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Properties of knit fabrics made from recycled cotton/ r-PET blended yarns

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In this study, open-end spun yarns have been produced from recycled cotton fibres by blending with r-PET fibres in three blend ratios (80/20, 70/30, and 60/40). The linear density of the yarn is maintained at 20Ne. Tensile strength, elongation at break, unevenness (CVm%), and hairiness of the produced yarns have been measured. It is found that the yarn manufactured with 60/40 recycled cotton/r-PET blend ratio has better yarn quality index value as compared to other blend ratios. The single jersey fabric has been developed from the 60/40 recycled cotton/r-PET yarn. Bursting strength, pilling resistance, and dimensional stability of the developed fabric are studied and compared with the commercial fabric. It is found that the properties of the developed fabric are comparable with commercial fabric and can be used to produce knit top garments, such as T-shirts and polo shirts.

Keywords: Open end spun yarn, Recycled cotton, r-PET fibres, Single jersey fabric, Textile recycling

1 Introduction

The textile industry has the most significant impact on the global economy and the environment. Textile waste is produced in every phase of the textile manufacturing process, viz. spinning, weaving, knitting, dyeing, finishing, garment manufacturing and even at the consumer end. In addition, with rapid growth and evolution in fashion trends along with the fast throw away culture of the new generation, textile production and waste generation rates have increased substantially over the last decades. Globally, around 87% of total discarded textiles, of which around 90% is reusable and recyclable, ended up through landfill or are burnt, creating a serious environmental threat. As a result of severe environmental impacts created by the textile industry, environmental sustainability has become a fundamental concern for textile manufacturers[1].

Aiming to protect the environment from pollution and waste, Environment Protection Act 2017 formulated a framework for how to comply with the new waste duties that are applied to people who generate, transport or receive industrial waste (Summary of Waste Regulations, 2022). The act supports and encourages the recycling of waste and resource recovery to divert as much waste from landfill as possible. The Global Recycled Standard (GRS) is an international standard for tracking and verifying the content of recycled materials in a final product complying with environmental regulations. GRS covers the manufacturing of products containing at least 20% recycled material. The GRS applies to the companies involved in the ginning, spinning, weaving, knitting, dyeing, printing, and sewing processes in more than 50 countries[2].

Cotton is one of the most important commodity fibres and is widely employed in apparels. Cotton cultivation is vital for mankind but it has severe environmental impacts. In the context of facing a high demand for cotton and the environmental regulations on the waste management system, the development of a sustainable strategy to recover cotton from textile waste is clear in an eco-responsible approach. As the cost of cotton fibre accounts for the majority (over 50%) of the production cost of ring-spun yarn, the reduction of raw material costs by utilizing recycled cotton will provide considerable advantages to the spinners and consumers. Recycling can be accomplished by extracting fibres from waste yarns and fabrics using a mechanical shredding machine that vigorously strikes and tears them into their original fibre components. However, recovered fibres obtained in this way manifest very short lengths and small lumps of fibres. That's why these fibres solely cannot be converted into yarns by spinning. To get rid of this problem, virgin fibres are blended with recycled fibres which act as carriers during the spinning process. By using this technique, coarser yarns were produced in rotor spinning system[3].

Musa *et al*.[4] produced OE-rotor yarns at different virgin cotton /waste cotton blend ratios (25/75, 50/50

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and 75/25) and compared the properties of the developed OE-rotor yarns with 100% virgin cotton OE rotor yarn. They showed that the use of up to 75% of waste cotton blended yarns show no statistically significant differences on yarn properties. Yeasin *et al.*[5] produced ring spun yarns by blending recycled cotton fibres from pre and post consumer wastes and virgin cotton, and showed that up to 25% recycled cotton fibres can be used as an alternative to virgin cotton to manufacture medium count yarn in ring spinning. Burcin *et al.*[6] produced 100% cotton Mélange yarns with different recycled/virgin fibre blend ratios (80/20, 72/28, 64/36, and 56/44) at different yarn counts (30 and 20 tex) and by different spinning methods (compact and open-end spinning). They observed that the yarn properties improved when the proportion of virgin cotton fibre in the yarn is increased. They also showed that the compact spinning method is advantageous in achieving the target of increasing the ratio of recycled fibre use with good tenacity for the production of 100 % cotton yarns[6].

The use of recycled polyester is a best practice for eco-friendly manufacturing in the textile industry, providing multiple benefits to the environment and society, such as reducing petroleum usage, decreasing greenhouse gas emissions, and promoting polyester-made clothing recycling streams. Recycled polyester (r-PET) has been suggested as an eco-friendly alternative to virgin polyester for two reasons, viz. r-PET production requires approximately 33–53 % less energy as compared to virgin polyester, and r-PET generates 54.6 % fewer CO_2 emissions than virgin polyester[7]. Uyanık[8] showed that r-PET fibre is suitable for coarser yarns which are especially 10 Ne and 20Ne as pure and in all blend ratios. The r-PET fibre is also suitable if it is used in lower ratios than 65% for 30 Ne yarns, and 35% for 40 Ne yarns. He also showed that the r-PET fibres provided the bursting strength values which are close to that of virgin PET fibres for the knitted fabrics having coarse yarns, whereas they do not contribute positively to the knitted fabrics having fine yarns[9].

Telli *et al.*[10] determined the performance of r-PET- and v-PET-blended yarns with cotton at different blend ratios. In addition, according to another study, knitted fabrics including v-PET had better performance specifications than that of r-PET. In order to prevent the decrease in fabric performance, suitable proportions of r-PET fibre can be used instead of v-PET or together with v-PET in an optimum ratio[11]. Esin[12] produced 30 Ne compact and ring spun yarns by blending recycled-PET and virgin PET fibres with cotton fibre. He showed that blend type, blend ratio and yarn manufacturing technology have statistical significant effect on bursting strength and air permeability of the single jersey fabrics manufactured from the developed yarns.

Ahu and Eren[13] investigated the quality properties of the open-end spun yarns produced from blends of recycled cotton and virgin polyester fibres and showed that the incorporation of virgin polyester fibre to recycled fibre causes improvement in yarn quality. Khan *et al.*[14] showed that the recycled polyester fibres can be used as an alternative to virgin polyester fibres in siro spun medium-count yarns and consequent fabrics. Basit *et al.*[15] developed tetra blended yarns by blending tencel fibres (regenerated) and r-PET (recycled) fibres with cotton and v-PET fibres, and found that it is possible to reduce the consumption of unsustainable cotton and PET fibres by tencel and r-PET fibres.

Several studies have been reported in terms of yarn production by blending the recycled cotton with raw cotton/virgin polyester fibres. The production of yarn by blending recycled cotton with recycled polyester fibres is not reported in the literature. In this research, an attempt has been made to produce OE yarns by blending recycled cotton with recycled polyester fibres in different blend ratios instead of raw cotton/virgin polyester. The strength and evenness properties of the developed yarns are studied. Single jersey-knit fabric has been produced from the developed yarns. The properties of the fabric have been studied and compared with commercial fabric made from 20 Ne cotton hosiery yarn used for producing knit garments.

2 Materials and Methods

2.1 Materials

In this study, 20 Ne rotor-spun yarns were produced by blending recycled cotton fibre with recycled PET fibres in three blend ratios (80/20, 70/30, and 60/40). Recycled cotton fibres obtained from pre-consumer wastes were sourced from in and around Coimbatore, India, and recycled polyester fibres were sourced from Sulochana Cotton Spinning Mills, Tirupur, India. The properties of the sourced fibers are given in Table 1.

The required amount of recycled cotton and recycled PET fibres were taken for blending according to the blend ratio, and fibres were mixed thoroughly. Then 0.125 Ne slivers were produced after two draw frame passages. In rotor yarn production, rotor and opening roller revolutions were 40000 and 5500 rpm respectively. The produced yarn had 20 Ne count with 18 twist per inch. The single jersey knit fabric was produced by using a Burn Knit machine (Model HKSJ), having a cylinder diameter 24 inch, number of needles 1200, and number of feeders 21.

2.2 Methods

2.2.1 Characterization of Yarns

All the tests were carried out in the laboratory under a standard testing atmosphere (65 ± 2 % relative humidity and 25 ± 2 ºC temperature). Tensile properties of yarns were studied by using a single yarn tensile tester operated with a constant rate of extension principle according to EN ISO 2062:2009 with 50 N load cell, 500 mm gauge length, and 500 mm/min crosshead speed.

The coefficient of mass variation (CVm%), imperfections, and hairiness of yarns were ascertained by Uster® Tester 6 (ASTM D1425/1425M-14:2020 standard) with the testing speed of 400 m/min. The sensitivity thresholds of thick place (+50%), thin place (-50%), and neps (+200%) per 1000 m of yarn were considered for data analysis. Yarn hairiness (H), measured by the hairiness sensor of the evenness tester based on optical principle, is the total length of protruding fibres (cm) within the measurement field of 1 cm length of yarn. Yarn quality index (YQI), comprising tensile strength, elongation, and unevenness of yarns was calculated for each yarn[16]. The yarn quality index was calculated using the following equation:

$$\text{Yarn quality index} = \frac{\text{Strength} \times \text{Elongation}}{\text{Unevenness}} \quad \ldots(1)$$

2.2.2 Characterization of Fabrics

The dimensional stability of the fabrics was carried out using a Washcat or front-loading washing machine by ISO 6330:2010.The bursting strength of the fabrics was measured by using a Mullen bursting strength tester as per the ASTM D 3786 standards. The pilling tendency of the fabrics was measured by ICI Pill box tester using ASTM D 3512 standards.

3 Results and Discussion

Table 2 shows the physical properties of the developed yarns. It is observed that the yarn produced from 80/20 recycled cotton/ r-PET has the lowest tenacity value as compared to other blend ratios. This may be due to the short fibre % in the recycled cotton fibres that are generated during the shredding process. When a yarn is subjected to tensile loading, short fibres present in the yarn are more prone to slip rather than participation against the applied load, leading to a lower strength value. The tenacity of the yarns increases with an increase in r-PET fibre %. The increase in r-PET % reduces the amount of short fibre % in the recycled cotton fibres that are generated during the shredding process. Also, r-PET fibres have higher tensile strength than recycled cotton fibres. The yarn produced from 60/40 recycled cotton/ r-PET has the highest tenacity value as compared to yarns produced from other blend ratios.

In addition to breaking strength, yarns must have enough breaking elongation to withstand stresses during the many steps involved in turning yarn into fabric. It also establishes how effectively the finished product can be extended while in use. It is observed that the yarn produced from 80/20 recycled cotton/ r-PET blend ratio has the lowest elongation % as compared to other blend ratios. When a load is applied to yarn, it is distributed among the constituent fibres. The arrangement of the fibres within the yarn's body and fibre extension are factors in yarn-breaking elongation. As recycled cotton fibres contain a high amount of short fibres, they are poorly integrated

Table1 — Properties of recycled cotton and r-PET fibres

Cotton fibre		Polyester fibre	
Property	Value	Property	Value
2.5% span length	17.90 mm	Fiber length	32.00 mm
Fineness	4.55 μg/in	Fiber fineness	0.80 den
Strength	14.40 g/tex	Tenacity	6.70 g/den
Elongation	10.10 %	Elongation	20.00 %
Maturity ratio	0.91	Density	1.38 g/cm^3

Table 2 — Properties of developed OE yarns (recycled cotton/r-PET)

Yarn parameter	80/20 yarn		70/30 yarn		60/40 yarn	
	Mean	CV%	Mean	CV%	Mean	CV%
Count, Ne	18.90	3.32	19.25	3.45	19.23	3.41
Strength, g/tex	62.50	11.70	64.84	10.90	66.54	11.95
Tenacity, RKM	8.24	11.80	8.53	10.95	9.72	10.83
Elongation, %	5.49	12.30	5.67	12.20	6.48	12.25

Table 3 — Evenness test results of the developed yarns

Yarn parameter	80/20 yarn	70/30 yarn	60/40 yarn
Co-efficient of mass variation (CVm %)	19.25	19.03	18.50
Unevenness % (U %)	16.40	15.70	13.17
Thick place (+50%)	62	50	40
Thin place (-50%)	18	15	10
Neps (+200%)	56	48	40
Hairiness index	5.22	5.09	4.81
Yarn quality index	17.82	19.32	23.30

with the yarn body and slip out easily during the application of load, resulting in lower elongation of yarns. With the increase in r-PET fibre%, the increase in elongation % is also observed. This may be due to higher elongation values of r-PET fibres as compared to recycled cotton.

Table 3 shows the evenness test results of the developed yarns. Unevenness of yarns is usually expressed by the coefficient of mass variation (CVm%). It is observed that the yarn produced from 80/20 recycled cotton/ r-PET has the highest CVm% value as compared to other blend ratios. The explanation for this can be attributed to the shorter fibre length and the large number of small fibres in the recycled cotton fibres. It is observed that the CVm% of yarns shows a decreasing trend with the increase of r-PET fibre %. In addition to CVm%, the yarn faults, viz. thick, thin, and neps, can also be used to describe the mass variation of yarn. As the faults in the yarn are closely linked to its strength values, yarns with higher imperfections perform poorly in processes, like warping, sizing, weaving, and knitting. Yarn faults also have a negative impact on the characteristics and appearance of the fabric.

It is observed that an increase in recycled cotton fibre in yarn has a detrimental effect on the thick and thin places. The reason can be attributed to the lower fibre length and higher short fibre of recycled cotton fibres. Thick and thin values show a gradually decreasing trend with the increase of r-PET fibre content in the yarn. Neps primarily consist of chiefly small clusters of entangled fibres and are found scattered throughout the fabric surface if they are present in the yarn. They are considered blemishes in dyed fabrics. After the last stage of clothing manufacture, lot rejection may even occur due to the severity of neps. It is observed that neps (+200%) of the manufactured yarns have similar pattern like thick and thin places.

The yarn hairiness, which is caused by fibre protrusion from the yarn surface, is one of the yarn's significant qualities, since it has a substantial impact on fabric performance. Depending on the use, a certain level of hairiness may be required to achieve the fabric's aesthetic qualities. For example, a cloth with some hairiness would feel softer and can wick away moisture, but excessive hairiness is undesirable. Like CVm% and imperfections, a similar pattern is observed in the hairiness values of the developed yarns, i.e. a decrease in yarn hairiness values with the increase in r-PET % in yarn.

Table 4 — Comparison of developed fabric properties with commercial fabric

Fabric parameter	60/40 r-Co/ r-PET fabric	Commercial fabric
Loop length, mm	3.90	4.00
Courses per inch	38	40
Wales per inch	29	30
GSM	187	182
Thickness, mm	0.58	0.53
Dimensional stability (Wales direction), %	1.50	1.50
Dimensional stability (Course direction), %	3.00	2.50
Bursting strength, Kpa	427	548
Pilling, grade	4	4

Tensile strength, elongation, and unevenness are the three factors that make up the yarn quality index, which indicates the satisfaction of customers. The mean values of the above-mentioned three properties are used to determine the yarn quality index. Among the developed yarns, 60/40 recycled cotton/r-PET yarn has the highest yarn quality index value. Single jersey fabric has been manufactured from 60/40 recycled cotton/r-PET yarn to check the possible production of knitwear like T-shirts and polo shirts. The developed fabric has been characterized for its performance properties and compared with the commercial fabric made from 20 Ne cotton hosiery yarn.

3.1 Comparison of Developed Fabric Properties with Commercial Fabric

Table 4 shows the comparison of the developed fabric properties with commercial fabric. The vertical force or pressure required to break the knitted fabric is known as the bursting strength. The bursting strength depends on various factors; however, the primary factor is the material with which fabrics are made. The bursting strength depends on the fibre type, strength, and breaking elongation of yarns. It is observed that the developed single jersey fabric has lower bursting strength as compared to commercial fabric. This is an expected result, that the recycling process of cotton fibre may affect the fibre properties negatively and cause lower yarn strength. Furthermore, the recycling procedure most likely causes the r-PET fibre, which is made from PET bottles, to lose its strength. In the pilling resistance testing, both developed and commercial fabrics have similar results and are in the "slight pilling" category. Dimensional stability has been investigated as shrinkage percentage in both course and wale directions. It is observed that there is no difference in shrinkage percentage between the developed and commercial fabrics in the wales direction. But in course direction, the developed fabric has a slightly higher shrinkage percentage as compared to commercial fabric. The produced single jersey fabrics can be used to manufacture knit garments, like T-shirts and polo shirts.

4 Conclusion

The study shows that the tenacity and elongation of the recycled cotton/r-PET yarns increase with the increase in r-PET fibre %. The CVm% of yarns decreases with the increase in r-PET fibre %. The yarn manufactured with 60/40 recycled cotton/r-PET blend ratio has better strength and evenness properties as compared to other blend ratios. The single jersey fabric has been developed using 60/40 recycled cotton/r-PET yarn. It is found that the performance characteristics of the fabrics developed from the 60/40 recycled cotton/r-PET yarns are comparable with commercial fabric and can be used to produce knit top garments, like T-shirts and polo shirts.

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