(REFEREED RESEARCH)

PROPERTIES OF THE YARNS PRODUCED FROM r-PET FIBERS AND THEIR BLENDS

r-PET LİFLERİ VE KARIŞIMLARINDAN ÜRETİLEN İPLİKLERİN ÖZELLİKLERİ

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Received: 13.04.2012 Accepted: 16.10.2012

ABSTRACT

r-PET fibers are basically derived from recycling PET bottle wastes. These fibers can be accepted as eco-friendly because of their advantages and contributions to the reduction of energy and raw material costs. In this study, properties of the yarns produced by r-PET fibers and their blends and their availability for textile industry were comparatively investigated. Tensile strength, elongation, evenness, hairiness properties and IPI fault values of yarns spun using 9 different blend ratios were measured and their results were statistically evaluated.

Key Words: r-PET fibers, PET bottle, Recycling, PET, Yarn properties.

ÖZET

r-PET lifleri, PET şişe atıklarından geri dönüştürülerek elde edilen liflerdir. r-PET lifleri, enerji ve hammadde maliyetlerinde getirdiği büyük avantajın yanı sıra daha az oluşum enerjisi ve karbon salınımıyla çevre dostu bir lif olarak karşımıza çıkmaktadır. Bu çalışmada r-PET lif ve karışımlarından elde edilen ipliklerin özellikleri kıyaslamalı olarak incelenerek tekstil endüstrisinde kullanılabilirliği araştırılmıştır. Farklı karışım oranlarındaki 9 farklı ipliğin kopma mukavemeti ve kopma uzaması, ince-kalın yer ve neps sayısı, düzgünsüzlük ve tüylülük değerleri ölçülerek istatistikî olarak değerlendirilmiştir.

Anahtar Kelimeler: r-PET lifleri, PET şişe, Geri dönüşüm, PET, İplik özellikleri.

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1. INTRODUCTION

Reasons like industrial developments, rise of the population density, etc. bring along environmental problems. We are running out of raw material resources fast but, still, individual consumption of these raw materials is gradually rising. This circumstance may cause large-scale environmental disasters later on. If it is investigated in terms of textile industry, the answer will be the same. In 1998, consumption of textile fibers were between 8,2 kg and 8,6 kg per person. In 2013, this consumption will be increased up to 11,8-12,2 kg (1). If this rise in the consumption of textile fibers per person is paired with the overpopulation, it is reasonable to say that environmental problems of textile industry reached massive amounts. For these reasons, finding new solutions is expected from the textile industry for easing these environmental problems they have caused. In this situation, the most important topic to be focused on is extending the lifecycle of the materials used, by recycling. r-PET fibers are obtained by recycling of PET bottle wastes. Firstly, PET bottle wastes are cleaned from the other wastes; then they are broken into flakes, washed and dried respectively before spinning process of the fiber (2). PET flakes are converted to fibers using with chemical and mechanical methods. PET is degraded into oligomer or monomer form and again a polymerization happens in chemical method. In mechanical method, PET flakes are melted and r-PET fibers are obtained by melt-spinning process.

35% of the world consumption of fiber is natural fibers and 65% of that is man-made fibers. 70% of man-made fibers are formed by PET and PET based fibers. 60% of PET consumption is used for fiber production while 30%

of this consumption is used for bottle production (3). Using PET bottles could cause some problems. It is known that it could take 35-48 years for PET bottles to degrade in soil with conditions of 20 °C and 100% relative humidity and degradation could increase 45% with changing humidity (4). Also, low density of PET bottles causes some problems during storing the wastes. Instead of burning or burying, PET bottles can be turned into primary or secondary raw materials and this could decrease raw material requirement of textile industry and this way, they could contribute to the economy.

PET bottle consumption in 2007 was 15 million tons in the world and this value was 8% of total plastics demand. Moreover, 4,5 million tons of PET bottles were recollected and 3,6 million tons of recollected bottles were recycled into PET flakes, (5). It is expected that, in 5-10 years, PET bottle recollection and recycling them into PET flakes will increase 10% - 20% of the consumption (6). But, continuity of this increase in PET bottle recycling and being successful in environmental recycling programs depends on extending the usage area (after recollection) of recycled wastes.

In reference to environmental approach, waste of a product should be used for producing the same product. PET bottle waste can be accepted valuable if it can be used for PET bottle production again. Because this way, it will gain primary raw material characteristics again and therefore its life cycle will be longer. However, medical and technological developments point out that PET bottle wastes should not be used for PET bottle production. Mancini et al. (7) applied a chemical washing procedure for PET flakes derived from mechanical recycling steps. After this procedure they have realized that purity degrees of the material increased but this increase was not enough for bottle production. Contamination in the recycled polymers is higher than expectations for the products which contact with food and this situation is unhealthy. Colour content, yellowing index, metal content PVC and polyolefin contents are expected to be lower than limit ppm values (8). The most restrictive matter for PET bottle recycling is intrinsic viscosity. In each of the recycling steps, this viscosity decreases and according to waste's condition it can decrease below 0,9dl/g. Ideal intrinsic viscosity for PET bottle is 1 dl/g. These restrictions prevent using PET flakes as raw material of PET bottle production. Decrease of viscosity to 0,4-0,5 dl/g is acceptable for fiber spinning in textile industry (9).

Studies about PET bottle and its recycling is mostly based on PET flakes processes, comparing the environmental effects of raw PET and recycled PET productions (7,8,10, 11,12). Mannhart (9) conducted 8 experiments with recycled PET flakes in Rieter compact spinning system. In these experiments different spinning temperatures, pumping velocities, winding velocities and filament finenesses were used. Based on the results it was indicated that filaments could be produced from PET flakes without granulation process. In a study of Abbasi et al. (13) the effects of structural and physical properties of conventional and recycled PET polymers to spinning speed were investigated. It was found that in the spinning speed of 2500-3000 m/min, r-PET filaments have higher density and crystallinity than PET filaments.

In recent years PET flakes are produced for secondary textile products like as carpet bottoms, sleeping bags, pillows and insulation materials. They are not used solely or blending with other recycled fibers. But for these products, other low quality raw materials have been used already. In this kind of consumption, PET polymers could only substitute other products. Therefore, using recycled PET fibers in apparel industry can extend their life cycle and make them primary raw material for this industry. When it is considered that the highest consumption of PET polymer in the world is for filament and staple fiber production, it is clear that, this study can present environmental advantages. Recycled fibers have economical advantages like low energy comsumption and raw material costs. Moreover, comparing to the other fibers in terms of embodied energy and carbon emissivity, r-PET fibers are less harmful to the environment (5). On the other hand, usage of the chemicals which are used for producing PET fibers and harmful for body hormonal system, such as bisphenol- a and antimony will decrease as the increase of r-PET fiber consumption,

In this study, properties of the yarns produced with r-PET fibers and their blends were investigated comparatively.

2. MATERIAL AND METHOD

r-PET fibers used in this study were supplied from one of the company that produce r-PET fibers using PET flakes by mechanical method in Turkey. The properties of cotton, polyester and recycled PET bottle fibers are given in Table 1. Cotton fiber properties were measured using Premier High Volume Fibre Tester and Trützschler Length-meter were used for determination of the length of PET and r-PET fibers. Single fibre tenacity and elongation values were determined using Textechno Favigraph Fibretest. 20 fiber specimens were tested according to ASTM 3822 and average values were taken. To determine fineness values of the PET and r-PET fibres, diameter of the fibers measured by Leica projection microscope. 20 measurements were taken and using average values, the fineness values were calculated in dtex.

Three different types of slivers were produced on carding machine by the fibers whose properties were given on Table 1(14). These slivers were blended in 9 different blending ratios in first draw frame machine as shown in Table 2. After second draw frame machine rovings were produced and Ne 20 yarns in the twist coefficient of α_e= 3,6 were produced in ring spinning system (Table 2).

Table 1. Fiber properties

Fiber Properties	Cotton (Co)	Poliester (PET)	Recycled PET Bottle (r-PET)
Fineness (dtex)	1,78	1,57	1,85
Mean length (mm)	26,51	28,77	32,62
Tenacity (cN/tex)	27,30	50,66	26,92
Elongation at break (%)	7,0	25,74	39,13

Table 2. Yarn types produced in experimental

Spinning System	Yarn Count	Twist	Blending Ratio
Ring Spinning System (Carded)	Ne 20	α_e= 3,6 T/m=634	100%Co
			70% Co 30% r-PET
			50% Co 50% r-PET
			30% Co 70% r-PET
			100% r-PET
			100% PET
			70% PET 30% r-PET
			50% PET 50% r-PET
			30% PET 70% r-PET

RIETER G30 Ring Spinning Frame was used with 10000 rpm spindle speed. Ring diameter of this machine was 42 mm. ISO 90 travelers and 5,5 mm light grey clips of were used on this machine. Shore hardness of top roller covers were 75 shore for feeding rollers and 68 shore for exit rollers. 1,18 breaking draft and 20 total draft were used in drafting system.

Evenness measurements of the yarns were carried out in measurement speed of 400 meters per minute for 1000 meters of yarn, using ”Uster Tester 5 S800” instrument, in conformity with ISO 16549. 10 tests were done each type of yarn and the average value was taken. Evenness (CVm), imperfections (IPI fault) values [thin places (-40%), thick places (+50%) and neps (+140%)] and hairiness values were determined.

Tensile strength and breaking elongation of the yarns were carried out by Lloyd tensile testing device in conformity with TS 245 EN ISO 2062. During testing, 0,15 N pretension according to the yarn and 250 mm measuring range were used. 50 results per yarn type were determined with the testing speed of 250 mm/minute. Results were determined as tenacity (cN/tex) and elongation at break (%).

3. RESULTS AND DISCUSSION

Tensile strength, elongation at break, thin places, thick places, neps, evenness and hairiness results of the yarns with 9 different blending ratios and each of their averages were given in Table 3.

Results of the measurements were statistically investigated and Levene homogeneity test was used for determining if the groups had equal variances or not. “Full Factorial” method was used because; variances between the groups were not equal. Paired comparison results of the variance analysis are given in Table 4.

Table 3. Properties of the yarns

Material	Tensile strength (cN/tex)	Elongation at break (%)	Evenness (%CVm)	Thin places (-40%)	Thick places (+50%)	Neps (+140%)	Hairiness (H)
100%Co	12,77	9,68	13,65	56,9	65,9	500,6	5,59
70%Co 30%r-PET	13,57	12,75	13,35	32,6	73,1	425,7	5,4
50%Co 50%r-PET	13,42	15,14	13,44	47,9	90,7	493,2	5,45
30%Co 70%r-PET	12,28	13,19	12,68	24,5	60,1	397,8	5,64
100%r-PET	14,91	22,08	12,45	32,7	54,6	346,8	5,8
100%PET	28,66	21,28	10,78	3,1	11,2	23,1	4,77
70%PET 30%r-PET	23,30	20,60	11,46	9,6	16,4	112,6	5,09
50%PET 50%r-PET	21,08	21,92	11,32	9,1	23,9	154	5,18
30%PET 70%r-PET	18,60	20,35	11,8	13,3	27,4	209	5,49

Table 4. The result of multiple comparisons of the yarn properties (* α = 0,05)

	100% Co	70% Co-30% r-PET	50% Co-50% r-PET	30% Co-70% r-PET	100% r-PET	100% PET	70% PET-30% r-PET	50% PET - 50% r-PET
70% Co-30% r-PET	str: 0,031* elg:0,000* Cv: 1,000 thin: 0,517 thick:1,000 neps: 0,452 H: 0,414	-------------						
50% Co-50% r-PET	str:0,073 elg:0,000* Cv: 1,000 thin: 1,000 thick:0,042* neps: 1,000 H: 0,470	str:1,000 elg:0,000* Cv: 1,000 thin: 0,213 thick:0,151 nep:0,027* H: 1,000	-------------					
30% Co-70% r-PET	str: 0,661 elg:0,000* Cv: 0,183 thin: 0,180 thick:1,000 neps: 0,073 H: 1,000	str:0,000* elg:0,995 Cv: 0,027* thin: 1,000 thick:0,620 neps: 0,956 H: 0,072	str: 0,000* elg:0,000* Cv: 0,002* thin: 0,097 thic: 0,000* nep:0,000* H: 0,041*	-------------				
100% r-PET	str: 0,000* elg:0,000* Cv: 0,046* thin: 0,532 thick:0,990 neps: 0,003* H: 0,189	str: 0,000* elg:0,000* Cv: 0,000* thin: 1,000 thick:0,244 nep:0,030* H: 0,001*	str: 0,000* elg:0,000* Cv: 0,000* thin: 0,258 thic: 0,000* nep:0,000* H: 0,000*	str: 0,000* elg:0,000* Cv: 0,997 thin: 1,000 thick:1,000 neps: 0,326 H: 0,477	-------------			
100% PET	str: 0,000* elg:0,000* Cv: 0,000* thin: 0,004* thick:0,000* neps: 0,000* H: 0,000*	str: 0,000* elg:0,000* Cv: 0,001* thin:0,000* thic:0,000* nep:0,000* H: 0,000*	str: 0,000* elg:0,000* Cv: 0,001* thin:0,000* thic: 0,000* nep:0,000* H: 0,000*	str: 0,000* elg:0,000* Cv: 0,015* thin: 0,107 thic: 0,000* nep:0,000* H: 0,000*	str: 0,000* elg:0,967 Cv: 0,039* thin:0,000* thic: 0,000* nep:0,000* H: 0,000*	-------------		
70% PET-30% r-PET	str: 0,000* elg:0,000* Cv: 0,000* thin: 0,010* thick:0,000* neps: 0,000* H: 0,000*	str: 0,000* elg:0,000* Cv: 0,000* thin:0,000* thic:0,000* nep:0,000* H: 0,006*	str: 0,000* elg:0,000* Cv: 0,001* thin:0,000* thic: 0,000* nep:0,000* H: 0,000*	str: 0,000* elg:0,000* Cv: 0,026* thin: 0,597 thic: 0,000* nep:0,000* H: 0,000*	str: 0,000* elg:0,024* Cv: 0,108 thin:0,001* thic: 0,000* nep:0,000* H: 0,000*	str: 0,000* elg:0,968 Cv: 0,995 thin: 0,509 thick:0,971 nep:0,000* H: 0,000*	-------------	
50% PET - 50% r-PET	str: 0,000* elg:0,000* Cv: 0,000* thin: 0,008* thick:0,000* neps: 0,000* H: 0,000*	str: 0,000* elg:0,000* Cv: 0,000* thin:0,001* thic: 0,000* nep: 0,000* H: 0,191	str: 0,000* elg:0,000* Cv: 0,000* thin:0,000* thic: 0,000* nep:0,000* H: 0,008*	str: 0,000* elg:0,000* Cv: 0,000* thin: 0,588 thic: 0,000* nep:0,000* H: 0,000*	str: 0,000* elg:1,000 Cv: 0,000* thin:0,001* thic: 0,001* nep:0,000* H: 0,000*	str: 0,000* elg:0,994 Cv: 0,999 thin: 0,931 thick:0,083 nep:0,000* H: 0,000*	str: 0,000* elg:0,018* Cv: 1,000 thin: 1,000 thick:0,663 nep:0,002* H: 0,995	-------------
30% PET-70% r-PET	str: 0,000* elg:0,000* Cv: 0,001* thin: 0,019* thick:0,000* neps: 0,000* H: 1,000	str: 0,000* elg:0,000* Cv: 0,000* thin:0,002* thic: 0,000* nep:0,000* H: 1,000	str: 0,000* elg:0,000* Cv: 0,000* thin:0,000*thi c: 0,000* nep:0,000* H: 1,000	str: 0,000* elg:0,000* Cv: 0,002* thin: 0,938 thic: 0,001* nep:0,000* H: 0,877	str: 0,000* elg:0,003* Cv: 0,015* thin:0,004* thic: 0,003* nep:0,000* H: 0,028*	str: 0,000* elg:0,536 Cv: 0,535 thin:0,010* thic: 0,002* nep:0,000* H: 0,000*	str: 0,000* elg:1,000 Cv: 1,000 thin: 1,000 thic:0,009* nep:0,000* H: 0,002*	str: 0,000* elg:0,001* Cv: 0,141 thin: 1,000 thick:1,000 nep:0,002* H: 0,040*

3.1 Strength and Elongation Results

Tenacity results of the yarns for 9 different blending ratios were given in Figure 1.

As shown in Figure 1, the highest value of strength belongs to 100% PET yarns. Results also indicates that, as the r-PET fiber content in PET/ r-PET blends increases, strength of the yarn decreases. This decrease was expected, because of the lower strength of r-PET fibers than PET fibers, as shown in Table 1.

Both 100% Co and Co/r-PET blended yarns have lower strength values than 100% r-PET yarns. Results indicate that tenacity values of the yarns decreases with the increase of r-PET fiber content in r-PET/cotton blends. 70% Co- 30% r-PET yarn has the highest tenacity among these blended yarns.

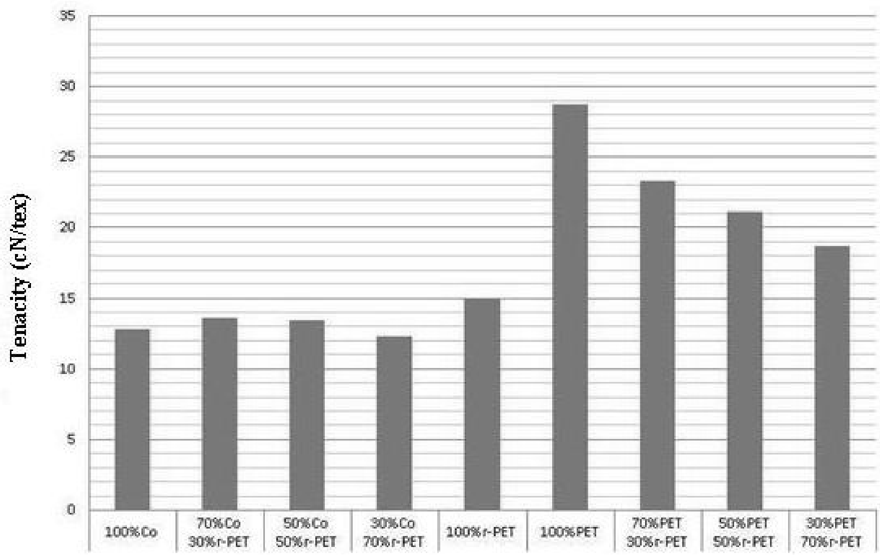

Figure 1. Tenacity results of the yarns

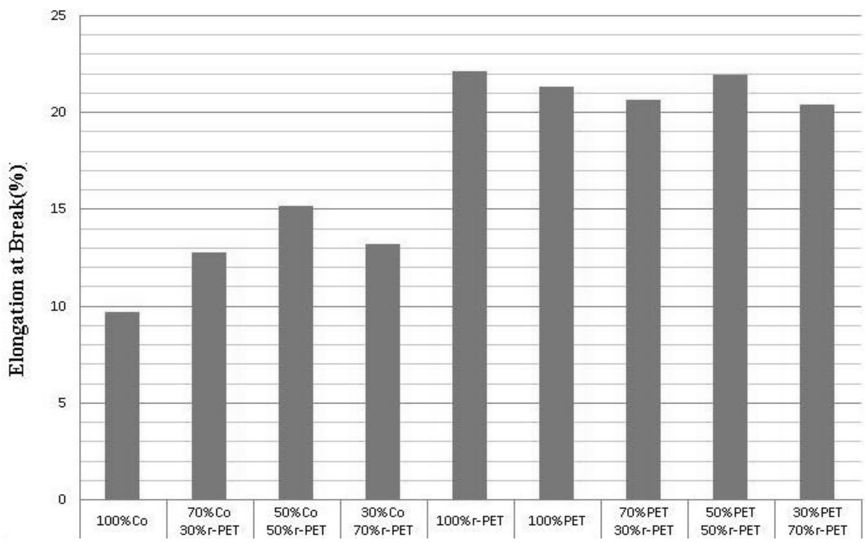

Figure 2. Elongation at break results of the yarns

as elongation at break results is analyzed, it can be seen that yarns produced with 100% r-PET yarns have highest result because of the highest fibre elongation properties. 100% PET and 50% PET 50% r-PET yarns show higher results in comparison with the others and no significant statistical differences have been found between these yarns (Table 4). r-PET / Co blends have lower results than r-PET / PET blends, but higher results compared to 100% Co yarn. But, the differences between these yarns are not found statistically important.

3.2 Evenness Results

Evenness results of 9 different yarns, those were produced in this study were given in Figure 3.

Evenness results of PET yarns are better than cotton yarns, because PET fibers have higher uniformity. The results of this study indicates that lowest % CVm value belongs to 100% PET yarns and the highest % CVm value belongs to 100% Co yarns. Even though the CVm values increase with increasing r-PET fiber content in PET/r-PET blends, these increases do not have a statistical significance for 95% confidence interval (Table 4). Co/r-PET blends have higher CVm results than PET/r-PET blends. Comparison in between Co/r-PET blends shows that 100% Co yarns again have the highest % CVm value whereas 100% r-PET yarns have the lowest. Blended yarn with the highest r-PET content which is 30% Co-70% r-PET yarn has the lowest CVm values (Figure 3, Table 4).

3.3 Thin -Thick Places and Neps Results

Thin places (-40%) of 9 different yarns, were given in Figure 4. The results indicate that 100% PET and PET blended yarns have lower number of thin place faults than 100% Co and cotton blended yarns. The highest results belong to 100% Co yarns while the lowest belong to 100% PET yarns (Figure 4). 100% r-PET yarns have higher number of thin place faults than 100% PET yarns. The difference between %100 PET yarns and 30% PET 70% r-PET yarns was found statistically significant. The differences between r-PET blends yarns for PET and cotton were found insignificant (Table 4).

Figure 5 shows thick places (+50%) of 9 different yarns. The results indicate that 50% Co 50% r-PET yarns have the highest number of thick places results while 100%PET yarns have the lowest value. The number of thick places faults of PET/r-PET blends increase as r-PET content of these yarns increase.

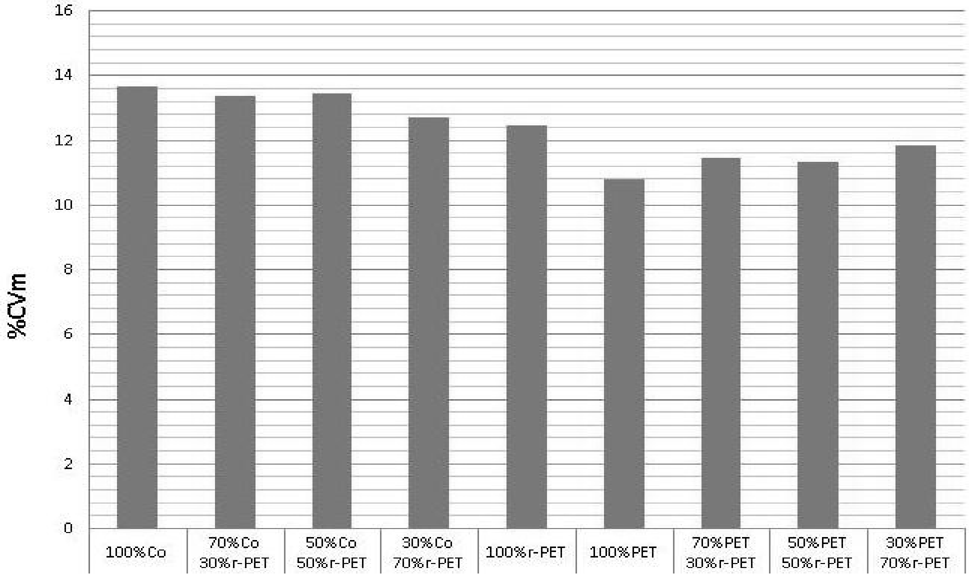

Figure 3. Evenness results of the yarns

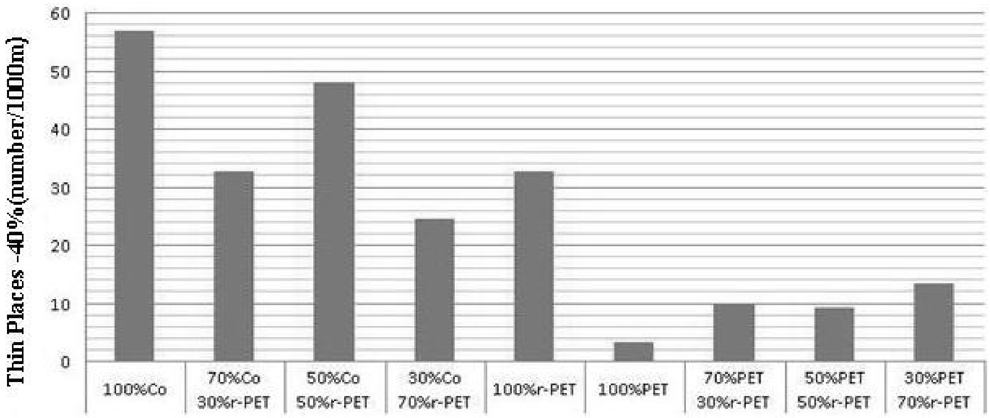

Figure 4. Thin places results of the yarns

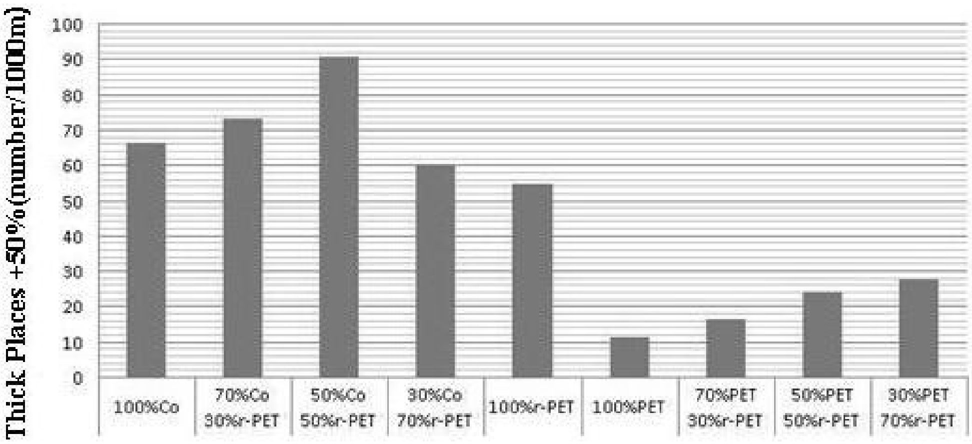

Figure 5. Thick places results of the yarns

Neps (+140%) values of 9 different yarns, were given in Figure 6.

Analysis of variance showed that differences between the neps faults of the yarns are statistically significant. The number of lowest neps faults was obtained in 100% PET yarns. It has been observed that increase of the r-PET fiber content in PET/r-PET blends causes increase in number of neps fault (Figure 6, Table 4). Results of r-PET fibers' blends with cotton show that, the 100% Co yarns have highest number of neps faults whereas 100% r-PET yarns have the lowest value.

3.4 Hairiness Results

Hairiness results of the yarns were given in Figure 7.

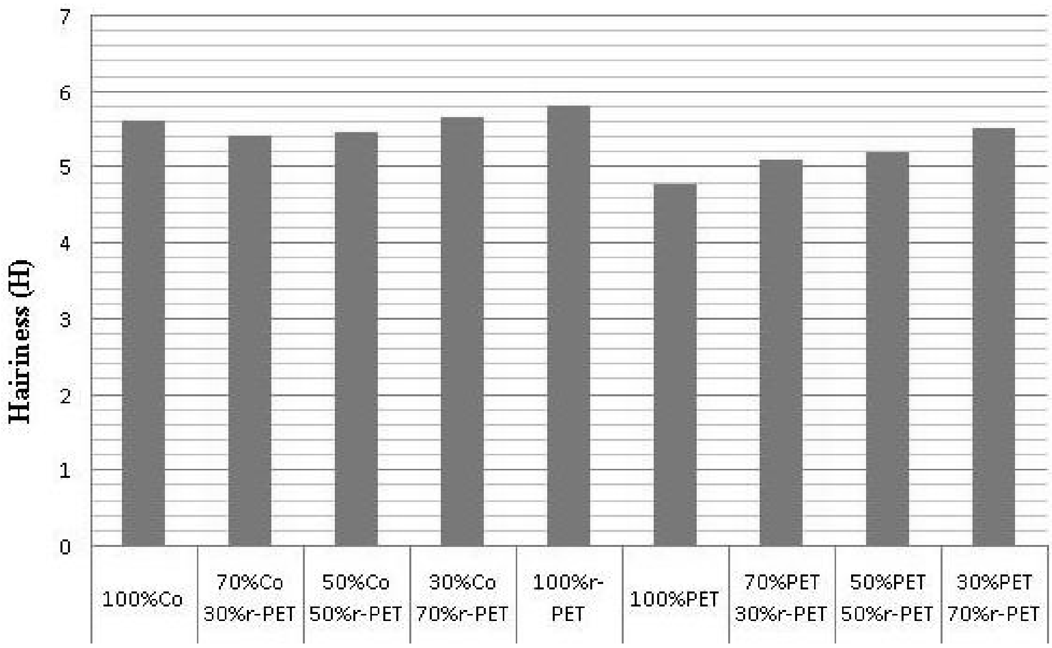

Figure 7. Hairiness results of the yarns

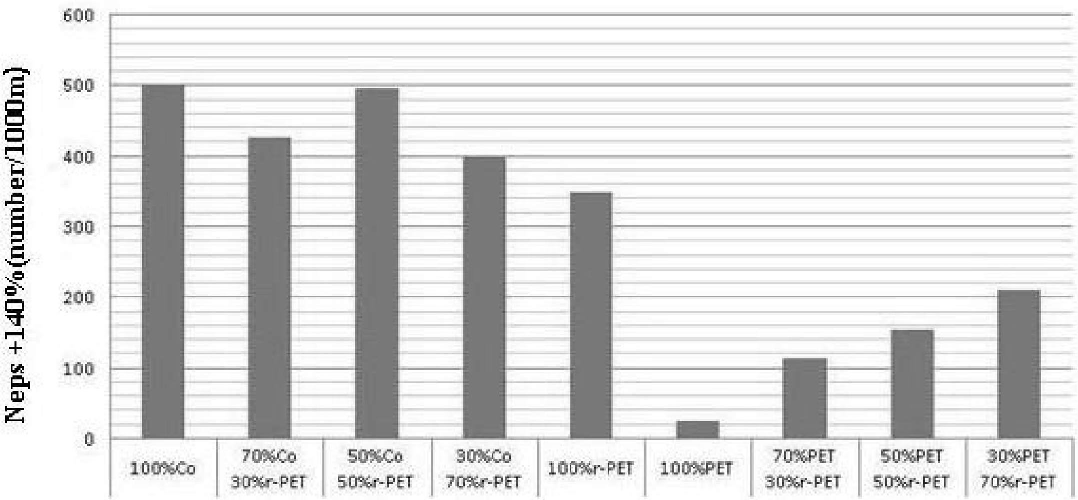

Figure 6. Neps results of the yarns

As it can be seen from Figure 7, 100% r-PET yarns have highest hairiness value; meanwhile the lowest value belongs to 100% PET yarns. Difference of hairiness values for cotton blends have been found insignificant. Higher r-PET fiber content in PET/r-PET blended yarns causes increase of hairiness values (Figure 7). But, it has been found that the hairiness value difference between 50% PET 50% r-PET and 70% PET 30% r-PET, is not found significant (Table 4).

4. CONCLUSIONS

Important data have been obtained in this study which aimed to research usage of r-PET fibers in yarn production process for textile and apparel industry.

In terms of yarn manufacturing process, it was noticed that, in production with r-PET fibers, no unusual problems have been encountered.

According to the test results, it is confirmed that 100% r-PET yarns have lower tensile strength than 100% PET yarns and despite this fact, they have higher elongation at break results. Thus, increasing of r-PET content causes decrease in tensile strength for PET/r-PET blended yarns. The results indicate that tenacity values of the yarns decreases with the increase of r-PET fiber content in r-PET/cotton blends as well.

With respect to the results; evenness values and the number of IPI faults of 100% r-PET yarns are worse than 100% PET yarns. But, there is not significant difference for these properties, between r-PET fibers' blends with cotton and PET. It is found that Co/r-PET blends have higher CVm values and IPI faults than PET/r-PET blends. This is an expected result of the lower length uniformity of the cotton fibers. 100% r-PET yarns have higher hairiness values than 100% PET yarns. However, the results indicate that there is no statistical difference about hairiness values between blended yarns.

In conclusion, it can be said that required performance of the r-PET yarns can be achieved not by producing 100% pure yarns but blending with other fibers. The important point here is, selecting proper r-PET content of the fabric for usage area. Developments in PET bottle recycling could improve the way for producing higher standard r-PET fibers and so high quality end products. However, r-PET fibers' cost advantage (approximately half of PET fibers' cost) can be the encouraging factor to consumption of this fiber in their current quality standards. In addition to this cost advantage, being less harmful to environment can increase marketing opportunities of the r-PET fibers.

REFERENCES

1. Davies B., 2007, "Poliester and Nylon: What does the future hold?", 46. Man Made Fiber Congress, Dornbirn
2. Telli A. and Özdil N., Lint Generation of the Yarns Produced PET Fibers, International Congress of Innovative Textiles- ICONTEX, 20-22 October 2011, 32-35
3. Anne, P., "Why is recycled polyester considered a sustainable textile?", http://oecotextiles.wordpress.com/2009/07/14/why-is-recycled-polyester-considered-a-sustainable-textile/ (Son Erişim Tarihi: 07.03.12)
4. Hakkarainen M. and Albertsson A.C., 2008, Chromatography for Sustainable Polymeric Materials Renewable, Degredable and Recycable, Springer-Verlag Berlin Heidelberg, 191p
5. Shen, L., Worrell, E. and Patel, M., 2010, Open-Loop Recycling: A LCA Case Study of Pet Bottle-to-Fibre Recycling, *Resources Concervation and Recycling Journal*, 55:34-52
6. Napcor: National Association for Pet Container Resources, "Comprehensive Information about the PET package", http://www.napcor.com/pdf/v4-11_NAPCOR_PET_Interactive.pdf (Son Erişim Tarihi: 01.05.11)
7. Mancini, S.D., Schwartzman, J.A.S., Nogueira, A.R., Kagohara, D.A. and Zanin, M., 2009, Additional Steps in Mechanical Recycling of Pet, *Journal of Cleaner Production*, 18:92-100
8. Awaja, F. and Pavel, D., 2005, Recycling of Pet, *European Polimer Journal*, 41:1453-1477
9. Mannhart, M., 1998, Pet Şişelerden Filament İplik, *Melliand Türkiye Sayısı*, 3:166-169
10. Öktem, T., 1998, Polyester Atıkların Değerlendirilmesi, *Tekstil ve Konfeksiyon*, 6:396-400
11. Sevencan, F. ve Vaizoğlu, S., 2007, Pet ve Geri Dönşümü, *TSK Koruyucu Hekim Bülteni*, 6(4):307-312
12. Küçükgül, E. ve Kırşen Doğan, S., 2007, Pet Şişenin Yaşamsal Döngü Analizi, 7.Uluslararası Çevre Mühendisliği Kongresi, s:491-501
13. Abbasi, M., Mojtahedi M.R.M. and Khosroshahi A., 2007, Effect of Spinning Speed on the structure and physical properties of filament yarns produced from used pet bottles, *Journal of Applied Polymer Science*, 103:3972-3975
14. Telli A., 2011, Pet Şişe Geri Dönüşüm PES İle Klasik PES Liflerinden Üretilen İplik ve Kumaş Özelliklerinin Karşılaştırılması Üzerine Bir Çalışma, Yüksek Lisans Tezi, Ege Üniversitesi Fen Bilimleri Enstitüsü, Bornova-İzmir.