaya ME, Celep G, Doğan G, Tercan M, Urhan BA. Comparative study of physical properties of yarns and fabrics produced from virgin and recycled fibers. Journal of Engineered Fibers and Fabrics. 2016;**11**:68-76

[29] Mari I, Shinji Y. Performance and durability of woven fabrics including recycled polyester fibers. Journal of Textile Engineering. 2004;**50**:25-30. DOI: 10.4188/jte.50.25

[30] Rajamanickam S, Vasudevan K. Study of antibacterial activity of chitosan on lyocell and recycled polyester yarns. International Journal of Innovative Research in Science Engineering and Technology. 2014;**3**:9480-9486

[31] Telli A, Özdil N. Properties of the yarns produced from r-pet fibers and their blends. Tekstil ve Konfeksiyon. 2013;**23**:3-10

[32] Sarıoğlu E. Ecological approaches in textile sector: The effect of r-pet blend ratio on ring spun yarn tenacity. Periodicals of Engineering and Natural Sciences. 2017;**5**:176-180. DOI: 10.21533/pen.v5i2.110

[33] BS EN ISO 139:2005+A1:2011Textiles. Standard atmospheres for conditioning and testing

[34] BS EN ISO 2062:2009 Textiles. Yarns from packages. Determination of single-end breaking force and elongation at break using constant rate of extension (CRE) tester

[35] ISO 16549:2004Textiles. Unevenness of textile strands – Capacitance method

[36] Nicolic M, Stjepanovic Z, Lesjak F, Stritof A. Compact spinning for improved quality of ring-spun yarns. Fibres & Textiles in Eastern Europe. 2003;**11**:30-35

[37] Jackowski T, Cyniak D, Czekalski J. Compact cotton yarn. Fibres & Textiles in Eastern Europe. 2004;**12**:22-26

[38] Altas S, Kadoğlu H. Comparison of conventional ring, mechanical compact pneumatic compact yarn spinning systems. Journal of Engineered Fibers and Fabrics. 2012;**7**:87-100

[39] Dash JR, Ishtiaque SM, Alagirusamy R. Properties and processibility of compact yarns. Indian Journal of Fibre & Textile Research. 2002;**27**:362-368

[40] Yilmaz D, Usal MR. A comparison of compact-jet, compact, and conventional ring-spun yarns. Textile Research Journal. 2011;**81**:459-470. DOI: 10.1177/0040517510385174

[41] Mamun RA, Repon MR, Jalil MA, Uddin AJ. Comparative study on card yarn properties produced from conventional ring and compact spinning. Universal Journal of Engineering Science. 2017;**5**:5-10. DOI: 10.13189/ujes.2017.050102