(REFEREED RESEARCH)

# USAGE OF RECYCLED COTTON AND POLYESTER FIBERS FOR SUSTAINABLE STAPLE YARN TECHNOLOGY

# SÜRDÜRÜLEBİLİR KISA LİF İPLİK TEKNOLOJİSİ İÇİN GERİ DÖNÜŞÜM PAMUK VE POLYESTER LİFLERİNİN KULLANIMI

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**ABSTRACT**

In this study, yarns were produced from cotton fibers (CO), recycled cotton fibers obtained from yarn wastes (r-CO) and fibers produced from recycled PET bottles (r-PET). Tensile strength, elongation at break, unevenness (CVm), yarn imperfections (IPI) values and hairiness properties of these yarns were measured. The purpose of this study was to eliminate negative characteristics of recycled cotton and polyester fibers with using together by open-end spinning system. There was no study about r-CO/r-PET blends in the literature. This study was also given significant findings related to these blends. This paper obtained results which corroborate the findings of a considerable number of the previous works in CO/r-CO and CO/r-PET binary blends. Furthermore, this study contributes to the extant literature.

**Keywords:** Sustainable textiles, Recycling, Recycled fibers, Yarn spinning, OE Rotor yarns

**ÖZET**

Bu çalışmada pamuk lifi (CO), iplik üretimi sırasında oluşan atıklardan geri dönüşüm pamuk lifi (r-CO) ve PET şişe atıklarından geri dönüştürülen lif (r-PET) kullanılarak iplikler üretilmiştir. Üretilen ipliklere kopma mukavemeti, kopma uzaması, düzgünsüzlük ve tüylülük performans testleri uygulanmıştır. Çalışmada geri dönüşüm pamuk ve polyester liflerinin open-end iplik eğirme sisteminde olumsuz özelliklerini elimine etmek amaçlanmıştır. Literatürde r-CO/r-PET karışımlarına dair bir bilgi bulunmamaktadır. Çalışmada bu karışımlar ile ilgili önemli bulgular elde edilmiştir. Çalışmadaki CO/r-CO ve CO/r-PET ikili karışımlarından elde edilen sonuçlar literatürde yer alan bilgileri doğrulamaktadır. Ayrıca, çalışma mevcut literatüre katkıda bulunmaktadır.

**Anahtar Kelimeler:** Sürdürülebilir tekstiller, Geri dönüşüm, Geri dönüşüm lifler, İplik eğirme, OE Rotor iplikler

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## INTRODUCTION

Cotton and polyester are the most used fibers in this age. The increase of cotton cultivation areas may seem possible above of the 36 million hectares in terms of geographical but it is not possible economically. The demand of food plants are increasing quickly. The usage of fertile cotton land for food production is dominant idea nowadays. Polyester fibers that are a petroleum derivative are obtained from fossil fuels. The majority of the released $CO_2$ emissions in the world are caused by fossil fuels. Furthermore, world fiber consumption is expected to reach to 150-160 million tons from 89,5 million tons in 2050. Therefore, this fiber demand must be met with recycled fibers from textile wastes [1, 2]. For example, Turkey is an outstanding textile and apparel manufacturer with production of about 3.873.842 tons in the world. 458.484 tons of production waste in a year was generated by the textile industry during these productions. When taken into account 426.406 tons of household textile wastes, total waste amount was estimated to have reached up to 884.890 tons. It was underlined that these wastes have recycled but approximately 500.000 tons of waste was not recovered from landfills [3]. These values show a great loss in terms of environmental and economic reality. Previous studies have suggested that some consumers will consistently select recycled textile products. The findings have indicated that there is a large segment of consumers who will select recycled textiles regardless of product category if priced competitively with products made from virgin fibers [4]. Academic studies were performed for the usage of recycled fibers and the success of recycling operations. As distinct from previous studies, yarns were produced by blending recycled cotton fibers obtained from yarn wastes (r-CO) and fibers produced from recycled PET bottles (r-PET) in this study.

A considerable amount of literature has been published on recycled cotton fiber as an industrial waste. Wulfhorst (1984) has discussed that recovered fibers can be blended with raw materials and can be reused for the open-end spinning, without noticeable changes in yarn quality [5]. Duru and Babaarslan (2003) have examined to determine optimum opening roller speed and other process parameters for the production of recycled cotton [6]. Merati and Okamura (2004) have modified the feeding part of friction spinning in order to increase the use of recycled fibers at multi-component medium count yarns [7]. Halimi et al. (2007) have investigated the effects of recycled cotton and spinning parameters on rotor yarn quality [8]. Halimi et al. (2009) demonstrated that with a good choice of spinning parameters, 25% recycled cotton proportion does not alter the uniformity and the appearance of rotor yarn [9]. Researchers also worked to optimize machine parameters for rotor yarn with recycled cotton from ginning process [10, 11]. Kurtoglu Necef et al. (2013) and Demıroz Gun et al. (2014) have used recycled cotton from fabric scraps for yarn spinning and compared with original rotor yarn [12, 13]. Khan et al. (2015) have pointed out that blending ratio and rotor speed are most influencing factors on recycled rotor yarns [14]. Khan and Rahman (2015) have discussed the effects of rotor speed, opening roller speed and pneumafil ratio on the performance of rotor spun yarn produced from recycled waste [15]. In recent years, there are various studies about r-PET. Recycled polyester fibers (r-PET) are produced by melt spinning process of chips which obtained from recycled PET flakes. Studies conducted by Frounchi et al. (1997) and Elamri et al. (2007) have shown that reprocessing of PET decreases slightly the mechanical properties but molecular weight and melt viscosity drops somewhat substantially. Findings have indicated that melt spinning process allows to obtain recycled fibers having mechanical characteristics close to those issued from virgin PETs and to reduce raw material cost [16, 17]. There were limited papers related to the staple fiber specifications, the comparison with polyester fibers of r-PET, the performance of filament forms and yarn/fabric characteristics obtained from r-PET staple/filament fibers in the literature [18-22]. The first serious research on r-PET fiber was emerged by Telli and Ozdil (2013). Properties of the ring yarns produced from r-PET fiber were compared with original polyester yarn. The findings have showed that unevenness and IPI values of 100% r-PET are worse than 100% PET yarns [19]. Telli and Özdil (2015) have emphasized that yarn results will be positively affected according to r-PET/polyester blends in the case that r-PET fiber is blended with cotton [21]. Most these studies in the field of r-PET have only focused on ring spinning system. Our idea was to eliminate negative characteristics of these recycled fibers with using together in open-end spinning by looking at literature. In this study, yarns from r-CO/r-PET and their blends were analyzed in terms of acceptable quality. Furthermore, these yarns were compared with the cotton blends of recycled fibers and unblended yarns.

**MATERIAL AND METHODS**

CO, r-CO and r-PET fibers were used as raw material in this study. Single fibre tenacity and elongation were determined using Favigraph Fibretest according to ASTM 3822. TS 715 ISO 6989 was used for determination of the length of fibers. To determine these results, fifty fiber specimens were tested and average values are given in Table 1. Table 2 provides the properties of CO and r-CO fibers. The properties of these fibers were measured using Uster HVI-1000 with five specimens.

Three different types of slivers were produced on carding machine by the fibers whose properties are given in Table 1 and Table 2. The blending ratio was considered as 25% in order to see easily the effect of the fibers on the yarn structure. This opinion with three different fibers was resulted in 15 different compositions.

The sixteenth composition containing the equal ratio from three fibers was added to these. Thus, three different types of slivers were blended in 16 different blending ratios in first draw frame machine as shown in Table 3. Yarns were produced by open-end spinning system after second draw frame.

Yarn production parameters were designed to produce such as a yarn which will be used in denim fabric production. Advised production parameters for the better unevenness and hairiness values in recycled yarns from literature were used as shown in Table 4 [6, 8-11]. Therefore, pre-production trials were conducted up to a certain value (Rkm=10) in 100% r-CO yarns to avoid problems in terms of strength in fabric production. Twist factor was used to reach this strength value essentially. 60.000 (r/min) was achieved as the highest rotor speed for optimum yarn quality in yarn spinning trials. Yarn exit speed was 91, 6 m/min at this stage. After that, all yarns were produced using same production parameters.

**Table 1.** Properties of r-PET fiber

| | Fineness (dtex) | Tenacity (cN/tex) | Elongation at break (%) | Length (mm) |
|---|---|---|---|---|
| **Mean** | 1,56 | 46,20 | 24,28 | 38,00 |
| **Std. Dev.** | 0,05 | 6,76 | 5,63 | 0,04 |
| **CV%** | 3,30 | 14,63 | 23,19 | 0,01 |

**Table 2.** Properties of CO and r-CO fibers

| Properties | SCI | Mst Dry (%) | Mic | Mat | UHML (mm) | UI (%) | SFI (12,7 mm) | Str (g/tex) | Elg (%) | Rd | +b | C Gr | Tr Cnt | Tr Ar % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **CO** | 126 | 8,22 | 4,54 | 0,88 | 29,4 | 82,1 | 11,5 | 33,0 | 5,1 | 68,3 | 10,3 | 43-1 | 68,4 | 0,77 |
| **r-CO** | 103 | 8,02 | 4,64 | 0,89 | 25,5 | 75,8 | 20,5 | 31,4 | 3,9 | 75,8 | 10,2 | 22,2 | 15,6 | 0,08 |

**Table 3.** Blending composition and ratios

| Type | 01 | 02 | 03 | 04 | 05 | 06 | 07 | 08 | 09 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **CO** | 100 | 75 | 75 | 50 | 50 | 50 | 25 | 25 | 25 | 25 | 0 | 0 | 0 | 0 | 0 | 33 |
| **r-CO** | 0 | 0 | 25 | 0 | 25 | 50 | 0 | 25 | 50 | 75 | 0 | 25 | 50 | 75 | 100 | 33 |
| **r-PET** | 0 | 25 | 0 | 50 | 25 | 0 | 75 | 50 | 25 | 0 | 100 | 75 | 50 | 25 | 0 | 33 |

**Table 4.** Yarn production parameters

| Parameters | Preferred |
|---|---|
| Yarn Count (Ne) | 12 |
| Twist Coefficient ($\alpha_e$) | 4,8 |
| Rotor Type and Diameter | T40 |
| Rotor Speed (r/min) | 60.000 |
| Opening Roller Type | SN21DN |
| Opening roller speed (r/min) | 8.800 |
| Nozzle | K4KK |

Tensile strength, elongation at break, unevenness, hairiness properties and IPI values of yarns were measured. Tensile strength and elongation at break of the yarns were carried out using Uster Tensorapid 3 with twenty specimens according to TS 245 EN ISO 2062. Unevenness measurements of the yarns were tested in speed of 400 meters per minute for 1000 meters of yarn, using ”Uster Tester 4-FX” instrument, in conformity with ISO 16549. Hairiness properties were measured using Zweigle G 567. Ten tests were done for each type of yarn from two bobbins in Uster and Zweigle measurements. Results of the measurements were statistically investigated and Levene homogeneity test was used for determining if the groups had equal variances or not. “Tamhane T2” method was used because; variances between the groups were not equal. Furthermore, the relationships between blending ratio of fibers and the yarn results were analyzed using correlation analysis. According to the data set, Sperman’s rho correlation analysis and coefficient of correlation (r) were used for the examination of the correlation. The value of “r” is such that $-1<r<+1$. A correlation greater than 0,75 is generally described as strong, whereas a correlation less than 0,5 is generally described as weak.

## RESULTS AND DISCUSSION

The properties of raw materials are determinative factor on yarn features. Firstly, we can see from Table 2 that CO has better fiber properties than r-CO in terms of the length parameters such as UHML, UI and SFI. It is apparent from Table 1 that r-PET has higher tensile strength and elongation at break according to CO and r-CO. However, the variation of tensile strength and elongation at break of r-PET draw attention (Table 1). The linear relationships between blending ratio of fibers and the yarn results obtained from correlation analysis are given in Table 5.

**Table 5.** The obtained correlation coefficient between blending compositions and yarn performance

| Yarn Tests | Coefficient of correlation coefficient (r) values | | |
|---|---|---|---|
| | CO | r-CO | r-PET |
| Tensile Strength | -0,001 | -0,489 | 0,391 |
| Elongation at Break | -0,648* | -0,128 | 0,751** |
| Unevenness | -0,503* | 0,930** | -0,363 |
| Thin Places | -0,383 | 0,952** | -0,501* |
| Thick Places | -0,115 | 0,813** | -0,655* |
| Neps | -0,088 | 0,500* | -0,414 |
| Hairiness (Uster H) | -0,373 | 0,403 | -0,146 |
| Hairiness (Zweigle S3) | -0,591* | 0,749* | -0,104 |

(*) good correlation (**) strong correlation (-) negative correlation

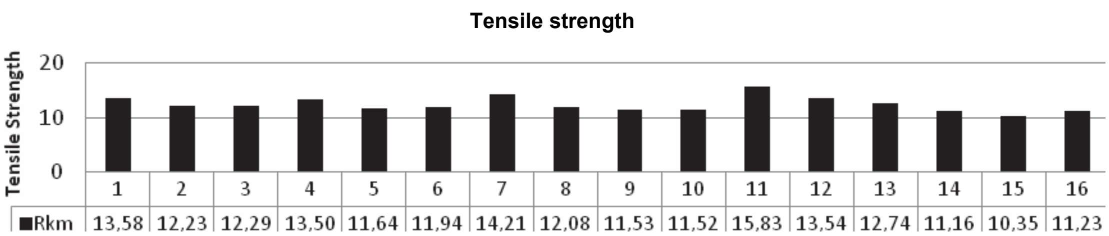


**Figure 1.** Tensile strength results

The highest tensile strength was measured in 100% r-PET coded as “11” (Figure 1). There was no significant difference between “11” and 25% CO/75% r-PET coded as “07” (p=0,47) as can be seen in Table 6. The lowest tensile strength was measured in 100% r-CO coded as “15”. It can be observed from data that unblended yarns showed similar results to fiber properties. The tenacity of fibers in the same measurement unit were 32,4 cN/tex for CO, 30,8 cN/tex for r-CO and 46,20 cN/tex for r-PET. There was not significant difference between CO and r-CO in terms of fiber tenacity, but r-PET has higher tenacity than others. 100% r-PET has the highest tensile strength, due to the higher fiber tenacity. The reason of difference between 100% CO and 100% r-CO in terms of tensile strength is that r-CO has lower uniformity index and higher short fiber index (Table 2).

Lower tensile strength is related to worse length uniformity. Halimi et al. (2007) also draw on relationship between r-CO and short fiber index [8]. This negative feature of r-CO was maintained in previous studies [9-13]. On the other hand, the correlation between tensile strength and fibers is interesting because blended yarns have different results from unblended yarns. The correlation results indicate that tensile strength has a weak positive correlation (r=0,391) with r-PET and a weak negative correlation (r=-0,489) with r-CO. It is clear that other parameters come into play in blended yarns in addition to fiber properties. Although tensile strength decreased with increase of r-CO in CO/r-CO blends, there was no significant difference between these yarns and 100% r-CO differently from previous studies (Table 6). It is apparent from the data in Figure 1 that tensile strength decreased for much of samples except yarns coded as “07” and “11” according to 100% CO. And no significant difference was found between 100% CO and yarn coded as “07” (p=1,00). No difference greater than 100% CO in CO/r-PET blends was observed. Likewise, Telli and Özdil (2001) have pointed out that CO/r-PET blends showed similar results to 100% CO while 100% r-PET has higher tensile strength than 100% CO [19]. But increases of r-PET ratio in r-CO/r-PET blends were provided increase in tensile strength. The best results are shown in 25% r-CO/75% r-PET among the r-CO/r-PET blends. Contrary to expectations, this study did not find a significant difference between this yarn and 100% CO (p=1,00).

The highest elongation at break was measured in 100% r-PET (Figure 2). There was no significant difference between “11” and 25% CO/75% r-PET coded as “07” from the data in Table 7 (p=1,00). The lowest elongation at break was measured in 75% CO/25% r-CO coded as “03”. As Table 1 and Table 2 shows, the elongation at break of fibers were 5,1% for CO, 3,9% for r-CO and 24,28% for r-PET. The elongation at break of r-PET was seriously higher than other fibers. It can be observed that these results reflected to yarn values. The highest value for unblended yarns was detected in 100% r-PET. The increase in elongation at break of CO/r-PET blends and r-CO/r-PET blends was observed in association with increase of r-PET ratio. The best results are shown in 25% r-CO/75% r-PET among the r-CO/r-PET blends.

**Table 6.** The results (p values) of multiple comparisons for tensile strength

| | 01 | 02 | 03 | 04 | 05 | 06 | 07 | 08 | 09 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 01 | - | 0,27 | 0,93 | 1,00 | 0,53 | 0,07 | 1,00 | 0,12 | 0,20 | 0,07 | 0,04 | 1,00 | 1,00 | 0,03 | 0,00 | 0,00 |
| 02 | 0,27 | - | 1,00 | 0,06 | 1,00 | 1,00 | 0,00 | 1,00 | 1,00 | 1,00 | 0,00 | 0,04 | 1,00 | 1,00 | 0,03 | 0,85 |
| 03 | 0,93 | 1,00 | - | 0,88 | 1,00 | 1,00 | 0,06 | 1,00 | 1,00 | 1,00 | 0,00 | 0,81 | 1,00 | 1,00 | 0,17 | 1,00 |
| 04 | 1,00 | 0,06 | 0,88 | - | 0,49 | 0,01 | 1,00 | 0,02 | 0,16 | 0,04 | 0,01 | 1,00 | 1,00 | 0,02 | 0,00 | 0,00 |
| 05 | 0,53 | 1,00 | 1,00 | 0,49 | - | 1,00 | 0,04 | 1,00 | 1,00 | 1,00 | 0,00 | 0,42 | 1,00 | 1,00 | 1,00 | 1,00 |
| 06 | 0,07 | 1,00 | 1,00 | 0,01 | 1,00 | - | 0,00 | 1,00 | 1,00 | 1,00 | 0,00 | 0,01 | 1,00 | 1,00 | 0,18 | 1,00 |
| 07 | 1,00 | 0,00 | 0,06 | 1,00 | 0,04 | 0,00 | - | 0,00 | 0,01 | 0,00 | 0,47 | 1,00 | 0,82 | 0,00 | 0,00 | 0,00 |
| 08 | 0,12 | 1,00 | 1,00 | 0,02 | 1,00 | 1,00 | 0,00 | - | 1,00 | 1,00 | 0,00 | 0,01 | 1,00 | 1,00 | 0,07 | 0,99 |
| 09 | 0,20 | 1,00 | 1,00 | 0,16 | 1,00 | 1,00 | 0,01 | 1,00 | - | 1,00 | 0,00 | 0,13 | 1,00 | 1,00 | 1,00 | 1,00 |
| 10 | 0,07 | 1,00 | 1,00 | 0,04 | 1,00 | 1,00 | 0,00 | 1,00 | 1,00 | - | 0,00 | 0,03 | 1,00 | 1,00 | 1,00 | 1,00 |
| 11 | 0,04 | 0,00 | 0,00 | 0,01 | 0,00 | 0,00 | 0,47 | 0,00 | 0,00 | 0,00 | - | 0,01 | 0,00 | 0,00 | 0,00 | 0,00 |
| 12 | 1,00 | 0,04 | 0,81 | 1,00 | 0,42 | 0,01 | 1,00 | 0,01 | 0,13 | 0,03 | 0,01 | - | 1,00 | 0,02 | 0,00 | 0,00 |
| 13 | 1,00 | 1,00 | 1,00 | 1,00 | 1,00 | 1,00 | 0,82 | 1,00 | 1,00 | 1,00 | 0,00 | 1,00 | - | 0,95 | 0,06 | 0,84 |
| 14 | 0,03 | 1,00 | 1,00 | 0,02 | 1,00 | 1,00 | 0,00 | 1,00 | 1,00 | 1,00 | 0,00 | 0,02 | 0,95 | - | 1,00 | 1,00 |
| 15 | 0,00 | 0,03 | 0,17 | 0,00 | 1,00 | 0,18 | 0,00 | 0,07 | 1,00 | 1,00 | 0,00 | 0,00 | 0,06 | 1,00 | - | 1,00 |
| 16 | 0,00 | 0,85 | 1,00 | 0,00 | 1,00 | 1,00 | 0,00 | 0,99 | 1,00 | 1,00 | 0,00 | 0,00 | 0,84 | 1,00 | 1,00 | - |

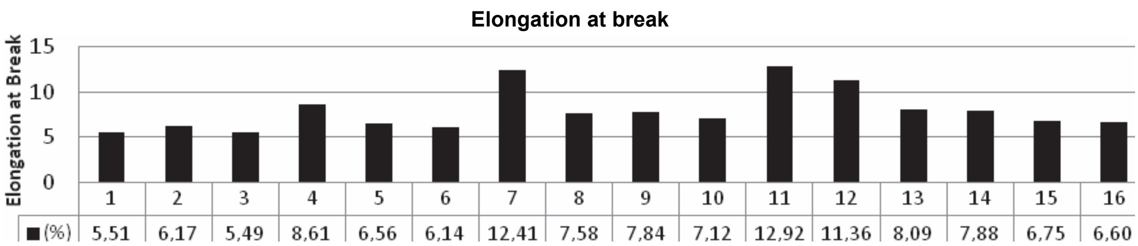


**Figure 2.** Elongation at break results

**Table 7.** The results (p values) of multiple comparisons for elongation at break

| | 01 | 02 | 03 | 04 | 05 | 06 | 07 | 08 | 09 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 01 | - | 0,01 | 1,00 | 0,00 | 0,00 | 0,02 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 |
| 02 | 0,01 | - | 0,00 | 0,00 | 0,82 | 1,00 | 0,00 | 0,08 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,02 | 0,97 |
| 03 | 1,00 | 0,00 | - | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 |
| 04 | 0,00 | 0,00 | 0,00 | - | 0,00 | 0,00 | 0,00 | 0,97 | 0,96 | 0,00 | 0,00 | 0,00 | 1,00 | 0,98 | 0,00 | 0,00 |
| 05 | 0,00 | 0,82 | 0,00 | 0,00 | - | 0,68 | 0,00 | 0,73 | 0,00 | 0,21 | 0,00 | 0,00 | 0,00 | 0,00 | 1,00 | 1,00 |
| 06 | 0,02 | 1,00 | 0,00 | 0,00 | 0,68 | - | 0,00 | 0,07 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,01 | 0,93 |
| 07 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | - | 0,00 | 0,00 | 0,00 | 1,00 | 0,75 | 0,00 | 0,00 | 0,00 | 0,00 |
| 08 | 0,00 | 0,08 | 0,00 | 0,97 | 0,73 | 0,07 | 0,00 | - | 1,00 | 1,00 | 0,00 | 0,00 | 1,00 | 1,00 | 0,98 | 0,87 |
| 09 | 0,00 | 0,00 | 0,00 | 0,96 | 0,00 | 0,00 | 0,00 | 1,00 | - | 0,04 | 0,00 | 0,00 | 1,00 | 1,00 | 0,00 | 0,00 |
| 10 | 0,00 | 0,00 | 0,00 | 0,00 | 0,21 | 0,00 | 0,00 | 1,00 | 0,04 | - | 0,00 | 0,00 | 0,03 | 0,02 | 0,95 | 0,84 |
| 11 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 1,00 | 0,00 | 0,00 | 0,00 | - | 0,01 | 0,00 | 0,00 | 0,00 | 0,00 |
| 12 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,75 | 0,00 | 0,00 | 0,00 | 0,01 | - | 0,00 | 0,00 | 0,00 | 0,00 |
| 13 | 0,00 | 0,00 | 0,00 | 1,00 | 0,00 | 0,00 | 0,00 | 1,00 | 1,00 | 0,03 | 0,00 | 0,00 | - | 1,00 | 0,00 | 0,00 |
| 14 | 0,00 | 0,00 | 0,00 | 0,98 | 0,00 | 0,00 | 0,00 | 1,00 | 1,00 | 0,02 | 0,00 | 0,00 | 1,00 | - | 0,00 | 0,00 |
| 15 | 0,00 | 0,02 | 0,00 | 0,00 | 1,00 | 0,01 | 0,00 | 0,98 | 0,00 | 0,95 | 0,00 | 0,00 | 0,00 | 0,00 | - | 1,00 |
| 16 | 0,00 | 0,97 | 0,00 | 0,00 | 1,00 | 0,93 | 0,00 | 0,87 | 0,00 | 0,84 | 0,00 | 0,00 | 0,00 | 0,00 | 1,00 | - |

There was a significant correlation (r=0,751) between r-PET and elongation at break in Table 5. Furthermore, a good negative correlation (r=-0,648) was found between CO and elongation at break. However, increase of r-CO provided some increase in elongation at break of CO/r-CO blends although r-CO has the lowest values according to the others. In all addition to this, Figure 2 shows that elongation at break increased for much of samples except 75% CO/25% r-CO coded as “03” according to 100% CO yarn. As shown in Table 8, there was significant difference in all samples showing an increase compared to the 100% CO yarn. Moreover, the elongation at break of 100% r-CO was higher than 100% CO. These results match those observed in earlier study by Demiroz Gun et al. (2014). Researchers have indicated that yarn containing recycled fiber has a higher elongation at break than 100% CO [13]. However, it can be observed that these data are misleading owing to recycled yarns containing original polyester in that study. A possible explanation of these results is that the same machine and production parameters were preferred. The obtained results shows that preferred production parameters have negative effect on yarns containing CO and have a positive contribution to yarns containing r-CO. Because, production parameters were designed to produce such as a recycled yarns in this study. Advised parameters for the better unevenness and hairiness values in recycled yarns from literature were used. It was especially focused on 100% r-CO which can be the biggest problem in experimental design of yarn production. For example, the speed of opening roller was used as 8.800 (r/min) in this study. In recycling applications, it is well known that higher opening roller speed have a positive effect on yarn unevenness, thin-thick places and neps. However, it can be estimated that the range of 6.500-8.000 rpm can give better results for 100% CO according to previous studies. It is likely that the elongation at break of 100% CO was be adversely affected by the higher opening roller speed. Results can change in favor of 100% CO with a different rotor type or lower roller speeds.

**Unevenness**

The highest unevenness was detected in 100% r-CO (Figure 3). There was no significant difference between “15” and 75% r-CO/25% r-PET coded as “14” (Table 8). The lowest unevenness was measured in 50% CO/50% r-PET coded as “04”. It is apparent from the data in Figure 5 that unevenness increased for much of samples except yarns coded as “04” and “11” according to 100% CO. The unevenness result of 100% r-PET was lower than 100% CO. But no significant difference was found between amongst (p=1,00). No significant difference was found between CO/r-PET blends with 100% r-PET and 100% CO. Similar results were recorded in previous studies [19].

There was a clear trend of increasing for unevenness in association with increase of r-CO ratio in r-PET/r-CO blends and CO/r-CO blends. There was a significant correlation (r=-0,503) between CO and unevenness. Moreover, a strong correlation (r=0,930) was found between r-CO and unevenness. In fact, these results were related to the deteriorating fiber quality of r-CO during recycling process [8, 10]. CO/r-CO blends have better results than r-PET/r-CO blends. A weak negative correlation (r=-0,363) was observed between r-PET and unevenness. Normally, original polyester has lower unevenness than cotton. However, coefficients of variations of tensile strength and elongation at break of r-PET in Table 1 have prevented similar results.

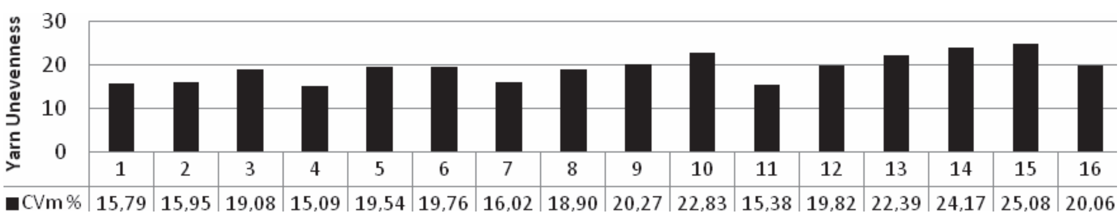


**Figure 3.** Unevenness results

**Table 8.** The results (p values) of multiple comparisons for unevenness

| | 01 | 02 | 03 | 04 | 05 | 06 | 07 | 08 | 09 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 01 | - | 1,00 | 0,00 | 0,11 | 0,00 | 0,00 | 1,00 | 0,00 | 0,00 | 0,00 | 1,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 |
| 02 | 1,00 | - | 0,00 | 1,00 | 0,00 | 0,00 | 1,00 | 0,00 | 0,00 | 0,00 | 1,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 |
| 03 | 0,00 | 0,00 | - | 0,00 | 1,00 | 0,77 | 0,00 | 1,00 | 0,02 | 0,00 | 0,00 | 0,89 | 0,00 | 0,00 | 0,00 | 0,03 |
| 04 | 0,11 | 1,00 | 0,00 | - | 0,00 | 0,00 | 1,00 | 0,00 | 0,00 | 0,00 | 1,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 |
| 05 | 0,00 | 0,00 | 1,00 | 0,00 | - | 1,00 | 0,00 | 0,99 | 0,82 | 0,00 | 0,00 | 1,00 | 0,00 | 0,00 | 0,00 | 0,98 |
| 06 | 0,00 | 0,00 | 0,77 | 0,00 | 1,00 | - | 0,00 | 0,50 | 1,00 | 0,00 | 0,00 | 1,00 | 0,00 | 0,00 | 0,00 | 1,00 |
| 07 | 1,00 | 1,00 | 0,00 | 1,00 | 0,00 | 0,00 | - | 0,00 | 0,00 | 0,00 | 1,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 |
| 08 | 0,00 | 0,00 | 1,00 | 0,00 | 0,99 | 0,50 | 0,00 | - | 0,01 | 0,00 | 0,00 | 0,62 | 0,00 | 0,00 | 0,00 | 0,04 |
| 09 | 0,00 | 0,00 | 0,02 | 0,00 | 0,82 | 1,00 | 0,00 | 0,01 | - | 0,00 | 0,00 | 1,00 | 0,00 | 0,00 | 0,00 | 1,00 |
| 10 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | - | 0,00 | 0,00 | 1,00 | 0,78 | 0,00 | 0,00 |
| 11 | 1,00 | 1,00 | 0,00 | 1,00 | 0,00 | 0,00 | 1,00 | 0,00 | 0,00 | 0,00 | - | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 |
| 12 | 0,00 | 0,00 | 0,89 | 0,00 | 1,00 | 1,00 | 0,00 | 0,62 | 1,00 | 0,00 | 0,00 | - | 0,00 | 0,00 | 0,00 | 1,00 |
| 13 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 1,00 | 0,00 | 0,00 | - | 0,22 | 0,00 | 0,00 |
| 14 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,78 | 0,00 | 0,00 | 0,22 | - | 1,00 | 0,00 |
| 15 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 1,00 | - | 0,00 |
| 16 | 0,00 | 0,00 | 0,03 | 0,00 | 0,98 | 1,00 | 0,00 | 0,04 | 1,00 | 0,00 | 0,00 | 1,00 | 0,00 | 0,00 | 0,00 | - |

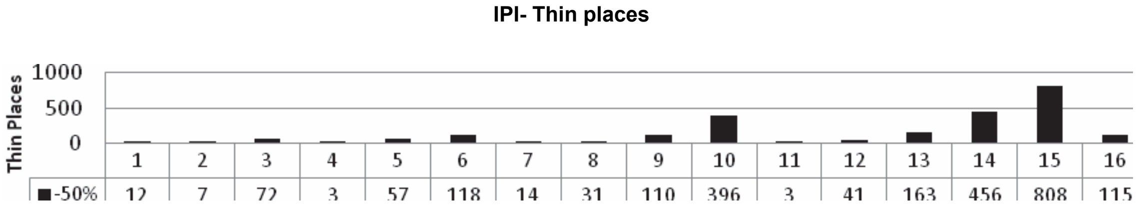


**Figure 4.** Thin places results

The maximum thin places were measured in 100% r-CO. The minimum thin places were measured in 100% r-PET and 50% CO/50% r-PET (Figure 4). There was a clear trend of increasing for thin places depending on increase of r-CO ratio in r-PET/r-CO blends and CO/r-CO blends. r-CO also showed more negative effect in ternary blends containing above 25 % of r-CO coded as “09” and “16”. The correlation in Table 5 also indicates that there was a strong negative correlation (r=0,952) between thin places and r-CO. Moreover, Table 5 shows that there was a benefit of r-PET in the prevention of thin places (r=-0,501). The thin places result of 100% r-PET was lower than 100% CO. But no significant difference was found between 100% r-PET and 100% CO (p=0,20). It can be seen from the data in Figure 4 that thin places increased for much of samples except yarns coded as “02”, “04” and “11” according to 100% CO. Surprisingly, significant difference was found between 100% CO and yarns coded as “04” (p=0,04). The best results obtained from thin places are shown in 25% r-CO/75% r-PET among the r-CO/r-PET blends. One unanticipated finding was that no significant difference was found statistically between this yarn and 100% CO (p=0,08).

**Table 9.** The results (p values) of multiple comparisons for thin places

| | 01 | 02 | 03 | 04 | 05 | 06 | 07 | 08 | 09 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 01 | - | 0,97 | 0,01 | 0,04 | 0,00 | 0,00 | 1,00 | 0,13 | 0,00 | 0,00 | 0,20 | 0,08 | 0,00 | 0,00 | 0,00 | 0,00 |
| 02 | 0,97 | - | 0,00 | 0,99 | 0,00 | 0,00 | 1,00 | 0,02 | 0,00 | 0,00 | 1,00 | 0,02 | 0,00 | 0,00 | 0,00 | 0,00 |
| 03 | 0,01 | 0,00 | - | 0,00 | 1,00 | 0,08 | 0,00 | 0,10 | 0,88 | 0,00 | 0,00 | 0,68 | 0,00 | 0,00 | 0,00 | 0,18 |
| 04 | 0,04 | 0,99 | 0,00 | - | 0,00 | 0,00 | 0,98 | 0,01 | 0,00 | 0,00 | 1,00 | 0,01 | 0,00 | 0,00 | 0,00 | 0,00 |
| 05 | 0,00 | 0,00 | 1,00 | 0,00 | - | 0,00 | 0,00 | 0,04 | 0,13 | 0,00 | 0,00 | 1,00 | 0,00 | 0,00 | 0,00 | 0,00 |
| 06 | 0,00 | 0,00 | 0,08 | 0,00 | 0,00 | - | 0,00 | 0,00 | 1,00 | 0,00 | 0,00 | 0,00 | 0,63 | 0,00 | 0,00 | 1,00 |
| 07 | 1,00 | 1,00 | 0,00 | 0,98 | 0,00 | 0,00 | - | 0,75 | 0,00 | 0,00 | 0,99 | 0,20 | 0,00 | 0,00 | 0,00 | 0,00 |
| 08 | 0,13 | 0,02 | 0,10 | 0,01 | 0,04 | 0,00 | 0,75 | - | 0,01 | 0,00 | 0,01 | 1,00 | 0,00 | 0,00 | 0,00 | 0,00 |
| 09 | 0,00 | 0,00 | 0,88 | 0,00 | 0,13 | 1,00 | 0,00 | 0,01 | - | 0,00 | 0,00 | 0,02 | 0,57 | 0,00 | 0,00 | 1,00 |
| 10 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | - | 0,00 | 0,00 | 0,00 | 1,00 | 0,00 | 0,00 |
| 11 | 0,20 | 1,00 | 0,00 | 1,00 | 0,00 | 0,00 | 0,99 | 0,01 | 0,00 | 0,00 | - | 0,01 | 0,00 | 0,00 | 0,00 | 0,00 |
| 12 | 0,08 | 0,02 | 0,68 | 0,01 | 1,00 | 0,00 | 0,20 | 1,00 | 0,02 | 0,00 | 0,01 | - | 0,00 | 0,00 | 0,00 | 0,00 |
| 13 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,63 | 0,00 | 0,00 | 0,57 | 0,00 | 0,00 | 0,00 | - | 0,01 | 0,00 | 0,51 |
| 14 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 1,00 | 0,00 | 0,00 | 0,01 | - | 0,00 | 0,00 |
| 15 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | - | 0,00 |
| 16 | 0,00 | 0,00 | 0,18 | 0,00 | 0,00 | 1,00 | 0,00 | 0,00 | 1,00 | 0,00 | 0,00 | 0,00 | 0,51 | 0,00 | 0,00 | - |

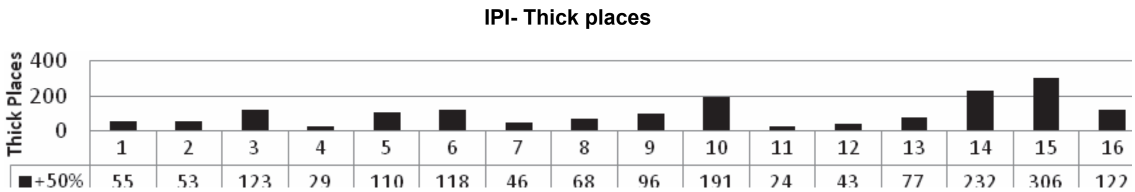


**Figure 5.** Thick places results

**Table 10.** The results (p values) of multiple comparisons for thick places

| | 01 | 02 | 03 | 04 | 05 | 06 | 07 | 08 | 09 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 01 | - | 1,00 | 0,00 | 0,08 | 0,04 | 0,00 | 1,00 | 1,00 | 0,01 | 0,00 | 0,79 | 1,00 | 0,33 | 0,00 | 0,00 | 0,00 |
| 02 | 1,00 | - | 0,00 | 0,85 | 0,04 | 0,00 | 1,00 | 1,00 | 0,06 | 0,00 | 0,98 | 1,00 | 0,84 | 0,00 | 0,00 | 0,00 |
| 03 | 0,00 | 0,00 | - | 0,00 | 1,00 | 1,00 | 0,00 | 0,00 | 0,49 | 0,03 | 0,00 | 0,00 | 0,00 | 0,15 | 0,00 | 1,00 |
| 04 | 0,08 | 0,85 | 0,00 | - | 0,00 | 0,00 | 1,00 | 0,00 | 0,00 | 0,00 | 1,00 | 0,96 | 0,00 | 0,00 | 0,00 | 0,00 |
| 05 | 0,04 | 0,04 | 1,00 | 0,00 | - | 1,00 | 0,01 | 0,27 | 1,00 | 0,01 | 0,00 | 0,01 | 0,76 | 0,06 | 0,00 | 1,00 |
| 06 | 0,00 | 0,00 | 1,00 | 0,00 | 1,00 | - | 0,00 | 0,00 | 0,86 | 0,01 | 0,00 | 0,00 | 0,01 | 0,11 | 0,00 | 1,00 |
| 07 | 1,00 | 1,00 | 0,00 | 1,00 | 0,01 | 0,00 | - | 0,90 | 0,01 | 0,00 | 1,00 | 1,00 | 0,26 | 0,00 | 0,00 | 0,00 |
| 08 | 1,00 | 1,00 | 0,00 | 0,00 | 0,27 | 0,00 | 0,90 | - | 0,12 | 0,00 | 0,12 | 0,08 | 1,00 | 0,01 | 0,00 | 0,00 |
| 09 | 0,01 | 0,06 | 0,49 | 0,00 | 1,00 | 0,86 | 0,01 | 0,12 | - | 0,00 | 0,00 | 0,00 | 0,89 | 0,03 | 0,00 | 0,83 |
| 10 | 0,00 | 0,00 | 0,03 | 0,00 | 0,01 | 0,01 | 0,00 | 0,00 | 0,00 | - | 0,00 | 0,00 | 0,00 | 1,00 | 0,02 | 0,03 |
| 11 | 0,79 | 0,98 | 0,00 | 1,00 | 0,00 | 0,00 | 1,00 | 0,12 | 0,00 | 0,00 | - | 1,00 | 0,03 | 0,00 | 0,00 | 0,00 |
| 12 | 1,00 | 1,00 | 0,00 | 0,96 | 0,01 | 0,00 | 1,00 | 0,08 | 0,00 | 0,00 | 1,00 | - | 0,00 | 0,00 | 0,00 | 0,00 |
| 13 | 0,33 | 0,84 | 0,00 | 0,00 | 0,76 | 0,01 | 0,26 | 1,00 | 0,89 | 0,00 | 0,03 | 0,00 | - | 0,01 | 0,00 | 0,02 |
| 14 | 0,00 | 0,00 | 0,15 | 0,00 | 0,06 | 0,11 | 0,00 | 0,01 | 0,03 | 1,00 | 0,00 | 0,00 | 0,01 | - | 0,96 | 0,14 |
| 15 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,02 | 0,00 | 0,00 | 0,00 | 0,96 | - | 0,00 |
| 16 | 0,00 | 0,00 | 1,00 | 0,00 | 1,00 | 1,00 | 0,00 | 0,00 | 0,83 | 0,03 | 0,00 | 0,00 | 0,02 | 0,14 | 0,00 | - |

The maximum thick places were measured in 100% r-CO (Figure 5). There was no significant difference between "15" and 75% r-CO/25% r-PET coded as "14" (p=0,96) as can be seen in Table 10. The minimum thick places were measured in 100% r-PET (Figure 5). There was a clear trend of increasing for thick places in association with increase of r-CO ratio in r-PET/r-CO blends and CO/r-CO. The correlation in Table 5 also indicates that there was a strong positive correlation (r=0,813) between thick places and r-CO. These results are consistent with those of other studies because r-CO has lower uniformity index and higher short fiber index [10, 11]. These fiber properties negatively affect thick places results. Moreover, Table 5 shows that there was a benefit of r-PET in the prevention of thick places (r=-0,655). The higher r-PET showed more positive effect on ternary blends. The thick places result of 100% r-PET was lower than 100% CO. But no significant difference was found between amongst (Figure 5, Table 10). In addition to this, no difference was found between CO/r-PET blends with 100% r-PET and 100% CO. It can be seen from the data in Figure 5 that thick places increased for much of samples except yarns coded as "02", "04", "07", "11" and "12" according to 100% CO (Table 10). The best results obtained from thick places are shown in 25% r-CO/75% r-PET among the r-CO/r-PET blends. What is surprising is that, no significant difference was found statistically between yarns coded as "12" (p=1,00) and "13" (p=0,33) with 100% CO.

The maximum neps were measured in 75% r-CO/25% r-PET coded as "14" (Figure 6). No difference was found between "14" and yarns coded as "03", "15" and "16" from the data in Table 11. The minimum neps were measured in 50% CO/50% r-PET yarn coded as "04" (Figure 6). The correlation results, as shown in Table 5, indicate that there was a good negative correlation (r=0,500) between neps and r-CO. There was a trend of increasing for neps depending on increase of r-CO ratio in r-PET/r-CO blends. Neps places decreased for much of samples except yarns coded as "03", "14", "15" and "16" according to 100% CO yarn (Figure 6). There were no significant differences among the samples showing an increase except yarns coded as "14" (p=0,02). The best results obtained from neps places are shown in 25% r-CO/75% r-PET and 50% r-CO/50% r-PET yarns among the r-CO/r-PET blends. Furthermore, no difference was found statistically between yarns coded as "12" (p=1,00) and "13" (p=1,00) with 100% CO.

### Yarn Hairiness

The highest Uster hairiness (H) was measured in 100% r-CO (Figure 7). There was no significant difference between "15" and 75% r-CO/25% r-PET coded as "14" (Table 12). The lowest hairiness was measured in 75% CO/25% r-CO coded as "03". The best results obtained from Uster hairiness are shown in 25% r-CO/75% r-PET and 50% r-CO/50% r-PET among the r-CO/r-PET blends. And no significant difference was found statistically between yarns coded as "12" (p=1,00) and "13" (p=1,00) with 100% CO (Table 12). There was a trend of increasing in CO/r-CO and r-PET/r-CO blends depending on increase of r-CO. The highest hairiness in ternary blends was measured in 25% CO/50% r-CO/25% r-PET coded as "09", consists of higher r-CO. Halimi et al. (2009) have noted that Uster hairiness showed a geometric increase in CO/r-CO blends containing more than 25% of the r-CO [9]. In contrast, interestingly, Table 5 shows that there was a weak correlation (r=0,403) between Uster H and r-CO. And no significant correlation was found between Uster H with CO (r=-0,373) and r-PET (r=-0,146) fibers. Uster hairiness increased for much of samples except yarns coded as “03”, “04”, “05”, “07”, “12” and “13” according to 100% CO (Figure 7). But there were no significant differences among the samples showing an increase except yarns coded as “15” (p=0,00).

**IPI- Neps**

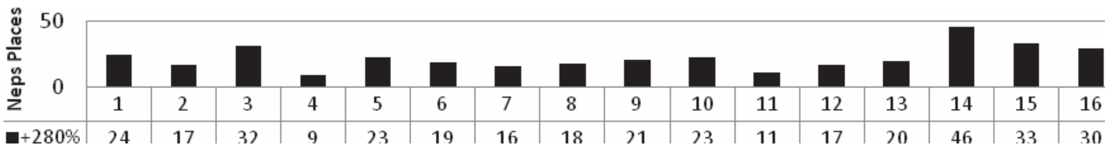


**Figure 6.** Neps places results

**Table 11.** The results (p values) of multiple comparisons for neps places

| | 01 | 02 | 03 | 04 | 05 | 06 | 07 | 08 | 09 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 01 | - | 1,00 | 1,00 | 0,05 | 1,00 | 1,00 | 1,00 | 1,00 | 1,00 | 1,00 | 0,61 | 1,00 | 1,00 | 0,02 | 0,93 | 1,00 |
| 02 | 1,00 | - | 1,00 | 1,00 | 1,00 | 1,00 | 1,00 | 1,00 | 1,00 | 1,00 | 1,00 | 1,00 | 1,00 | 0,00 | 0,08 | 0,80 |
| 03 | 1,00 | 1,00 | - | 0,49 | 1,00 | 1,00 | 1,00 | 1,00 | 1,00 | 1,00 | 0,78 | 1,00 | 1,00 | 1,00 | 1,00 | 1,00 |
| 04 | 0,05 | 1,00 | 0,49 | - | 0,02 | 0,07 | 1,00 | 0,20 | 0,00 | 0,01 | 1,00 | 1,00 | 0,00 | 0,00 | 0,00 | 0,02 |
| 05 | 1,00 | 1,00 | 1,00 | 0,02 | - | 1,00 | 1,00 | 1,00 | 1,00 | 1,00 | 0,65 | 1,00 | 1,00 | 0,01 | 0,35 | 1,00 |
| 06 | 1,00 | 1,00 | 1,00 | 0,07 | 1,00 | - | 1,00 | 1,00 | 1,00 | 1,00 | 1,00 | 1,00 | 1,00 | 0,00 | 0,00 | 0,88 |
| 07 | 1,00 | 1,00 | 1,00 | 1,00 | 1,00 | 1,00 | - | 1,00 | 1,00 | 1,00 | 1,00 | 1,00 | 1,00 | 0,00 | 0,07 | 0,72 |
| 08 | 1,00 | 1,00 | 1,00 | 0,19 | 1,00 | 1,00 | 1,00 | - | 1,00 | 1,00 | 1,00 | 1,00 | 1,00 | 0,00 | 0,00 | 0,78 |
| 09 | 1,00 | 1,00 | 1,00 | 0,00 | 1,00 | 1,00 | 1,00 | 1,00 | - | 1,00 | 0,89 | 1,00 | 1,00 | 0,00 | 0,01 | 0,99 |
| 10 | 1,00 | 1,00 | 1,00 | 0,01 | 1,00 | 1,00 | 1,00 | 1,00 | 1,00 | - | 0,65 | 1,00 | 1,00 | 0,00 | 0,13 | 1,00 |
| 11 | 0,61 | 1,00 | 0,78 | 1,00 | 0,65 | 1,00 | 1,00 | 1,00 | 0,89 | 0,65 | - | 1,00 | 0,97 | 0,00 | 0,00 | 0,11 |
| 12 | 1,00 | 1,00 | 1,00 | 1,00 | 1,00 | 1,00 | 1,00 | 1,00 | 1,00 | 1,00 | 1,00 | - | 1,00 | 0,00 | 0,14 | 0,88 |
| 13 | 1,00 | 1,00 | 1,00 | 0,00 | 1,00 | 1,00 | 1,00 | 1,00 | 1,00 | 1,00 | 0,97 | 1,00 | - | 0,00 | 0,00 | 0,93 |
| 14 | 0,02 | 0,00 | 1,00 | 0,00 | 0,01 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | - | 0,48 | 0,47 |
| 15 | 0,93 | 0,08 | 1,00 | 0,00 | 0,35 | 0,00 | 0,07 | 0,00 | 0,01 | 0,13 | 0,00 | 0,14 | 0,00 | 0,48 | - | 1,00 |
| 16 | 1,00 | 0,80 | 1,00 | 0,02 | 1,00 | 0,88 | 0,72 | 0,77 | 0,99 | 1,00 | 0,11 | 0,88 | 0,93 | 0,47 | 1,00 | - |

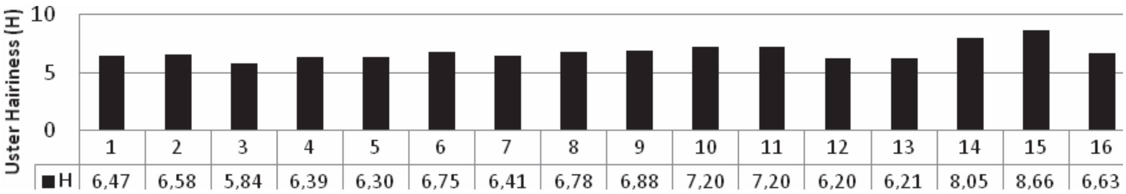


**Figure 7.** Uster hairiness (H) results

**Table 12.** The results (p values) of multiple comparisons for Uster hairiness (H)

| | 01 | 02 | 03 | 04 | 05 | 06 | 07 | 08 | 09 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 01 | - | 1,00 | 1,00 | 1,00 | 1,00 | 1,00 | 1,00 | 1,00 | 1,00 | 0,97 | 0,99 | 1,00 | 1,00 | 0,93 | 0,00 | 1,00 |
| 02 | 1,00 | - | 0,26 | 1,00 | 1,00 | 1,00 | 1,00 | 1,00 | 1,00 | 0,55 | 0,81 | 1,00 | 1,00 | 0,96 | 0,00 | 1,00 |
| 03 | 1,00 | 0,26 | - | 0,66 | 0,33 | 0,00 | 0,07 | 0,00 | 0,00 | 0,00 | 0,00 | 1,00 | 0,98 | 0,28 | 0,00 | 0,19 |
| 04 | 1,00 | 1,00 | 0,66 | - | 1,00 | 0,99 | 1,00 | 1,00 | 0,73 | 0,03 | 0,11 | 1,00 | 1,00 | 0,81 | 0,00 | 1,00 |
| 05 | 1,00 | 1,00 | 0,33 | 1,00 | - | 0,00 | 1,00 | 0,18 | 0,01 | 0,00 | 0,01 | 1,00 | 1,00 | 0,71 | 0,00 | 1,00 |
| 06 | 1,00 | 1,00 | 0,00 | 0,99 | 0,00 | - | 0,07 | 1,00 | 1,00 | 0,06 | 0,83 | 0,97 | 0,07 | 0,99 | 0,00 | 1,00 |
| 07 | 1,00 | 1,00 | 0,07 | 1,00 | 1,00 | 0,07 | - | 0,75 | 0,07 | 0,00 | 0,04 | 1,00 | 1,00 | 0,83 | 0,00 | 1,00 |
| 08 | 1,00 | 1,00 | 0,00 | 1,00 | 0,18 | 1,00 | 0,75 | - | 1,00 | 0,65 | 0,99 | 0,97 | 0,18 | 1,00 | 0,00 | 1,00 |
| 09 | 1,00 | 1,00 | 0,00 | 0,73 | 0,01 | 1,00 | 0,07 | 1,00 | - | 0,92 | 1,00 | 0,74 | 0,02 | 1,00 | 0,00 | 1,00 |
| 10 | 0,97 | 0,55 | 0,00 | 0,03 | 0,00 | 0,06 | 0,00 | 0,65 | 0,92 | - | 1,00 | 0,09 | 0,00 | 1,00 | 0,00 | 0,77 |
| 11 | 0,99 | 0,81 | 0,00 | 0,11 | 0,01 | 0,83 | 0,04 | 0,99 | 1,00 | 1,00 | - | 0,14 | 0,01 | 1,00 | 0,00 | 0,94 |
| 12 | 1,00 | 1,00 | 1,00 | 1,00 | 1,00 | 0,97 | 1,00 | 0,97 | 0,74 | 0,09 | 0,14 | - | 1,00 | 0,63 | 0,00 | 1,00 |
| 13 | 1,00 | 1,00 | 0,98 | 1,00 | 1,00 | 0,07 | 1,00 | 0,18 | 0,02 | 0,00 | 0,01 | 1,00 | - | 0,62 | 0,00 | 1,00 |
| 14 | 0,93 | 0,965 | 0,28 | 0,81 | 0,71 | 0,99 | 0,83 | 1,00 | 1,00 | 1,00 | 1,00 | 0,63 | 0,62 | - | 1,00 | 0,98 |
| 15 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 1,00 | - | 0,00 |
| 16 | 1,00 | 1,00 | 0,19 | 1,00 | 1,00 | 1,00 | 1,00 | 1,00 | 1,00 | 0,77 | 0,94 | 1,00 | 1,00 | 0,98 | 0,00 | - |

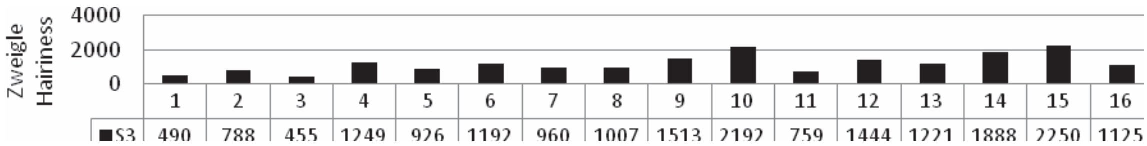


**Figure 8.** Zweigle hairiness results

This interesting situation became apparent with controlling the Zweigle hairiness. There was a significant negative correlation (r=-0,591) between CO and “S3”. A good positive correlation (r=0,749) was found between r-CO and S3. As noted by Hasani and Tabatabaei (2011), r-CO has a negative effect on yarn Zweigle hairiness [11]. Actually, these results were parallel to Uster H, but the effects of fibers were clearer in here according to the correlation results in Table 5. The highest S3 value was measured in 100% r-CO (Figure 8). There was no significant difference between “15” and 25% CO/75% r-CO coded as “10” (Table 13). The lowest hairiness value was measured in 75% CO/25% r-CO coded as “03”. No significant difference was found between “03” and 100% CO (Table 13). Uster H and Zweigle S3 gave same results in terms of the highest and lowest hairiness values among all yarns. The lowest hairiness for unblended yarns was detected in 100% CO. However, there was a significant difference between 100% CO and 100% r-PET differently from Uster H. The higher hairiness values than unblended yarns was observed in CO/r-PET blends.

There was a clear trend of increasing for hairiness in association with increase of r-CO ratio in r-PET/r-CO blends. The highest hairiness in ternary blends was measured in 25% CO/ 50% r-CO/ 25% r-PET coded as 09, consists of higher r-CO. Zweigle hairiness increased for much of samples except yarns coded as “03” according to 100% CO (Figure 8). Furthermore, there were significant differences in all yarns among the samples showing an increase. The best results obtained from Zweigle hairiness are shown in 50% r-CO/50% r-PET among the r-CO/r-PET blends.

## CONCLUSION

This study provided an important opportunity to advance the understanding of r-CO/r-PET blends. There was no study about these blends in the earlier studies. A significant reduction on yarn unevenness, IPI values and hairiness was found with increase of r-PET in r-CO/r-PET binary blends. The best yarn results were obtained in 25% r-CO/75% r-PET. These yarns have higher elongation at break values than %100 CO. Contrary to expectations, no significant difference was found between these yarns and 100% CO in terms of tensile strength, thin and thick places, neps and Uster hairiness (H). Furthermore, this paper have maked an important contribution to the field of CO/r-CO and CO/r-PET blends. It was seen that 50% CO/50% r-PET come to the forefront compared to all yarns. Yarn coded as “04” has lowest unevenness, thin places, thick places and neps according to all yarns. The findings have shown that this blend can be used instead of open-end rotor CO/PES yarns as an alternative. Moreover, a limitation of this study is that same machine and production parameters were preferred. Further research might explore role of production parameters for recommend yarn types. Thus, eco-friendly yarns can be produced with lower raw material costs.


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**Table 13.** The results (p values) of multiple comparisons for Zweigle hairiness (S3)

| | 01 | 02 | 03 | 04 | 05 | 06 | 07 | 08 | 09 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 01 | - | 0,02 | 1,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 |
| 02 | 0,02 | - | 0,01 | 0,00 | 0,97 | 0,00 | 0,91 | 0,22 | 0,00 | 0,00 | 1,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,33 |
| 03 | 1,00 | 0,01 | - | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 |
| 04 | 0,00 | 0,00 | 0,00 | - | 0,00 | 1,00 | 0,01 | 0,00 | 0,00 | 0,00 | 0,00 | 0,21 | 1,00 | 0,00 | 0,00 | 1,00 |
| 05 | 0,00 | 0,97 | 0,00 | 0,00 | - | 0,00 | 1,00 | 0,89 | 0,00 | 0,00 | 0,02 | 0,00 | 0,00 | 0,00 | 0,00 | 0,99 |
| 06 | 0,00 | 0,00 | 0,00 | 1,00 | 0,00 | - | 0,03 | 0,00 | 0,00 | 0,00 | 0,00 | 0,01 | 1,00 | 0,00 | 0,00 | 1,00 |
| 07 | 0,00 | 0,91 | 0,00 | 0,01 | 1,00 | 0,03 | - | 1,00 | 0,00 | 0,00 | 0,13 | 0,00 | 0,01 | 0,00 | 0,00 | 1,00 |
| 08 | 0,00 | 0,22 | 0,00 | 0,00 | 0,89 | 0,00 | 1,00 | - | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 1,00 |
| 09 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | - | 0,00 | 0,00 | 1,00 | 0,00 | 0,00 | 0,00 | 0,10 |
| 10 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | - | 0,00 | 0,00 | 0,00 | 0,60 | 1,00 | 0,00 |
| 11 | 0,00 | 1,00 | 0,00 | 0,00 | 0,02 | 0,00 | 0,13 | 0,00 | 0,00 | 0,00 | - | 0,00 | 0,00 | 0,00 | 0,00 | 0,16 |
| 12 | 0,00 | 0,00 | 0,00 | 0,21 | 0,00 | 0,01 | 0,00 | 0,00 | 1,00 | 0,00 | 0,00 | - | 0,04 | 0,00 | 0,00 | 0,38 |
| 13 | 0,00 | 0,00 | 0,00 | 1,00 | 0,00 | 1,00 | 0,01 | 0,00 | 0,00 | 0,00 | 0,00 | 0,04 | - | 0,00 | 0,00 | 1,00 |
| 14 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,60 | 0,00 | 0,00 | 0,00 | - | 0,01 | 0,00 |
| 15 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 1,00 | 0,00 | 0,00 | 0,00 | 0,01 | - | 0,00 |
| 16 | 0,00 | 0,33 | 0,00 | 1,00 | 0,99 | 1,00 | 1,00 | 1,00 | 0,10 | 0,00 | 0,16 | 0,38 | 1,00 | 0,00 | 0,00 | - |

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