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Properties of recycled polyester-cotton blended melange yarns

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This investigation aims at studying the important yarn parameters of melange yarns prepared from the recycled polyester (r-PET) and cotton fibres. Twelve melange yarn samples have been spun using normal Indian cotton fibre (Shankar-6) and r-PET by the traditional ring spinning technique. Three different yarn linear densities of 15tex, 20tex and 30tex (rounded to next integer) have been spun from four different blend proportions (100% cotton, 75% cotton/25% r-PET, 50% cotton/50% r-PET and 25% cotton/75% r-PET). Important yarn properties, like tensile strength, breaking elongation, yarn evenness, hairiness, abrasion resistance and imperfections, of these twelve melange yarns are tested and analysed. The yarn hairiness and the imperfections decrease with the increase of r-PET fibre in the yarn regardless of the yarn linear density. But the abrasion resistance, yarn evenness, breaking strength and breaking elongation increase with the addition of recycled polyester fibre in the yarn for all three types of yarn linear densities. These melange yarn properties confirm its suitability for the fabrics for apparels. Hence, the recycled polyester can be used as an alternative fibre to the most used virgin polyester fibres in apparels.

Keywords: Abrasion resistance, Yarn hairiness, Melange yarns, Polyester-cotton yarn, Recycled polyester, Tensile strength

1 Introduction

The plastic materials in different forms are heavily associated with the human life. The textile articles made from synthetic fibres are also a form of plastic. The polyester is the most dominant synthetic fibre and commonly used in apparels, home furnishings and other textile articles[1]. The total production of the fibres in the year 2021 is 113 million tons and the share of the polyester fibre is around 54%[2]. The huge quantity of production of polyester fibre and their conversion into textile articles needs huge quantity of electricity and fresh water which ultimately contributes in the release of huge amount of greenhouse gases[3]. Polyethylene terephthalate (PET) is a very common polymer, derived from the petroleum source, which is used to produce polyester fibre as well as many types of packaging bottles[1]. This monomer is also used for the manufacturing of commonly used plastic materials, like polyester fibres, soda bottles and many more. After being used, polyester textiles, empty bottles, and containers are considered garbage and placed in the trash, which is later disposed of in landfills or ends up in the seas in a variety of ways. The plastic pollution can be reduced by recycling the plastic waste, as this process offer the non-decomposable plastic material a second chance[4]. The recycling of plastics, like polyester fibres and PET bottles, also extends the lifespan of synthetic textile items through reuse. Hence, recycling is an efficient method for ensuring sustainability for textile value chain, as it is estimated that 72% of the fibres are consumed for apparels after recycling PET bottles[5]. Recycled polyester (r-PET) is a sustainable fibre than virgin polyester, as the manufacturing of r-PET consumes 70% lower electricity as well as 54% reduction in carbon dioxide (CO_2) emissions than the production of virgin polyester[6]. Hence, the recycled polyester fibre is becoming popular in the apparels to achieve sustainability. The quality of the r-PET fibre for textiles is paramount important to achieve desired yarn and fabric properties. Several researchers investigated the yarn performance of the r-PET fibres blended with natural fibres to enhance the comfort properties of fabric. The spinning process parameters and manufacturing methods also play a pivotal role to control the yarn structure, as the yarn structure affects the quality of the final fabric. Teli and ozdil[7] reported that r-PET fibres in different blend proportions with cotton fibres can be used for knitted fabrics to achieve the similar performance as virgin polyester fibre. Yuksekkaya *et al*[8]. studied the performance of the

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open-end yarns and the fabrics produced from the different blend proportions of recycled polyester and cotton with similar proportions of virgin polyester with cotton. The study shows that the open-end yarn having recycled polyester has comparatively better unevenness and lesser imperfections, but lower tensile strength and bursting strength are observed from the knitted fabrics made from these yarns.

Uyanık[9] studied the suitability of r-PET and viscose blended yarn with different linear densities. He observed that the yarn properties like yarn diameter, density, unevenness, imperfections, and hairiness of r-PET rich yarns are lower as compared to the virgin polyester rich yarns due to the presence of contamination in the r-PET fibres. He also concluded that the coarser yarns are more suitable for the r-PET blended yarns.

In this study, different blends of r-PET fibre and cotton fibre have been spun in a ring frame at various ratios. While numerous studies have explored r-PET fibres, there is a noticeable gap in the literature regarding the utilization of r-PET fibres in melange yarns. As the PET bottles are available in various colours, the textiles manufactured from recycled polyester fibres are typically recommended in darker shades. So, this study aims to assess the physical and mechanical characteristics, including breaking strength, breaking elongation, unevenness, imperfection index, and abrasion resistance, of mélange yarns with different linear densities.

2 Materials and Methods

2.1 Materials

For this study, regular Indian cotton (Shankar-6) fibre and r-PET were used. The r-PET fibres are sourced from Daftech Engineering Pvt. Ltd. India. The specifications of the cotton and r-PET fibres used in the study are mentioned in Table 1.

2.1.1 Yarn Manufacturing Process

Twelve melange yarn samples were prepared using the traditional ring spinning system at Chenab Textiles Mills, Kathua (J&K) India under industrial conditions. The specifications of these yarns are shown in Table 2. Melange yarn samples of similar shade were prepared using traditional technique. In each case, 9-12% dyed fibres were mixed with the normal grey fibres as per the requirement of the samples. Manual mixing was laid according to the recipe by weighing the proportion of fibres and horizontally spreading them to sandwich the different layers. The layers were then cut vertically and fed to a blow room line manually. Fibre tufts were fed to the carding machine through aero feeding for individualization of fibres. The linear density of the carded sliver of 4.1 ktex was obtained in each case. Then, eight carded slivers were fed to the breaker draw frame for doubling and drafting. The output linear density of sliver was set as 5.14 ktex. Then, six slivers of breaker draw frame were fed to the finisher draw frame and a sliver of 5.4 ktex was formed. The finished sliver cans were fed to the speed frame for producing rove of 695 tex linear density. Finally, the roving bobbin was fed to the traditional ring frame to produce yarn samples having liner density of 30, 20, and 15tex. The yarn twist was determined by selecting the standard twist multiplier according to the linear density of the yarn, as outlined in Table 2. The ring bobbins were converted into cones by using the Schlafhorst Autoconer 338.

Table 1 — Fibre specifications

Fibre parameters	Cotton	Recycled polyester (r-PET)
Fineness, den	1.28	1.4
Length, mm	29.18	38
Tenacity, g/den	3.1	3.5
Elongation at break, %	6.8	27.5

2.2 Testing Methods

All the fibre and yarn samples are conditioned for 24 h prior to testing and then tested and 20 °C ± 2 °C at 65 % relative humidity. The testing parameters of the yarn samples were averaged over 10 observations.

The cotton fibre strength and elongation were tested by the High-Volume Instrument (HVI) tester under standard conditions as per ASTM D 1445-93, whereas the r- PET fibres strength and elongation were tested as per ASTM D 1445-93 using Stelometer flat bundle tester.

Table 2 — Yarn constructional parameters

Yarn code	Blend ratio, % (Cotton: r-PET)	Yarn linear density, tex	Nominal twist turns/cm
Y1	100: 0	30	6.8
Y2	75: 25	30	7.1
Y3	50: 50	30	6.8
Y4	25: 75	30	6.5
Y5	100: 0	20	8.3
Y6	75: 25	20	8.6
Y7	50: 50	20	8.3
Y8	25: 75	20	8.0
Y9	100: 0	15	9.6
Y10	75: 25	15	9.9
Y11	50: 50	15	9.6
Y12	25: 75	15	9.3

The unevenness and imperfection index of all the yarn samples were tested using PREMIER Tester 7000 in accord with ASTM D 1425-96. The yarn speed during the testing was 400 m/min and the duration of the test was 60 s. The yarn was checked for -50 % thin places, +50 % thick places and +200 % neps. The hairiness of the yarn samples was tested as per ASTM D 5647-01 using Zweigle Hairiness Tester G565 and the test length of the samples was set as 50 m with a speed of 50 m/min. The breaking strength and breaking elongation of yarns were determined using the PREMIER Tensomaxx 7000 V2.6, which operates based on the constant rate of elongation principle as per ASTM D 2256-02. The testing parameters included a sample length of 5000 mm, a testing speed of 5000 mm/min, and a pre-tension set at 0.50 cN/tex. The abrasion resistance of the yarn samples was assessed utilizing CSI-396 in accordance with ASTM D 1379-64. Yarn testing involved a specimen size of 8” × 1”. The calculation for the number of threads required was done using the following equation:

$$\text{Number of threads in specimen} = \frac{907}{0.5\times\text{Yarn linear density (tex)}} \quad \ldots (1)$$

During the test, the yarn samples underwent continuous rotational abrasion until rupture occurred.

3 Results and Discussion

The influence of both the process variables and their interaction on the yarn properties have been assessed for significance using two-way analysis of variance and their values are given in Table 3. The effect is found to be significant on all the yarn properties at 95% confidence level.

3.1 Yarn Evenness & Imperfections

Yarn evenness is regarded as one of the most critical quality aspects of a yarn. Figure 1(a) shows the trends of yarn evenness and imperfections of the melange yarns with different r-PET blend ratios. The higher value of CVm% indicates more irregularity of the yarn structure. Figure 1(a) also shows that the finer yarns are more irregular than the coarser yarns produced under identical processing conditions. As the yarn becomes finer, the number of fibres in the cross-section of the yarn decreases, causing the deterioration in yarn's evenness[10]. This observation is attributed to the established fact that the yarn evenness is proportional to the number of fibres in the cross-section. With regard to the blend proportion, as expected the addition of r-PET fibre in yarn blend ratio decreases the irregularity of the yarn. This trend is more prominent when the r-PET percentage is increased to 75 % from 50 %. This can be explained based on the fact that cotton being a natural fibre exhibits higher variations in fibre length and thickness, while r-PET being a synthetic fibre shows little variability in these parameters[11]. Hence, recycled polyester-majority blends demonstrate better evenness, irrespective of yarn linear density.

Figure 1(b) shows that relatively a smaller number of imperfections are present in coarser yarns than in finer yarns. The imperfections decrease gradually with the increase in percentage of r-PET fibres in the blend ratio, and the decline more noticeable when the blend ratio increases from 50% to 75%. This may be due to less fibre control during drafting and generation of drafting waves[12]. As indicated in Table 3, the interaction of yarn linear density and blend proportion is found to be statistically significant in both yarn evenness and imperfections.

3.2 Yarn Hairiness

Figure 1(c) depicts number of protruding hairs (S3 value) of melange yarns with different r-PET ratios. The coarser yarns show more protruding hairs than the finer yarns regardless of yarn blend proportion. The main reason behind more hairiness of coarse yarns is their high perimeter area[13]. As the diameter of fine yarn is lower, it shows a smaller number of

Table 3 — ANOVA results

Process variables	Yarn evenness	Imperfections	Hairiness	Breaking strength gf/tex	Breaking elongation %	Abrasion resistance
A	s	s	s	s	s	s
(F,P)	(31.4, 4×10^{-5})	(35.8, 7×10^{-5})	(25.6, 4×10^{-5})	(16.8, 8×10^{-5})	(17.6, 6×10^{-5})	(37.8, 4×10^{-4})
B	s	s	s	s	s	s
(F,P)	(45.5, 2×10^{-7})	(51.4, 5×10^{-7})	(38.1, 4×10^{-5})	(15.2, 6×10^{-5})	(14.8, 8×10^{-5})	(41.4, 4×10^{-6})
A×B	s	s	s	s	s	s
(F,P)	(28.7, 5×10^{-5})	(11.4, 3×10^{-6})	(17.9, 7×10^{-4})	(13.2, 9×10^{-4})	(12.6, 3×10^{-4})	(30.4, 7×10^{-4})

A- yarn linear density, B- blend proportion, s- significant- F-value and P- p-value.

protruding fibres, which results in lower hairiness. Figure 1(c) shows that there is a discernible trend for the protruding fibres in response to variation in blend ratio. Hairiness decreases as the percentage of recycled polyester fibre content increases[11]. This may probably be due to the longer fibre length of r-PET compared to cotton fibre. As fibre length increases, less number of fibre-ends will be available to protrude from the surface of the yarn, entailing less protruding fibres[14].

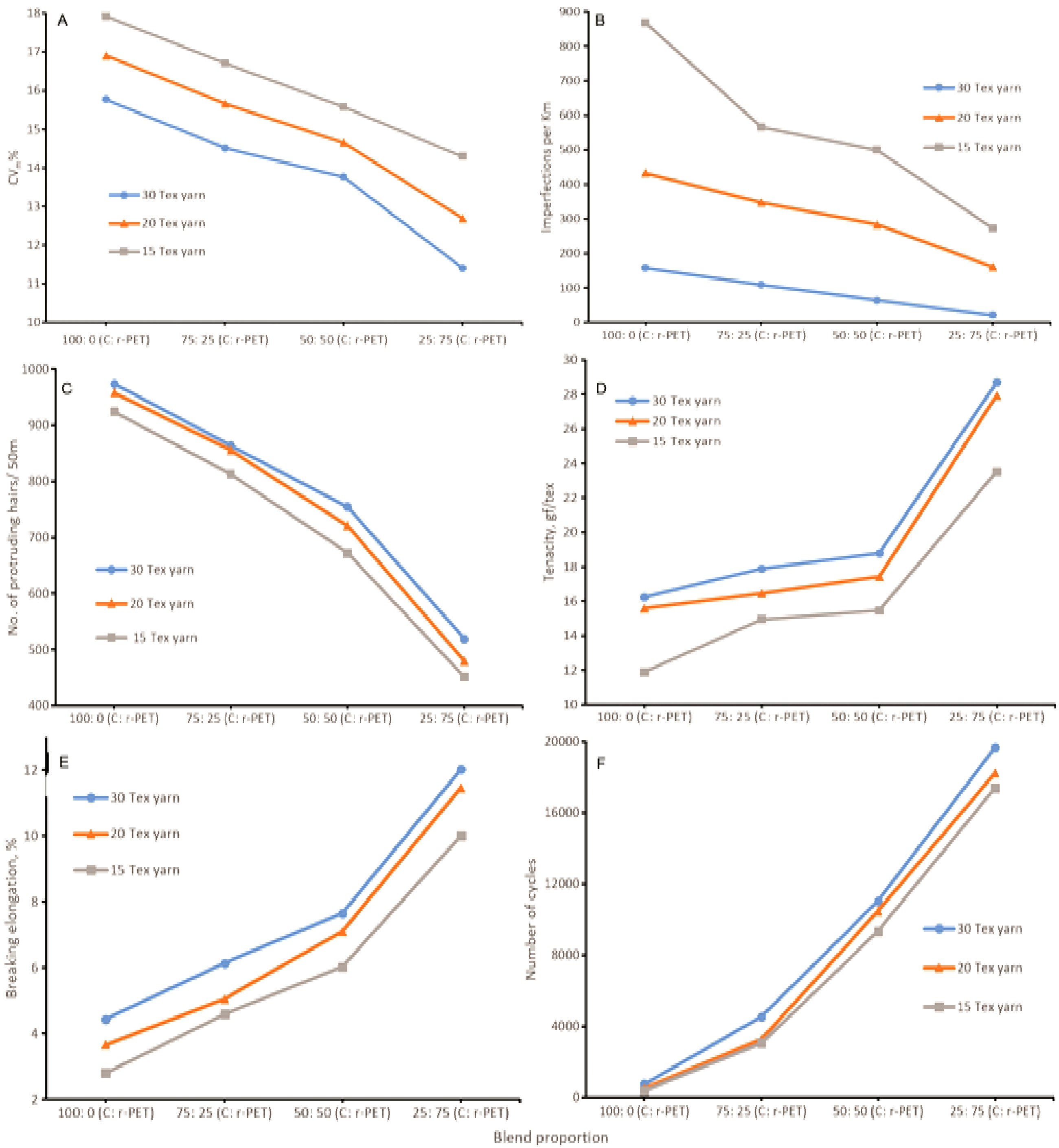

Fig. 1 — Effect of yarn linear density and blend proportion on (a) CVm%, (b) Imperfections, (c) yarn hairiness, (d) yarn tenacity, (e) yarn breaking elongation and (f) yarn abrasion resistance

3.3 Breaking Strength and Breaking Elongation %

From Fig. 1(d), it can be seen that the 30 tex yarn shows highest tenacity followed by 20 tex yarn and 15tex yarn. As the yarn becomes finer, the yarn strength reduces because of the poor utilization of fibre characteristics of constituting fibres towards yarn strength. Besides, higher unevenness of fine yarns also contributes to the lower tensile strength[15]. Also, it can be seen from Fig. 1(d), that the tenacity increases with the increase in proportion of r-PET fibre in the yarn blend ratio and this pattern is more noticeable when the r-PET blend proportion share is increased to 75% from 50%. The major parameters that affect the yarn tensile strength are fibre tensile strength and fibre length. Since recycled polyester fibres have higher tensile strength and higher length than that of cotton fibres, the r-PET blended yarns have higher strength[16].

Figure 1(e) shows that the finer yarns exhibit lower breaking elongation than the coarser yarns and it reflects a trend similar to yarn tenacity. This may probably be due to the reduced translational efficiency of fibre elongation to yarn elongation[17].

With regard to the blend proportion, as expected the addition of recycled polyester fibre in yarn blend ratio increases the breaking elongation and it shows an upward trend as the share of recycled polyester fibre increases. This can be explained as the recycled polyester fibre has a higher breaking elongation percentage than that of cotton[18]. The results are found significant at 95% confidence limit (Table 3).

3.4 Yarn Abrasion Resistance

Figure 1(f) shows the trend of abrasion resistance of the melange yarns with different r-PET ratios. About concerning abrasion resistance, 30 tex yarn shows the highest and 15 tex yarn shows the lowest values. Considering the different linear densities of yarns, the typical trend can be explained in the light of the fineness of the yarn. As yarn linear density shifts from coarser to finer, the abrasion resistance decreases. The factors, which affect the abrasion resistance of yarn, are the tensile strength and breaking elongation percentage of the yarn[17]. And, it is seen that the strength and elongation of the yarn decrease with finer count, which reduces abrasion resistance in the case of fine yarns[19].While considering different recycled polyester blend yarns, the addition of recycled polyester fibre increases abrasion resistance. This is because of the contribution of fibre strength and breaking elongation. The r-PET fibre has higher strength and higher breaking elongation as compared to cotton fibre[20].

4 Conclusion

The following conclusions are drawn based on the results of this study:

4.1 The yarn evenness increases with the increase of recycled polyester fibre proportion in the yarns. Also, the imperfections decrease as the share of recycled polyester increases. Further, coarser yarns possess better evenness and lower imperfections than the finer yarns.

4.2 The finer yarns exhibit lesser protruding fibres as compared to coarser yarns. It is observed that the hairiness decreases with the increase of recycled polyester fibres in the blends.

4.3 The coarser yarns possess higher tenacity than the finer yarns and the strength increases as the recycled polyester fibre proportion increases in the yarn. The same trend is observed for the yarn abrasion resistance as well.

The adoption of recycled polyester in yarn and various textile structures promotes sustainability through material repurposing, waste reduction, and lower environmental impact as compared to virgin polyester. The study confirms comparable properties between recycled polyester in melange yarns and virgin polyester. This utilization marks a positive step toward resource conservation, reducing the ecological footprint in textile manufacturing, and aligning with sustainable development goals.

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