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Analysis of Properties of Water-Repellent Fabrics Made from Recycled PET and Recycled Cotton Yarns

Padmalatha V. Rao, Research scholar,
Kavita Chaudhary, Associate Professor,
Department of Design,
Banasthali Vidyapith, Rajasthan,
India

ABSRACT

The textile industry is under increasing pressure to adopt sustainable practices due to its significant environmental impact. Among the most promising solutions is the use of recycled fibers in fabric production, which not only reduces waste but also decreases reliance on virgin resources. Water-repellent fabrics are essential for rainwear, technical textiles, and other products that require protection from moisture. This study focuses on developing water-repellent fabrics from recycled cotton and recycled polyethylene terephthalate (PET) yarns that are both functional and environmentally friendly. A sustainable finishing agent was used to apply water- repellent finish on both fabrics. Water-repellent fabrics made from sustainable yarns with an environment-friendly finish have the potential to address both functional and environmental concerns. The sample fabrics were tested for various mechanical, aesthetic, and functional properties. In the liquid wicking test, recycled cotton fabric showed slight wicking when exposed for a longer duration whereas, recycled PET fabric showed no wicking. Dimensional stability test results showed slight shrinkage of recycled cotton fabric whereas recycled PET fabric stretched a little. Recycled PET fabric demonstrated superior tear strength, better smoothness, fullness, stiffness, and overall hand feel, providing insights into its feasibility for widespread application in fashion accessories, outdoor gear, and other products requiring water-repellent textiles.

Keywords: recycled cotton, recycled PET, water repellent finishing, environmental impact, performance properties

1. Introduction

The textile industry is one of the largest contributors to environmental pollution. Among the most impactful changes is the increased focus on recycling pre-and post-consumer clothing. Only 25% of textile waste is recycled, whereas 75% ends up in landfills [1]. The economic, social, and environmental benefits of recycling are significant [2]. One of the most commonly used fabrics, cotton can be recycled to conserve precious natural resources, thus reducing the costs of growing cotton, which needs large amounts of water and chemical fertilizers. Discarded PET products like bottles, cutlery, disposable food containers, etc. can be recycled and made into new products. PET recycling reduces the demand for new petroleum thus decreasing the environmental footprint. It was found that producing recycled PET yarns requires only half the energy as compared to producing virgin polyester, carbon emissions during the process are less than 55% and water consumption is 20% less [3]. Recycling PET and cotton is not just a crucial component of a sustainable future conserving resources, saving energy, reducing waste, and decreasing pollution, recycling these fabrics addresses some of the most pressing environmental changes as consumers and industries work together to embrace and expand textile recycling. Advanced technical systems of close-loop manufacturing can recycle old, used cotton and synthetics in a sustainable way to manufacture products [4].

Recycling waste not only saves our planet but also gives livelihood to many people involved in the industries of recycling and manufacturing different products. The products can be cost-effective too thus benefiting different sections of the population.

Recycling and recreating new fabrics from cotton and PET wastes is giving new life to them as well as minimizing pollution and making optimal use of the resources. Some big brands like H&M, Levi's, ADAY, Patagonia, Batoko, Girlfriend Collective, American recycled clothing, etc. have been making apparel with fabrics made from recycled fibers [36]. But the accessory segment has been using film and faux leather which are not eco-friendly and are not long-lasting. Recycled water-repellent fabrics can be used in making accessories like laptop sleeves, fanny packs, bucket hats, sling bags, etc.

Water repellency is a desirable property in textiles, particularly for outdoor apparel and technical textiles. It enhances the comfort and durability of garments by protecting them from moisture, rain, etc. [5]. Recycled cotton and recycled PET are two options considered in this study for developing eco-friendly water-repellent fabrics. Recycled cotton is a sustainable alternative to virgin cotton, reducing waste and minimizing the environmental impact of textile production. Textile recycling is the reclaiming method, which includes mechanical, chemical, and thermal methods, of textile waste for use in new textile or non-textile products [6].

The textile processing and finishing industry consumes enormous amounts of chemicals and releases harmful effluents and gases to the environment. Water-repellent treatments are traditionally done using fluorocarbon-based finishing agents. These chemicals provide water-repellency however, due to environmental concerns, there has been extensive research going on in alternative, sustainable methods [5]. Rethinking and refinement of the techniques involved in processing and finishing are significant. Environmental protection, pollution control, and innovative trends with sustainable concepts where natural eco-friendly materials can be used for textile finishing are the need of the hour [7].

Through various testing methods, this research evaluates the fabrics' water repellency, mechanical properties (tensile strength, abrasion resistance), durability, handle, etc. providing insights into their feasibility for widespread application in fashion, outdoor gear, and other industries requiring water-repellent textiles.

2 Materials and Methods

2.1 Materials

In this study, two sample fabrics were woven using two types of recycled yarns. Yarn A is 29.5tex recycled cotton yarn made by recycling textile waste mainly used clothes and factory discards from spinning and weaving sector. This yarn has good strength, but the elongation is high which means fabrics made from the yarn may snag over a period of use. Yarn B is 29.5tex recycled PET yarn. Recycled PET (rPET) is made by recycling PET bottles and other disposables made of PET. This yarn showed less strength compared to cotton, but the elongation is less which makes it preferable for making structured accessories. PET is inherently hydrophobic compared to cotton. This property is an advantage for making water-repellent fabrics. The properties of both yarns are shown in Table-1.

Table 1. Properties of Yarns Used in This Study

Yarn Test	29.5tex Recycled cotton (Yarn A)	29.5tex Recycled PET (Yarn B)
Yarn strength (gf/tex)	18.14	12.94
Yarn elongation (%)	17.54	15.79

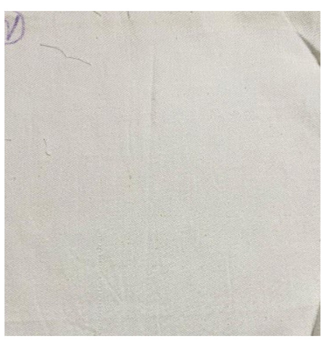
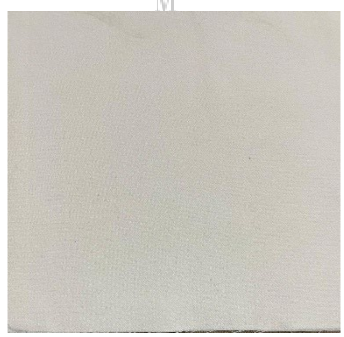
2.2 Fabric Production and Water-Repellent Finish Application

Both sample fabrics were woven using satin weaves in order to give a smooth hand. Recycled cotton yarn was used in warp and weft direction for sample fabric A and recycled PET yarn was used in warp and weft direction for sample fabric B. Both fabrics were woven with 72ends/inch and 64picks/inch, with 268gm/m² mass per unit area. For the water-repellent finish application, Ecoguard-NEW, a plant- based fluorine free product was used as it imparts very good water repellency and is better than the conventional paraffin wax -based and acrylate- based products. Ecoguard-NEW is non-ionic off-white liquid, pH of 1% solution is 5%+/-1, miscible with water and is stable to dilute acids and alkalis. Padding solution was prepared as per the following recipe-

Ecoguard-NEW- 30-80 kg/m³
Acetic acid- 0.001

Sample fabrics were padded with the prepared solution with 65–70% expression. Samples were dried at 120 ºC for 120 seconds. Samples were then cured on a stenter at 140–150 ºC for 180 seconds.

Figure 1. Sample Fabric Pictures

		
Recycled cotton fabric (Fabric A)	Recycled PET fabric (Fabric B)	After treatment with water-repellent finish

2.3 Methods

Both sample fabrics were tested for functional properties. Dimensional stability is of utmost importance as the products for which these fabrics were developed are expected to be exposed to moisture / water. It was tested by washing the samples at 40 ºC for 30 minutes. Shrinkage in both warp and weft direction was recorded. Liquid wicking rate was tested (ISO 9073-6) in both warp and weft directions, results were recorded for an exposure duration of 10, 30, 60 and 300 seconds for both samples. If the water - repellent finish is efficient there shouldn't be any liquid wicking. Both samples were tested for tear strength (N) (ASTM D 1424-2021) in warp and weft directions. High tear strength is essential for a fabric to have good performance and durability.

Abrasion resistance Martindale (ASTM D 4966-2016 (option 1 & 3)) was performed on the two sample fabrics at kPa load 9. Number of cycles for two- thread break and weight loss percentage were recorded. Abrasion is unavoidable during usage of any product. Fabric with good abrasion resistance has longer life. Fabric propensity for surface fuzzing and pilling (IS 10971:part 1:2022) was tested, resistance to pilling was tested with ICI Pillbox method at 18,000 cycles. If pilling resistance is good, the fabric surface will be smooth and clean for longer period of time.

Kawabata test was conducted on both samples for testing the handle. Properties like Numeri (smoothness), Fukurami (fullness & softness), Koshi (stiffness), fabric thickness, weight, tensile strength (KES-FB1A), shear properties (KES-FBI), surface properties (KES-FB4), bending properties (KES-FB2), compression properties (KES-FB3A) were recorded as shown in Tables:4a-4g. All these properties play an important role in determining the handle of the fabric which will be used to make water-repellent products. The requirements of this segment were considered while evaluating the functional properties.

3. Results and Discussion

Sample fabric test parameters and properties are summarized in tables 2-5 and represented graphically in figures 1 and 2. Each test recorded 3-8 readings per sample. Using statistical tool mean values of various test results are calculated and analyzed.

3.1 Performance Tests

Table 2 shows performance test results of both sample fabrics. The results show that the dimensional stability of Fabric B is better than Fabric A. In case of Fabric A, shrinkage was noticed in the warp direction though weft wise there was no shrinkage. Fabric B did not shrink but got stretched a little in the warp direction. Regarding tear strength, Fabric B had higher strength as compared to Fabric A in both warp and weft directions. Fabric B showed zero liquid wicking rate in both warp and weft directions whereas Fabric A showed a minor liquid seepage when exposed to liquid for 300 seconds though it exhibited zero liquid wicking at 10, 30 and 60 second exposure.

Table 2. Performance Test Results of Sample Fabrics

Fabric Code	Dimensional Stability		Tear Strength		Liquid wicking rate (mm)							
					Warp				Weft			
	Warp	Weft	Warp	Weft	10 secs	30 secs	60 secs	300 secs	10 secs	30 secs	60 secs	300 secs
Fabric A	-0.7	0	43.1	42.8	0	0	0	0.3	0	0	0	0.006
Fabric B	+0.3	0	50.6	46.1	0	0	0	0	0	0	0	0

3.2 Surface Property Tests

As evident from Table 3, abrasion resistance of Fabric A is slightly lower in view of early two thread breakage, but Fabric B had greater weight loss due to friction. Whereas pilling resistance is better for Fabric A as compared to Fabric B. As recycled PET yarn was used to make Fabric B, it is prone to pilling due to shorter fiber length.

Table 3. Results of Surface Tests of Sample Fabrics

Fabric code	Abrasion resistance @ kPa load	Two -thread break @ cycles	Weight loss %	Pilling resistance @ 18,000 cycles
Fabric A	9	15,000	6.04	4
Fabric B	9	17,000	8.08	3-4

3.3 Kawabata Testing for Fabric Handle

Table 4a, b, c, d, e, f and g show detailed results of fabric handle of both sample fabrics according to Kawabata testing method.

Fabric B showed higher compressional energy (WC) and compressional resilience (RC) which shows that the fabric is firm to compress and has good resiliency to bounce back after compression is removed (Table 4a).

Table 4a. Compression Properties

Fabric code	Linearity of compression thickness curve LC	Compressional energy WC (g.cm/cm²)	Compressional resilience RC (%)
Fabric A	0.298	0.267	38.46
Fabric B	0.312	0.29	46.74

Weight and thickness of Fabric B was higher than Fabric A though its weight was slightly less as compared to Fabric A (Table 4b).

Table 4b. Fabric Weight and Thickness

Fabric code	Fabric thickness (To mm)	Fabric thickness at max pressure (Tm mm)	Fabric weight (mg/cm²)
Fabric A	1.196	0.836	20.955
Fabric B	1.248	0.866	20.575

Tensile energy (WT) and extensibility (EMT) of Fabric A were higher whereas, tensile resilience (RT) and linearity of load (LT) of Fabric B were higher (Table 4c).

Table 4c. Tensile Properties

Fabric code	Linearity of load (LT)	Tensile energy WT (gf.cm/cm²)	Tensile resilience RT (%)	Extensibility EMT (%)
Fabric A	0.568	10.78	34.19	7.57
Fabric B	0.786	9.36	42.68	4.78

Table 4d shows that shear properties of Fabric B were higher, which implies that it is stiffer and less shear as compared to Fabric A.

Table 4d. Shear Properties

Fabric code	Shear stiffness G (gf/cm.deg)	Hysteresis of shear force at 0.5º shear angle 2HG (gf/cm)	Hysteresis of shear force at 5º shear angle 2HG5 (gf/cm)
Fabric A	2.06	2.59	2.75
Fabric B	2.17	2.78	2.85

It is evident from Table 4e that Fabric B is rougher than Fabric A hence coefficient of friction (MIU) is also higher.

Table 4e. Surface Properties

Fabric code	Coefficient of friction MIU	Mean deviation of MIU MMD	Geometrical roughness SMD (µm)
Fabric A	0.120	0.0150	3.365
Fabric B	0.146	0.0081	4.297

Bending rigidity (B) and hysteresis of bending moment (2HB) of Fabric B were much higher than Fabric A which shows that Fabric B is stiff and will not bend easily (Table 4f) with pressure.

Table 4f. Bending Properties

Fabric code	Bending rigidity B (gf.cm²/cm)	Hysteresis of bending moment 2HB (gf.cm²/cm)
Fabric A	0.1207	0.1325
Fabric B	0.1966	0.2293

Considering the test values of stiffness, smoothness, fullness and total hand values, it is evident that Fabric B performs better than Fabric A (Table 4g).

Table 4g. Primary and Total Hand Values of Fabrics

Fabric code	Koshi (Stiffness)	Numeri (Smoothness)	Fukurami (fullness & stiffness)	Total hand value KN-301
Fabric A	4.67	7.09	7.59	4.19
Fabric B	5.8	8.17	8.44	4.90

Water-repellent fabrics used in making products must possess good resistance to liquid wicking as they are intended to protect the contents from moisture and liquids. Water repellent agents can be eco-friendly when made with fluorine free compounds. Comparative statistical analysis of data (Table 5) shows that Fabric B is relatively better in terms of overall performance. Dimensional stability is good without shrinkage, and zero liquid wicking demonstrates that Fabric B has good water-repellent property. Tear strength, abrasion resistance, pilling resistance, stiffness, smoothness, fullness and total hand value of Fabric B are greater than that of Fabric A.

Table 5. Comparative Analysis of Test Results

Fabric Code	Dimensional Stability	Tear Strength	Liquid Wicking	Abrasion Resistance (2 Thread Break)	Weight Loss %	Pilling Resistance	Stiffness	Smoothness	Fullness	Total Hand Value
Fabric A	-0.7	42.95	0.25	15,000	6.04	4	4.67	7.09	7.59	4.19
Fabric B	+0.3	48.35	0	17,000	8.08	3-4	5.8	8.17	8.44	4.90

The results of various test parameters are compared using column graphs in Figures 1&2.

Figure 1 shows that Fabric A has better pilling resistance with relatively low weight loss when exposed to abrasion which implies that it is durable and can withstand wear and tear. Fabric B had relatively less pilling resistance and greater weight loss to abrasion. Overall, Fabric A performed better in these tests.

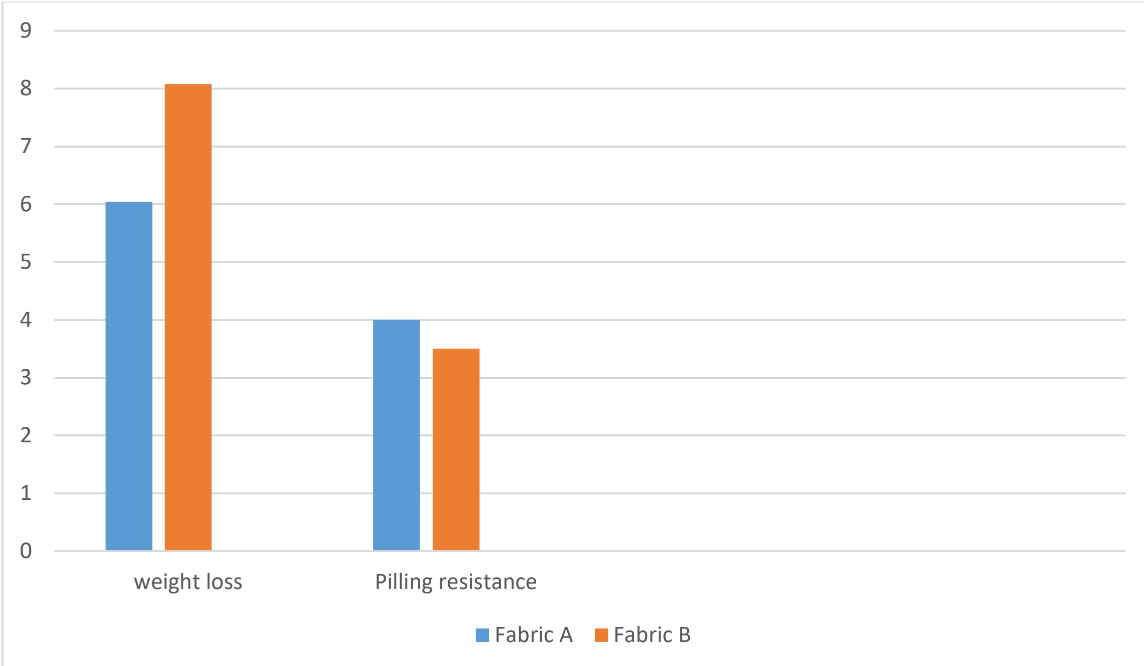


Figure 1. Surface Test Results

Figure 2 shows that there was significant difference between both the fabrics. Fabric A scored better in some parameters like fabric weight and tensile strength. Shear properties of both fabrics were similar and in results of surface property test showed that Fabric is rougher. Fabric B is better in stiffness (koshi), smoothness (numeri), fullness (fukurami) and total hand values.

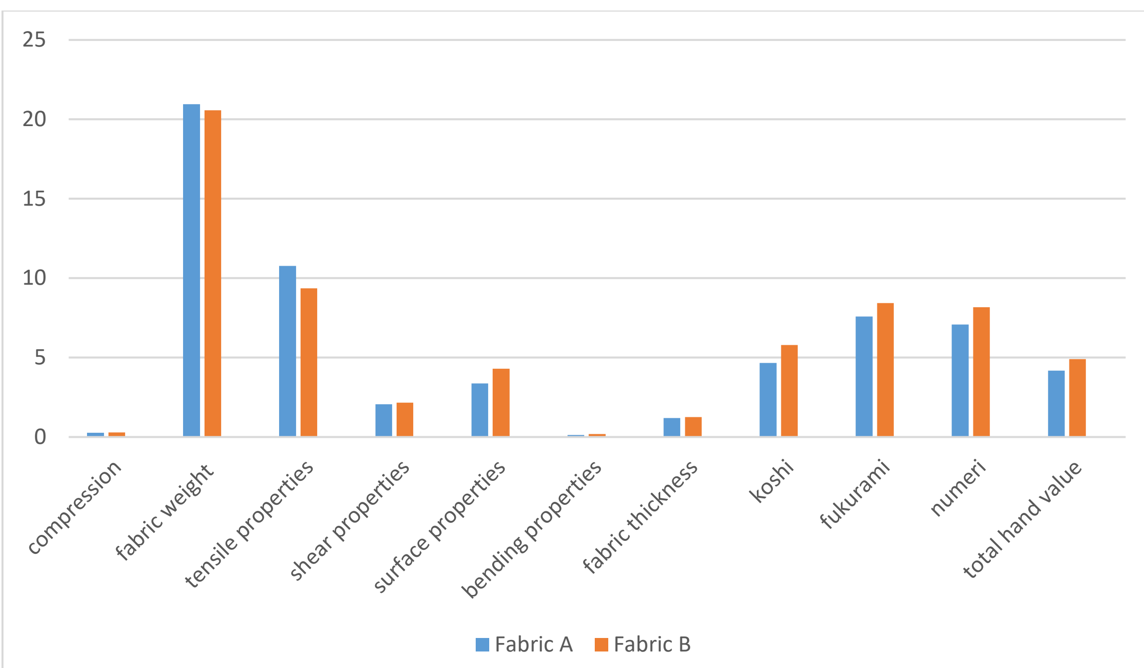


Figure 2. Kawabata Test Results

4. Conclusion

Two fabrics were developed with recycled yarns (recycled cotton and recycled PET) using satin weaves. An eco-friendly water-repellent finish was applied to both fabrics. Water repellent finish is given to fabrics by applying a repellent agent coating on the surface of fabrics which acts like a barrier, protecting the fabric from getting wet. The hand and air-permeability are not largely affected [8]. The fabrics were tested for various performance and functional properties. Statistical evaluation showed that there was some difference in the test results of both the fabrics. Water repellent test result of Fabric B showed zero liquid wicking rate which is considered excellent as products made using this fabric can give maximum protection to the contents. Though weight loss during abrasion test was more, tear strength was also higher for Fabric B so durability of this fabric seems better. Total hand value of Fabric B was better than Fabric A according to Kawabata test results. Though Fabric A (recycled cotton) had better tensile strength and less pilling, Fabric B (recycled PET) showed good dimensional stability, tear strength, zero liquid wicking and very good handle. Considering all the parameters, Fabric B can be recommended for making water-repellent products.

5. Limitations of the study

- The study tested only a single fabric sample per variant, with fixed parameters such as yarn number, satin weave and uniform thread count. This restricts the ability to assess variability within or across fabric types. Results are specific to the tested satin-weave recycled cotton and recycled PET samples and may not generalize to other weaves, thread counts, or picks.
- The research only examined the fabrics under static laboratory conditions. Real-world applications may affect fabric behavior differently than in controlled tests.

6. Scope for further research

- Comparing different types of yarns or exploring other weave patterns such as twill, plain weave could lead to more generalized conclusions applicable to a wider range of fabrics.
- It would be beneficial to test the fabrics under real-world conditions, under dynamic conditions such as mechanical stress due to repeated use or movement could further contribute to understanding how fabrics behave outside the lab. This would provide more insight into how these fabrics maintain their qualities after extended periods.

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