

Performance evaluation of woven fabrics made from recycled PET and recycled cotton fibres

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This study investigates the performance properties of woven fabrics produced using rotor yarns in both weft and warp directions, which contain recycled polyethylene terephthalate (r-PET) fibres from PET bottles and recycled cotton fibres (r-CO) from cotton clothing wastes in different blend ratios. Additionally, fabrics are produced using weft and warp yarns composed of virgin fibres, including 100% virgin cotton (CO), 100% virgin polyester (PET), and a 50/50% CO/r-CO blend, to enable performance comparisons. Samples containing recycled fibres exhibit higher yarn unevenness, thick places and neps values, along with lower breaking strength, tear strength, relative water vapour permeability, air permeability compared to their virgin counterparts. Among samples composed entirely of 100% recycled fibres, an increasing r-CO fibre ratio corresponds to greater unevenness, thick places and neps values, while air permeability and thermal resistance decrease. However, noconsistent trend emerges in breaking strength, elongation, tear strength, abrasion resistance, or relative water vapour permeability, depending on fibre blend ratios.

Keywords: Cotton waste, PET bottle, Recycled cotton, Recycled polyester, Woven fabric

1 Introduction

Cotton (CO) and polyester (PET) are among the most widely used fibres in the textile industry, meeting most fibre demands for decades. Synthetic fibres dominate the global textile fibre production with a share of 60%, while cotton contributes around 33%¹. In 2018, synthetic fibres constituted approximately 62.5% of total textile fibre consumption, whereas cotton accounted for 25%². The textile and apparel industry, recognised as one of the most polluting industries, has significant sustainability concerns due to excessive mass consumption, fast fashion trends, short-term use of products and increasing textile waste^{3,4}. The industry generates an estimated 1.2 billion tons of CO₂ emissions annually, contributing to approximately 2% of the total industrial CO₂ emissions in the world⁵. Despite being a natural fibre, cotton production has considerable environmental impacts. It occupies 2.5% of global arable land while consuming 25% of total insecticides and 11% of total pesticides^{6,7}. In addition, synthetic fertilisers and approximately 10,000-17,000 L of water per kg are used in cotton production^{8,9}.

Polyester, the most in-demand textile fibre, is derived from petroleum-based resources and persists in the environment for many years, exacerbating waste accumulation. In 2009, about 60% of the total global polyethylene terephthalate (PET) production was used for textiles, and 30% was used for PET bottles. Polyester fabric production alone requires approximately 70 million barrels of crude oil annually^{10,11}.

Recycling processes offer a potential solution to mitigate these environmental impacts in the textile industry. A sustainability classification by "Made-By" ranked 28 textile fibres according to their environmental impact, identifying recycled and organic fibres as the most sustainable, whereas conventional fibres were deemed less sustainable¹². The mechanical recycling of PET bottle waste involves sorting, crushing and washing, cleaning of impurities, drying and fibre spinning stages, making it a more complex process than cotton recycling, which primarily consists of waste sorting and shredding¹³⁻¹⁶. Recycled polyester (r-PET) accounts for approximately 14% of total polyester fibre production, while environmentally preferred cotton fibres (including organic and the Better Cotton

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Initiative) contribute 19% to total virgin cotton production¹⁷. In terms of energy consumption, the production of 1 kg of fibre requires 55 MJ for virgin cotton, 125 MJ for virgin polyester, and 66 MJ for recycled polyester^{11,18}.

Numerous studies have examined the impact of recycling on yarn performance properties¹⁹⁻²⁸, predominantly focusing on knitted fabrics. Gun *et al.*²⁹ reported that 50/50% virgin polyester/recycled cotton (PET/r-CO) knitted socks showed higher weight, thickness, pilling tendency and lower air permeability than 100% virgin cotton knitted socks. Choi and Kim³⁰ found that mechanically recycled PET knitted fabrics had comparable breaking strength, compression, and pilling resistance to virgin PET fabrics. Similarly, Kilic *et al.*³¹ demonstrated that open-end yarns and knitted fabrics with up to 75% waste cotton retained acceptable performance properties. Sarioğlu³² optimised the performance of knitted fabrics made from PET/CO and r-PET/CO yarns, concluding that knitted fabrics with PET/CO 58.62/41.38% compact yarns exhibited the highest desirability. Other research has explored thermal comfort properties, indicating that recycled acrylic knitted fabrics provide higher thermal resistance but lower water vapour and air permeability than virgin acrylic fabrics³³. Yılmaz and Özgen Keleş³⁴ also established that 50/50% recycled cotton/virgin polyester knitted fabrics demonstrated similar performance characteristics to 50/50% virgin cotton/virgin polyester fabrics.

In recent years, studies have also explored using recycled fibres in woven fabrics, often incorporating them solely in the weft direction or blends with virgin fibres. Telli and Babaarslan³⁵ investigated woven fabrics produced with varying weft yarn compositions of virgin cotton, recycled cotton, and r-PET, reporting that recycled cotton negatively affected fabric breaking and tear strength. Majumdar *et al.*³⁶ analysed woven fabrics with different proportions of recycled polyester in both weft and warp directions with virgin polyester and cotton fibres, concluding that higher r-PET content reduced thermal resistance while increasing shear and bending rigidity. Awgichew *et al.*³⁷ found that using up to 75% recycled fibres in the weft direction was economically and ecologically viable. Kırış and Yılmaz³⁸ reported that woven fabrics incorporating r-PET fibres in the weft exhibited comparable performance properties to those made from virgin PET. Similarly, Mezarlıoğlu *et al.*³⁹

compared the performance of denim fabrics woven with recycled cotton, virgin cotton, organic cotton, and Better Cotton Initiative cotton as weft yarns, observing lower breaking and tear strength in recycled cotton fabrics. Khan *et al.*⁴⁰ demonstrated that woven fabrics with 50/50% recycled polyester/virgin cotton in both warp and weft directions exhibited strength similar to virgin polyester-based fabrics while offering superior moisture management, air permeability, and drapeability.

The existing literature predominantly focuses on the impact of r-PET and r-CO fibres on knitted fabric performance. However, to facilitate the broader adoption of recycled fibres in clothing production, research must extend to other fabric structures. Woven fabrics, which possess superior durability and structural integrity compared to knitted fabrics, present a viable alternative for incorporating recycled fibres. Investigating woven fabrics composed of recycled fibre yarns in both warp and weft directions represents a practical and relevant approach. Therefore, this study aims to evaluate the performance properties of woven fabrics produced entirely from recycled PET and cotton fibre yarns in both warp and weft directions.

2 Materials and Methods

2.1 Materials

Sample yarns were produced using r-CO, r-PET, virgin cotton (CO) and virgin polyester (PET) fibres. The r-PET fibres were obtained from PET bottle waste, while the r-CO fibres were obtained from shredded post-consumer cotton fabric waste⁴¹. The fibre properties are given in Table 1.

Ne 20/1 rotor spun yarns were produced from these fibres with different blend ratios of r-PET and r-CO fibres (70/30%, 50/50%, and 30/70%) and 100% virgin cotton, 100% virgin polyester, 100% r-PET and 50/50% CO/r-CO fibres. The yarn samples were conditioned under standard atmospheric conditions (20±2°C temperature and 65±4% relative humidity) for 24 h before tests, which were conducted under the same conditions.

Table 1 — Fibre properties

Fibre	Fineness, dtex	Length, mm
CO	1.7	28
PET	1.3	32
r-PET	1.4	38
r-CO	1.7	20

2.2 Methods

Yarn breaking strength and elongation were tested using the Uster Tensojet 4 according to the TS 245 EN ISO 2062 standard. Yarn unevenness, imperfections and hairiness were evaluated using the Uster Tester 4, according to TS 628 standard. Woven fabric samples were produced using the sample yarns in both weft and warp directions. For warp direction, the prepared warp sheet was sized using a polyvinyl alcohol (PVA) sizing agent. Fabric samples were woven using a CCI brand sample loom with 2/2 Z and 1/3 Z twill weave types. Post-weaving, desized was performed by washing the fabrics in boiled water. All samples were conditioned under standard atmospheric conditions ($20\pm 2^\circ\text{C}$ and $65\pm 4\%$ relative humidity) for 24 h before testing. Fabric density, weight and thickness were determined following TS 250 EN 1049-2, TS 251 and TS 7128 EN ISO 5084 standards, respectively. The structural properties of the sample fabrics are given in Table 2⁴¹.

Fabric breaking strength and elongation were determined using the grab test method (TS EN ISO 13934-2). Tear strength was measured using the single tear method with trouser-shaped test specimens, according to TS EN ISO 13937-2. Abrasion resistance was evaluated using two methods: mass loss determination (TS EN ISO 12947-3) and specimen breakdown (TS EN ISO 12947-2). Mass loss percentage was measured after 1000, 2000, 3000, 4000 and 5000 abrasion cycles, while breakdown cycles were recorded when a hole appeared. Water vapour permeability and thermal resistance were measured using the Permetest device, following ISO 11092 standard. Air permeability was measured using a digital air permeability tester with a circular test area of

20 cm^2 at 100 Pa pressure, following TS 391 EN ISO 9237 standard.

2.3 Statistical Analysis

Test results were analysed using ANOVA (Analysis of Variance) with a 95% confidence interval in SPSS 20.0 software. Duncan's multiple range tests were used to identify statistically significant differences ($p < 0.05$). Samples marked with different letters (a,b,c,d,e) represent various groups, indicating significant differences. This test method was applied to compare mean values in order of magnitude.

3 Results and Discussion

3.1 Yarn Characteristics

The ANOVA and Duncan test results for yarn unevenness, imperfections and hairiness are presented in Table 3. Duncan's test results also indicate the values of yarn performance properties.

The ANOVA results indicate a significant effect of yarn type on unevenness, imperfections and hairiness values. Recycled yarns exhibit higher unevenness, thick places, and neps values compared to 100% PET yarns in samples produced from synthetic fibres (Table 3). Similar results are observed between 100% CO and 50/50% CO/r-CO yarns. This increase in imperfections in recycled yarns can be attributed to a higher proportion of short fibres, which disrupt fibre orientation in the sliver during drafting due to their uncontrolled behaviour, such as floating²⁰.

On the other hand, recycled cotton fibres used together with virgin cotton in the yarn structure lead to a slight increase in thin places, although this difference is statistically insignificant. Among synthetic fibre yarns, no significant variation is

Table 2 — Structural properties of sample fabrics

Sample	Density, yarns/cm		Thickness, mm	Weight, g/m ²
	Warp	Weft		
100% CO	20	15	0.62	129
100% PET			0.52	114
100% r-PET			0.52	115
2/2 Z Twill	70/30% r-PET/r-CO		0.56	114
	50/50% r-PET/r-CO		0.59	138
	30/70% r-PET/r-CO		0.66	133
	50/50% CO/r-CO		0.64	134
100% CO	20	15	0.64	126
100% PET			0.55	115
100% r-PET			0.51	109
1/3 Z Twill	70/30% r-PET/r-CO		0.56	115
	50/50% r-PET/r-CO		0.61	128
	30/70% r-PET/r-CO		0.64	135
	50/50% CO/r-CO		0.68	137

Table 3— ANOVA and Duncan test results for yarn characteristics

		ANOVA test <i>p</i> -value				
Parameter		Unevenness, CVm%	Thin places (-50%)	Thick places (+50%)	Neps (+200%)	Hairiness H
Yarn		0.000	0.000	0.000	0.000	0.000
		Duncan test				
Yarn	100% CO	13.182 f	5.417 c	26.250 e	102.083 e	4.667 d
	100% PET	14.287 d	53.333 a	51.667 d	26.667 f	5.290 b
	100% r-PET	14.942 c	53.333 a	55.833 d	136.667 e	6.583 a
	70/30% r-PET/r-CO	14.773 c	23.750 b	104.167 c	718.750 c	2.493 e
	50/50% r-PET/r-CO	15.850 b	50.000 a	206.667 b	1210.333 b	4.763 d
	30/70% r-PET/r-CO	16.547 a	14.583 bc	346.667 a	1285.167 a	4.633 d
	50/50% CO/r-CO	13.948 e	6.250 c	54.583 d	376.250 d	4.970 c

observed between 100% r-PET and 100% PET yarns. However, in blended yarns containing r-PET fibres, the values for unevenness, thick places, and neps decrease as the r-PET content increases while the recycled cotton fibre ratio decreases. This is likely due to the longer average fibre length of r-PET compared to recycled cotton fibres. Moreover, blended yarns tend to exhibit greater variation in fibre distribution across the yarn cross-section compared to 100% cotton yarns, primarily due to the higher proportion of short fibres²².

As shown in Table 3, the hairiness values of 100% PET yarns are higher than those of 100% CO yarns. Among synthetic yarns, 100% r-PET yarns exhibit higher hairiness than 100% PET yarns, likely due to the negative impact of PET recycling on fibre quality and yarn-breaking strength. The degradation of fibre properties during recycling contributes to increased hairiness. Similarly, 50/50% CO/r-CO yarns exhibit higher hairiness than 100% CO yarns, as recycled cotton fibres negatively affect fibre length and uniformity. Shorter fibres protrude from the yarn surface, increasing hairiness. In blended yarns containing both r-PET and r-CO fibres, no clear trend is observed in thin places or hairiness values in relation to fibre blend ratio.

3.2 Yarn Breaking Strength and Elongation

The ANOVA and Duncan test results for breaking strength and elongation of sample yarns are given in Table 4. The effect of yarn type on these properties is statistically significant. 100% PET yarns exhibit the highest breaking strength, followed by 100% CO yarns. This is expected, given the higher inherent strength of synthetic fibres compared to natural fibres. Yarns composed entirely of virgin fibres display superior breaking strength compared to those containing recycled fibres, as the contamination of post-consumer PET waste in the recycling process adversely affects

Table 4— ANOVA and Duncan test results for breaking strength and elongation of yarns

		ANOVA test <i>p</i> -value	
Parameter		Breaking strength, Rkm	Breaking elongation, %
Yarn		0.000	0.000
		Duncan test	
Yarn	100% CO	12.983 b	5.160 e
	100% PET	20.887 a	10.900 a
	100% r-PET	8.631 f	10.168 b
	70/30% r-PET/r-CO	11.022 d	10.228 b
	50/50% r-PET/r-CO	11.353 c	7.415 c
	30/70% r-PET/r-CO	8.355 g	6.247 d
	50/50% CO/r-CO	10.418 e	5.020 f

physical and chemical properties. It is possible to produce better quality r-PET yarns by reducing the amount of pollutants such as coloured bottles, ink-printed labels, pesticides and fuel residues¹³.

While statistical differences exist among yarns containing r-PET fibres, no linear trend is observed concerning the r-PET fibre ratio.

The 50/50% CO/r-CO yarns exhibit lower breaking strength than 100% CO yarns, consistent with previous studies that reported similar strength reductions due to the shredding process⁴². This reduction results from increased proportion of short fibres and decreased inter-fibre cohesion.

100% PET and 100% r-PET yarns display higher elongation values than 100% CO yarns, although the elongation values of recycled PET yarns are lower than 100% PET yarns. The higher the r-PET fibre content, the greater the elongation. In yarns containing cotton fibres, recycled cotton fibres slightly reduces elongation, aligning with previous findings that waste fibre additions reduce breaking strength and elongation due to shorter fibre length and diminished fibre contact³¹.

3.3 Fabric Breaking Strength and Elongation

Figures 1 and 2 illustrate the breaking strength and elongation values of fabrics, respectively. Due to the

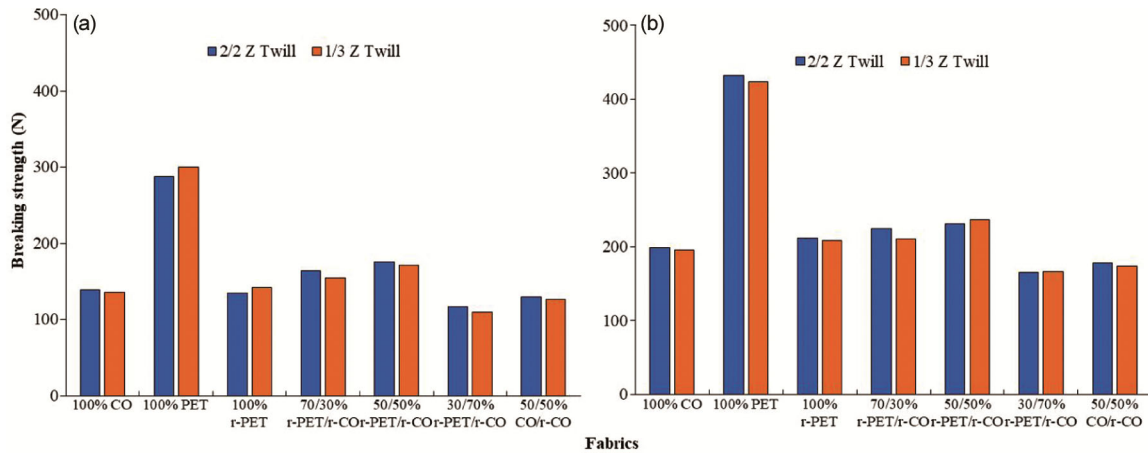


Fig. 1— Breaking strength values of fabrics in (a) weft and (b) warp directions

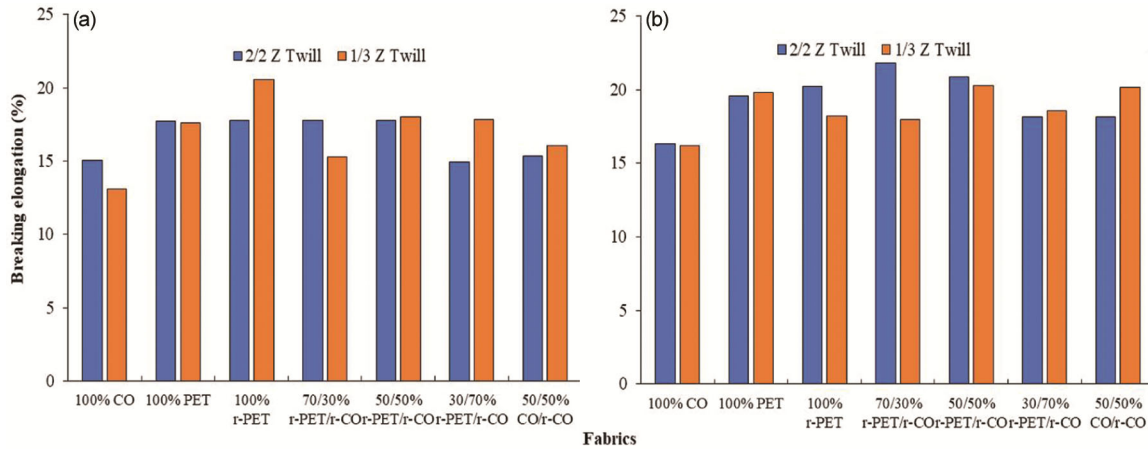


Fig. 2— Breaking elongation values of fabrics in (a) weft and (b) warp directions

Table 5 — ANOVA and Duncan test results for breaking strength, elongation and tear strength
ANOVA test *p*-value

Parameter	Breaking strength, N		Breaking elongation, %		Tear strength, N		
	Weft	Warp	Weft	Warp	Weft	Warp	
Yarn	0.000	0.000	0.000	0.000	0.000	0.000	
Weave	0.693	0.410	0.458	0.168	0.001	0.889	
Duncan test							
Yarn	100% CO	137.507 d	197.284 d	14.092 d	16.294 c	24.098 b	25.656 b
	100% PET	293.650 a	427.867 a	17.678 ab	19.690 ab	39.778 a	42.302 a
	100% r-PET	138.492 d	210.098 cd	19.183 a	19.217 ab	13.993 de	16.390 e
	70/30% r-PET/r-CO	159.717 c	217.338 bc	16.540 bc	19.892 ab	19.200 c	21.698 c
	50/50% r-PET/r-CO	173.582 b	233.538 b	17.905 ab	20.578 a	20.158 c	21.655 c
	30/70% r-PET/r-CO	113.125 e	165.430 e	16.378 bc	18.363 b	12.507 e	13.225 f
	50/50% CO/r-CO	128.402 d	175.948 e	15.703 c	19.150 ab	15.425 d	19.380 d

higher warp density, the fabric breaking strength values in the warp direction (about 165-428 N) are higher than those in the weft direction (about 113-294 N). Fabric elongation values range between 13% and 21% in the weft direction and 16% and 22% in the warp direction.

ANOVA and Duncan test results (Table 5) indicate that yarn type significantly influences fabric breaking

strength and elongation, whereas weave type does not. As seen in Figs 1 and 2 and Duncan’s test results, 100% PET fabrics exhibit higher breaking strength and elongation values than 100% CO fabrics in both weft and warp directions. This corresponds to the strength and elongation values of the respective yarns (Table 4). Fabrics containing 100% r-PET and r-PET

blended fabrics have lower breaking strength values than 100% PET fabrics, while adding recycled cotton to virgin cotton reduces fabric strength. The deterioration of fibre quality during recycling leads to a decrease in yarn and fabric strength. However, using recycled cotton (r-CO) alongside virgin cotton (100% CO) improves fabric elongation in both directions. In r-PET/r-CO blended fabrics, fabric-breaking strength and elongation values do not follow a distinct pattern in relation to the fibre blend ratio. Nevertheless, a similar trend is observed between yarn and fabric-breaking strength values (Tables 4 and 5).

3.4 Fabric Tear Strength

Figures 3 presents the tear strength values of fabrics produced from different yarn and weave types. 1/3 (Z) twill fabrics demonstrate higher tear strength than 2/2 (Z) twill fabrics in the weft direction. In the tearing stage, the yarns in the fabric are either torn individually or by forming groups. Compared to the fabrics with 2/2 (Z) twill weave type, the number of connections between the yarns is less in the fabrics with 1/3 (Z) twill weave type, and there is a more open structure that allows the yarns in the fabric to move. Therefore, this can be explained by the fact that the yarns have a better ability of group formation by slipping over each other at the time of tearing.

ANOVA and Duncan test results (Table 5) confirm the significant effect of yarn type on tear strength in both directions, while weave type significantly affects tear strength only in the weft direction. Despite higher warp density across all fabrics, tear strength values are generally higher in the warp direction. It is likely due to the uniform use of yarns in both directions and the relatively small difference in fabric density. The

observed trends in tear strength align with those for yarn breaking strength (Table 4), with 100% PET fabrics exhibiting the highest tear strength values. Compared to 100% CO fabrics, 100% PET fabrics display superior tear strength in both directions. The incorporation of recycled fibres reduces tear strength in both directions due to their negative impact on yarn strength. However, no linear relationship between fibre blend ratios and tear strength values in fabrics containing r-PET fibres is evident.

3.5 Abrasion Resistance

Mass loss values after different abrasion cycles are given in Fig. 4. In general, 1/3 (Z) twill fabrics exhibit higher mass loss values than 2/2 (Z) twill fabrics, except in the 70/30% r-PET/r-CO and 50/50% r-PET/r-CO samples. This can be explained by the longer yarn float length and lower inter-yarn attachment points in 1/3 (Z) twill fabrics, making them more susceptible to wear.

ANOVA and Duncan test results (Table 6) for mass loss values after 5000 cycles indicate that yarn type, weave type, and cycle number have statistically significant effects on mass loss. Fabrics made from 100% virgin cotton generally exhibit higher mass loss values than those made from 100% virgin polyester (Fig. 4 and Table 6). These results can be related to the higher fibre length and yarn strength of virgin polyester. Oner⁴³ reported that synthetic fibres have higher abrasion resistance since they are more resistant to mechanical damage than natural cellulosic fibres. While 100% CO fabrics generally exhibit greater mass loss than 50/50% CO/r-CO fabrics for both weave types, results reveal that adding recycled cotton to virgin cotton does not lead to statistically

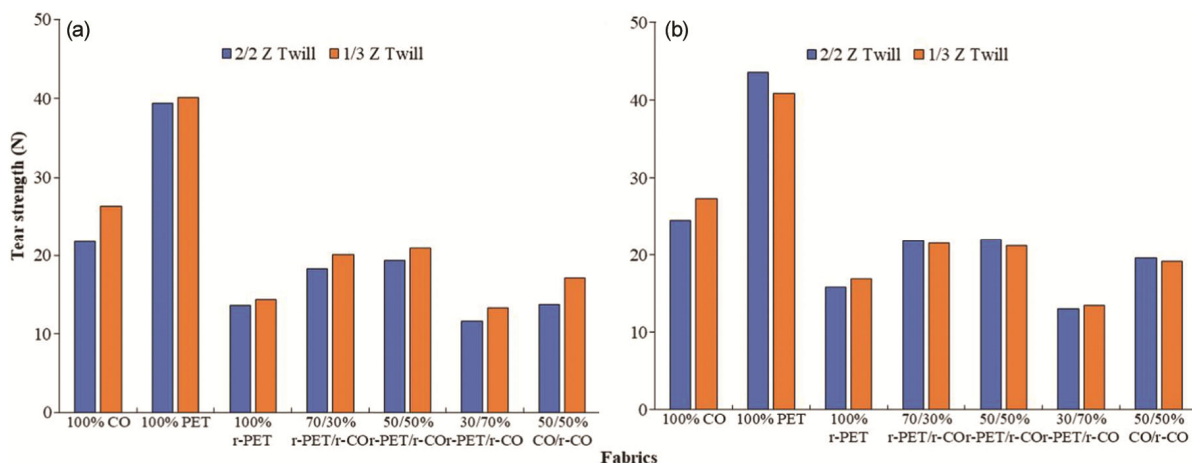


Fig. 3— Tear strength values of fabrics in (a) weft and (b) warp directions

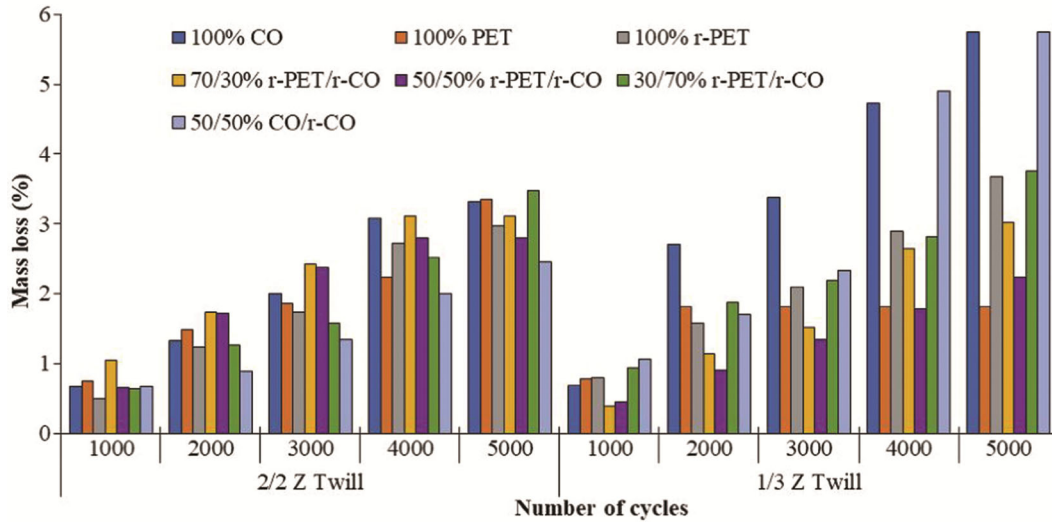


Fig. 4— Mass loss values after different cycles

Table 6— ANOVA and Duncan test results for mass loss after 5000 cycles

ANOVA test <i>p</i> -value		Mass loss, %
Parameter		
Yarn		0.006
Weave		0.037
Number of cycles		0.000
Duncan test		
Yarn	100% CO	2.628 a
	100% PET	1.738 b
	100% r-PET	2.020 ab
	70/30% r-PET/r-CO	2.013 ab
	50/50% r-PET/r-CO	1.706 b
	30/70% r-PET/r-CO	2.106 ab
	50/50% CO/r-CO	2.308 ab
Number of cycles	1000	0.709 e
	2000	1.499 d
	3000	1.971 c
	4000	2.838 b
	5000	3.332 a

significant differences in mass loss. Similarly, another study³¹ indicates that the difference in weight loss values after abrasion at 15000 cycles of 100% CO and 50/50% CO/r-CO knitted fabrics is insignificant. For comparing 100% synthetic fabrics, using r-PET fibres instead of virgin polyester fibres slightly increases the weight loss values after abrasion in the 1/3 twill weave type. However, the opposite effect is observed in the 2/2 Z twill weave type. These differences are found to be statistically insignificant. Furthermore, no clear trend or statistically significant difference is observed in r-PET/r-CO blended fabrics based on fibre blend ratio.

As shown in Fig. 4 and Table 6, the lowest weight loss is observed at 1,000 cycles, while the highest is recorded

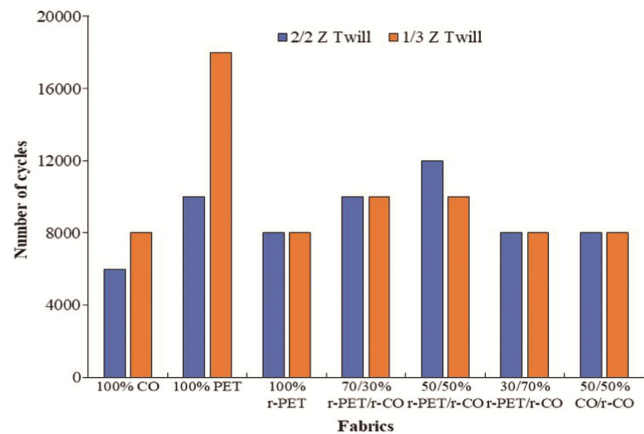


Fig. 5— Number of abrasion cycles at specimen breakdown

after 5,000 cycles. The results indicate that weight loss increases with the number of abrasion cycles, leading to a corresponding decrease in abrasion resistance.

The breakdown of specimens due to yarn breakages occurs between 6000-12000 abrasion cycles for 2/2 (Z) twill fabrics and between 8000-18000 abrasion cycles for 1/3 (Z) twill fabrics (Fig. 5). This suggests a correlation between weight loss results and the number of abrasion cycles at specimen breakdown across different yarn types.

3.6 Thermal Comfort Related Properties

The fabrics' relative water vapour permeability and thermal resistance values are shown in Fig. 6; ANOVA and Duncan test results are given in Table 7. It is determined that the effect of yarn type on these properties is statistically significant, whereas the effect of weave type is statistically insignificant.

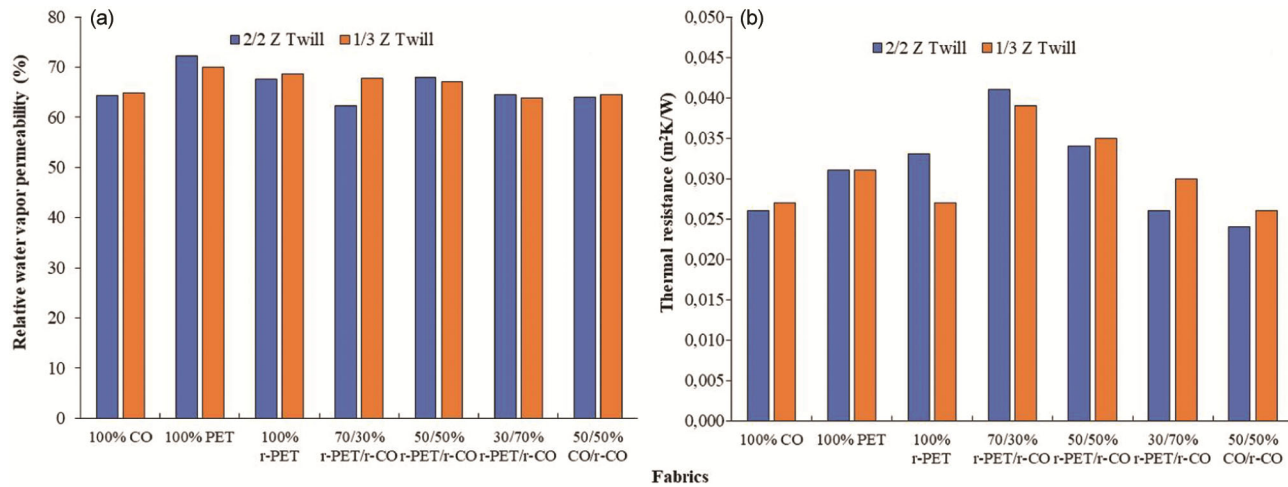


Fig. 6— Thermal comfort-related values of fabrics (a) relative water vapour permeability and (b) thermal resistance

Table 7 — ANOVA and Duncan test results for relative water vapour permeability, thermal resistance and air permeability

Parameter	ANOVA test <i>p</i> -value			
	Relative water vapour permeability, %	Thermal resistance, m ² K/W	Air permeability, mm/s	
Yarn	0.000	0.000	0.000	
Weave	0.287	0.832	0.000	
	Duncan test			
100% CO	64.672 c	0.027 de	1398.310 c	
100% PET	71.015 a	0.031 c	2774.780 a	
100% r-PET	68.224 b	0.030 cd	1948.400 b	
Yarn	70/30% r-PET/r-CO	64.992 c	0.040 a	1948.390 b
	50/50% r-PET/r-CO	67.483 b	0.035 b	1421.790 c
	30/70% r-PET/r-CO	64.204 c	0.028 cde	1017.000 d
	50/50% CO/r-CO	64.266 c	0.025 e	1018.670 d

It is observed that the relative water vapour permeability of 100% PET fabrics is higher than that of 100% CO fabrics. Similar results have been reported indicating that hydrophilic fibres swell and reduce porosity by retaining more water molecules during the water vapour transmission⁴⁴. Comparing 100% synthetic fibres, the relative water vapour permeability values of 100% r-PET fabrics are lower than those of 100% PET fabrics for both weave types. It may be attributed to the more hairy structure of r-PET fibres, which slightly distorts the fabric surface (Table 3). Similarly, previous studies have noted that bulky and hairy fabric structures reduce water vapour transmission due to increased fibre density and trapped air⁴⁵. While recycled cotton blended with virgin cotton slightly reduces the relative water vapour permeability, no significant difference is observed between 100% CO and 50/50% CO/r-CO fabrics. Additionally, for 2/2 Z twill weave fabrics, no clear trend is observed in r-PET/r-CO blends. However, for 1/3 Z twill weave fabrics, relative water vapour permeability decreases as the r-CO fibre ratio

increases and the r-PET fibre ratio decreases. These results are also in agreement with the previous study⁴⁶ related to the thermal comfort properties of the r-PET/CO blended fabrics, indicating that a reduction in r-PET content leads to lower water vapour transmission due to its lower moisture regain. In addition, a significant negative correlation is found between weight and thickness values and relative water vapour permeability (Tables 2 and 7).

Regarding thermal resistance, it is noteworthy that fabrics containing 100% PET fibres exhibit higher thermal resistance than those with 100% CO fibres. Various studies confirm that polyester fabrics, or those containing higher polyester fibre content, tend to have greater thermal resistance⁴⁷⁻⁴⁹. Since the thermal conductivity of air is lower than that of water, the decrease in the water volume held by the fabric could increase the thermal resistance⁵⁰. In 100% synthetic fabrics, no statistically significant difference is seen between 100% PET and 100% r-PET fabrics for thermal resistance values. Similar results can be seen for 100% CO and 50/50% CO/r-CO fabrics.

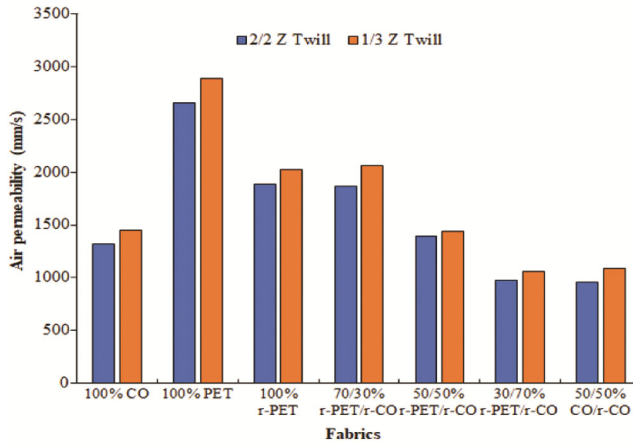


Fig. 7— Air permeability values of fabrics

Comparing r-PET/r-CO blended fabrics, it is observed that the thermal resistance values decrease as the r-CO fibre ratio increases in the fabric structure. These results reveal that recycled cotton and virgin cotton fibres exhibit similar behaviour in terms of thermal resistance. A possible reason for this might be a higher volume of water held in r-CO fibres⁴⁶.

3.7 Air Permeability

Figure 7 shows the air permeability values of fabrics with different yarn and weave types. As expected, the air permeability of 1/3 (Z) twill fabrics is higher than that of 2/2 (Z) twill fabrics due to fewer yarn intersections and a more open fabric structure, allowing easier and faster air passage.

According to the ANOVA and Duncan test results (Table 7), both yarn and weave types have statistically significant effects on air permeability. The highest air permeability is recorded for 100% PET fabrics, while lower air permeability is observed for 100% CO fabrics. Among 100% synthetic fibres, air permeability values are lower for 100% r-PET than for 100% PET fabrics. Additionally, the addition of r-CO fibre to virgin cotton results in reduced air permeability. A statistically significant difference between the fabrics containing different ratios of r-PET/r-CO fibres and the increase of the r-CO fibre ratio leads to a decrease in the air permeability values of the fabrics. A negative correlation is observed between fabric weight and thickness and air permeability values. (Table 2 and 7). It can be concluded that the air permeability of fabrics decreases due to the fact that the air travels more as it passes through the fabric, and its velocity decreases as the fabric weight and thickness values increase. These

findings also suggest a positive correlation between air permeability and water vapour permeability.

4 Conclusion

This study examines the performance properties of 2/2 and 1/3 (Z) twill woven fabrics produced using open-end yarns with varying ratios of r-PET and r-CO fibres alongside virgin CO and PET yarns. The key findings are as follows:

- Yarns containing recycled fibres show lower breaking strength and higher unevenness, thick places, and neps compared to virgin fibre yarns. In fully recycled yarns, an increased r-CO fibre ratio raises unevenness, thick places, and neps, while breaking strength, thin places, and hairiness show no consistent trend.
- 100% r-PET and r-PET blended fabrics have lower breaking and tear strength than those from 100% PET in warp and weft directions. The addition of recycled cotton to virgin cotton yarns similarly reduces fabric strength. However, 50/50% CO/r-CO fabrics exhibit higher breaking elongation than 100% CO fabrics. No clear correlation exists between fibre blend ratios and fabric strength or elongation in fully recycled fabrics.
- Replacing virgin PET with r-PET in synthetic fibre fabrics and incorporating recycled cotton in natural fibre fabrics does not significantly affect abrasion resistance. No clear trend emerges in fully recycled fabrics based on fibre blend ratios. Yarn breakage occurs between 6000-18000 abrasion cycles, with mass loss and specimen breakdown trends aligning across yarn types.
- Regarding water vapour and air permeability, 100% r-PET fabrics exhibit lower values than 100% PET fabrics. Similarly, adding recycled cotton to virgin cotton yarns reduces these properties, though thermal resistance remains largely unaffected. In r-PET/r-CO blends, increasing the recycled cotton ratio lowers air permeability and thermal resistance across both weave types, while water vapour permeability decreases only in 1/3 (Z) twill fabrics.

The findings highlight the influence of recycled fibres on yarn and fabric performance. Recycled fibre content affects fabric strength, permeability, and elongation, underscoring the need for strategic material selection and processing in sustainable textile applications.

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