COMPARATIVE ANALYSIS OF PHYSICAL, SERVICEABILITY, AND HANDLE PROPERTIES OF WOVEN FABRICS PRODUCED WITH VIRGIN AND RECYCLED POLYESTER WEFT YARNS: AN EXPERIMENTAL STUDY FOR PERFORMANCE AND SUSTAINABILITY

VISHESH KUMAR
DEPARTMENT OF TEXTILE ENGINEERING, TECHNICAL EDUCATION DEPARTMENT UTTAR PRADESH KANPUR, 208024, INDIA
Email: visheshkumar4067@gmail.com
ASHWANI KUMAR
DEPARTMENT OF MECHANICAL ENGINEERING, TECHNICAL EDUCATION DEPARTMENT UTTAR PRADESH KANPUR, 208024, INDIA
e-mail: drashwanikumardte@gmail.com
RAMONA BIRAU
"CONSTANTIN BRÂNCUȘI" UNIVERSITY OF TÂRGU JIU, FACULTY OF ECONOMIC SCIENCE, TG-JIU, ROMANIA
e-mail: ramona.f.birau@gmail.com
IULIANA CARMEN BĂRBĂCIORU
„CONSTANTIN BRÂNCUȘI" UNIVERSITY OF TÂRGU JIU, FACULTY OF ENGINEERING, TÂRGU JIU, GORJ COUNTY, ROMANIA
e-mail: cbarbacioru@gmail.com
ROXANA-MIHAELA NIOATA (CHIREAC)
UNIVERSITY OF CRAIOVA, DOCTORAL SCHOOL OF ECONOMIC SCIENCES "EUGENIU CARADA", CRAIOVA, ROMANIA
e-mail: roxananioata06@gmail.com
GABRIELA ANA MARIA LUPU (FILIP)
UNIVERSITY OF CRAIOVA, "EUGENIU CARADA" DOCTORAL SCHOOL OF ECONOMIC SCIENCES, CRAIOVA, ROMANIA
e-mail: Lupuanamariagabriela@yahoo.com
CRISTINA SULTĂNOIU (PĂTULARU)
UNIVERSITY OF CRAIOVA, DOCTORAL SCHOOL OF ECONOMIC SCIENCES "EUGENIU CARADA", CRAIOVA, ROMANIA
e-mail: cristinapatularu1973@gmail.com

Abstract

This paper presents a comparative analysis of the physical, serviceability, and handles properties of woven fabrics. The fabrics were manufactured using 20^S Ne virgin polyester or 20^S Ne recycled polyester yarns in the weft, with $2/20^S$ Ne cotton yarns in the warp, to assess material properties and sustainable viability. The study aims to determine if recycled polyester, derived from recycled PET bottles, can offer equivalent or superior characteristics compared to virgin polyester without compromising fabric quality.Fabrics were produced on a Rapier loom under controlled conditions at Singhal Textiles, Hapur, Uttar Pradesh, utilizing standardized construction parameters (EPI × PPI: 54 × 46). A total of six fabric samples were prepared, encompassing 0-washed, 2-wash, and 4-wash conditions for both virgin and recycled polyester weft fabrics, respectively, to capture the progressive impact of washing. Rigorous laboratory testing was conducted in accordance with Indian and international standards for various properties. Physical characteristics such as Ends Per Inch (EPI), Picks Per Inch (PPI), fabric thickness, moisture content, and fabric weight (GSM) were measured. Serviceability parameters including abrasion resistance and pilling resistance were evaluated to determine fabric durability under use. Fabric handle was characterized by assessing drape, crease recovery. Additionally, air permeability was measured to understand comfort properties.In conclusion, this study provides evidence to support informed decision-making by manufacturers, and policymakers aiming to align fabric performance with sustainability.

Keywords: *Recycled Polyester, Virgin Polyester, Woven Fabric, Sustainability, Performance, Washing Impact*

1. Introduction

The rising demand for sustainable alternatives in textile production has led to increased interest in the application of recycled materials [1], fundamentally driven by mounting environmental concerns related to the industry's massive resource consumption and waste generation [2-3].The conventional textile manufacturing cycle [4], particularly for polyester, relies heavily on fossil fuels a non-renewable resource for the synthesis of virgin polymers [5-6]. Furthermore, the production process is energy-intensive and contributes significantly to greenhouse gas emissions. Simultaneously, the problem of post-consumer waste [7], specifically plastic bottles (Polyethylene Terephthalate or PET) [8], has reached a critical stage globally [9]. Millions of tons of PET end up in landfills or pollute ecosystems, taking hundreds of years to degrade [10-11].

The adoption of recycled polyester (rPET), which is typically derived from these discarded PET bottles, directly addresses both of these issues [12-14]. By diverting plastic waste from landfills and oceans, the production of rPET significantly reduces the environmental footprint compared to manufacturing virgin polyester [15-17]. Life cycle assessments consistently show that producing rPET requires substantially less energy and reduces CO_2 emissions compared to its virgin counterpart [18-20]. This dual benefit waste reduction and resource conservation makes rPET a cornerstone of the textile industry's pivot toward circularity and sustainability [21-22].

This experimental study investigates and compares the physical properties, mechanical properties, serviceability properties and handle properties of woven fabrics made using Virgin Polyester and Recycled Polyester yarns in the weft direction, aiming to evaluate whether recycled polyester can be a feasible substitute without compromising fabric quality. For this purpose, three samples of each fabric type were developed under identical construction and weave parameters to ensure a controlled experimental comparison.

The physical properties evaluated include EPI, PPI, fabric thickness, fabric weight (GSM),Moisture content in fabric, mechanical properties evaluated includesTensile strength, Tearing strength, serviceability properties evaluated include Abrasion resistance, and Pilling behavior, handle properties evaluated include Drape ,Bending Length, Stiffness of fabric, Crease Recovery and comfort properties evaluated include Air Permeability. Testing was conducted in accordance with standardized procedures:Thickness, EPI & PPI was measured as per ASTM D3776,GSM according to IS 1964,tensile strength was measured as per IS 1969-1, tearing strength as per ASTM D1424, abrasion resistance using ISO 12947-1, and pilling resistance following ISO 12945-1. Drape according to ISO 9073-9,Crease Recovery according to ISO 2313, bending length according to ASTM D1388, Drape of fabric according to ASTM D1388,Each fabric type underwent washing treatments and assessments carried out on 0-washed, 2-times washed, and 4-times washed samples.

The serviceability properties evaluated include abrasion resistance, and pilling behavior. Testing was conducted in accordance with standardized procedures abrasion resistance using ISO 12947-1, and pilling resistance following ISO 12945-1. Each fabric type underwent washing treatments to simulate real-world usage and aging, with assessments carried out on unwashed, two-times washed and four-times washed samples.

The handle properties evaluated include Drape and Crease recovery. Testing was conducted in accordance with standardized procedures: Drape was measured as per ISO9073-9. Each fabric type underwent washing treatments to simulate real-world usage and aging, with assessments carried out on 0-washed, 2-times washed and 4-times washed samples

The comfort properties evaluated include Air permeability. Testing was conducted in accordance with standardized procedures: Air permeability as per ASTM D1424. Each fabric type underwent washing treatments to simulate real-world usage and aging, with assessments carried out on unwashed, two-times washed and four-times washed samples

In terms of fabric weight (GSM), both fabric types demonstrated comparable stability with minimal variation across wash cycles. Virgin Polyester ranged from 158 to 151 GSM, while Recycled Polyester ranged from 160 to 156 GSM. This indicates that the incorporation of Recycled Polyester in the weft does not significantly affect fabric density or structure.

Abrasion resistance results were consistent across both fabric types, with ratings of 2 to 3 after multiple washes, suggesting moderate durability. Pilling resistance showed a slightly better performance for Recycled Polyester in the later washes (rating of 3), whereas Virgin Polyester showed a tendency to degrade slightly faster (rating dropped to 2 after two washes), indicating that recycled yarns may offer improved resistance to surface fussing and pilling under certain conditions.

Overall, the study concludes that fabrics constructed with Recycled Polyester yarns in the weft direction can perform on par with those made using Virgin Polyester yarns in terms of essential physical properties. While minor differences were observed in specific test parameters post-washing, these variations do not significantly impact the overall fabric performance. These findings suggest that Recycled Polyester can be considered a viable and sustainable alternative in fabric production, especially in applications where eco-consciousness and resource conservation are priorities.

2. Material& Method

2.1 Sampling Plan

For the study, the two types of yarns (virgin polyester yarn and recycled polyester yarn) were procured. Two fabric samples were made using these two types of yarns in weft and cotton yarn on warp. Furthermore, these fabrics were washed for 0-wash, 2-wash and 4-wash to analyses the impact of washings. Thus, a total six fabric samples were prepared (as per Table 1)

Table 1: Sampling plan

Sr. No.	Warp Yarn	Weft Yarn	No of Wash	SampleName
1	$20^S/2$ Ne Cotton Yarn	20^S Ne Virgin Polyester Yarn	0-Wash	VP0W
2	$20^S/2$ Ne Cotton Yarn	20^S Ne Virgin Polyester Yarn	2-Wash	VP2W
3	$20^S/2$ Ne Cotton Yarn	20^S Ne Virgin Polyester Yarn	4-Wash	VP4W
4	$20^S/2$ Ne Cotton Yarn	20^S Ne Recycled Polyester Yarn	0-Wash	RP0W
5	$20^S/2$ Ne Cotton Yarn	20^S Ne Recycled Polyester Yarn	2-Wash	RP2W
6	$20^S/2$ Ne Cotton Yarn	20^S Ne Recycled Polyester Yarn	4-Wash	RP4W

2.2 Yarn procurement

To manufacture the required sample two set of yarn were procured from BST Textile Mill, Rudrapur, Uttrakhand,Both yarn type has fibre finess of 1.5 Diner and fiber lenth of 34mm , yarn count 20^S Ne.

(a) Recycled Polyester Yarn **(b);**Virgin Polyester Yarn **Figure 1:**Yarn types

2.3 Fabric Preparation

Two types of woven fabric with varying weft were developed at Rapier loom (Picanole Loom)setup at Singhal Textile Mill, Hapur,Uttar Pradesh.Both fabric variants (Figure 2) were produced under identical mechanical and environmental conditions to ensure that the comparative analysis of physical properties would be fair and based solely on the type of polyester used. Care was taken to maintain uniform tension, proper alignment, and consistent machine settings throughout the production process.The technical parameters of sample are as per the Table 2.

Table 2: Technical Parameter of fabric

Sr. No.	Types of fabric	Warp Yarn	Weft Yarn	EPI x PPI	Weave
1	Virgin polyester fabric	$20^S/2$ Ne Cotton Yarn	20^S Ne Virgin Polyester Yarn	54x46	Plain
2	Recycled polyester fabric	$20^S/2$ Ne Cotton Yarn	20^S Ne Recycled Polyester Yarn	54x46	Plain

(a) Virgin Polyester fabric **(b)**Recycled Polyester fabric

Figure 2: Fabric Types

2.4 Preparation of Washed Sample

To study the effect of washing on the physical, mechanical, handle, and serviceability properties of the fabric, a standardized washing procedure was followed. Both virgin polyester weft fabric and recycled polyester weft fabric, constructed with identical $2/20^S$ Ne cotton yarn in the warp, were washed at 60°C and 1.5 Hrs washing cycle at standard neutral detergent.

3. Sample Properties

3.1. EPI and PPI

The ends per inch (EPI) and picks per inch (PPI) were measured of samples using the ASTM D3776 method with the help of a pick glass. To count the EPI and PPI, the fabric sample was placed on a counting table, and the number of warp yarns (EPI) and weft yarns (PPI) within one inch were counted using the pick glass.

3.2. **Fabric thickness**

Thickness of fabric was measured as per ASTM D1777 standard testing method. After conditioning the fabric samples for**at least 24 hours** in a standard testing atmosphere; the **flat and wrinkle-free** sample was placed on the base of the thickness gauge (Figure 3.4). Slowly lower the presser foot onto the fabric with **standard pressure,** which is 1 kPa wait for**5 seconds,** then record the thickness value (in millimeter). Take **at least 5 readings**at different areas of the fabric and calculated the **average.**

3.3. **Fabric weight**

Fabric weight **(grams per square meter or GSM) of the fabric samples was measured as per the method in IS 1964.** Using a circular GSM cutter with a 100 cm² cutting area, swatches were carefully taken from different areas of each sample, ensuring that edges, folds, and distorted regions were avoided. Each swatch was weighed on a precision digital balance with 0.01 g sensitivity. The GSM was calculated by multiplying the sample weight by 100. For each fabric type, three readings were taken at different locations and the average GSM value was reported.

GSM of Fabric = Weight of Swatch X 100……..(1)

3.4. **Moisture content in fabric**

The moisture content of the fabric samples was determined according to ASTM D2654. The test was performed on all the six fabric samples. Prior to testing, the samples were conditioned for 24 hours in a standard testing environment. Each sample were accurately weighed and recorded as the initial conditioned weight. The samples were then placed in a hot air oven at 105°C ± 3°C for a minimum of 1 hour. After drying, the samples were removed from the oven, cooled in a desiccator, and weighed again to record the oven-dry weight. The moisture content (%) was calculated using the formula:

$$\text{Moisture Content (\%)} = \left(\frac{\text{Weight of water present in sample}}{\text{Oven dry weightof sample+Weight of water present in sample}}\right) \text{x}100 \ldots..(2)$$

. This procedure was repeated for each of the six samples, and the average moisture content was calculated.

3.5. **Abrasion resistance**

The abrasion resistance of the fabric samples was evaluated according to ISO 12945-1 (Martindale Method). Circular test specimens were cut and mounted onto the Paramount **Martindale** abrasion tester , model **Martindale MASTER** (Figure 3.9) using standard backing materials and holder rings. The specimens were subjected to a controlled rubbing motion against a standard wool abradant under a specified pressure of 9 kPa. The test was conducted for 12000 number of rub cycles. At the end of the test cycle, each sample was examined visually and grades the sample 1-5 scale. The results were recorded for each of the six samples, and the impact of washing and fiber type (virgin vs. recycled) on abrasion resistance was analyzed.

3.6. **Pilling resistance**

The pilling resistance of the fabric samples was evaluated using the ISO 12945-1 (Martindale method for assessment of pilling). Circular test specimens were cut from each sample and mounted on the Martindale abrasion and pilling tester using standard foam and backing fabric. The specimens were subjected to a controlled rubbing action against a standard wool abradant under a pressure of 9 kPa,. After a 12000 no of cycles the samples were removed and visually assessed for the degree of pilling. The evaluation was done under the scale of 1-5 by comparing the tested surfaces against standard photographic rating charts, and a pilling grade was assigned to each sample.

3.7. **Crease recovery of fabric**

The crease recovery angle of the fabric samples was measured using method ISO 2313:1972 using Paramount crease recovery tester, model CreaseMASTER**(Figure 3.11).** Rectangular test specimens measuring 40 mm × 15 mm were prepared in both the warp and weft directions. Each specimen was folded in half, with the crease pressed under a fixed load of 1 kg for duration of one minute to set the crease. Immediately after the load was removed, the folded specimen was carefully transferred to the crease recovery tester, and the fabric was allowed to recover under gravity for five minutes. The **angle between the two limbs**of the folded specimen was then measured using a protractor or an integrated scale on the tester. This angle represented the **crease recovery** of the fabric. Five readings were taken in both directions for each sample, and the average recovery angle was calculated.

3.8. Drape of fabric

The drape behavior of the fabric samples was evaluated with the help of Paramont Drape Meter, model Drape MASTER according to ISO 9073-9**.** Circular specimens of 30 cm diameter were cut from each fabric and centrally placed on a smaller support disc of 18 cm diameter, mounted on the drape meter. The fabric was allowed to fall freely under its own weight, forming natural folds or drapes around the edge of the supporting disc. A light source projected the shadow of the draped specimen onto a horizontal screen or paper placed beneath the setup. The outline of the shadow (representing the draped area) was traced and the area of the shadow was measured using a digital planimeter or by weight comparison with a known paper area. The drape coefficient (DC) was then calculated using the formula:

$$Drape\ coefficent(\%) = \left(\frac{\text{Area of Draped Shadow} - \text{Area of supporting disc}}{\text{Area of specimen} - \text{Area of supporting disc}}\right) x100 \ldots\ldots\ldots(3)$$

Lower values indicate better drapability. For each sample, multiple readings were taken, and average drape coefficients were calculated in both warp and weft directions. The results were used to assess the effect of washing cycles and fiber type (virgin vs. recycled polyester) on the drape characteristics of the fabric.

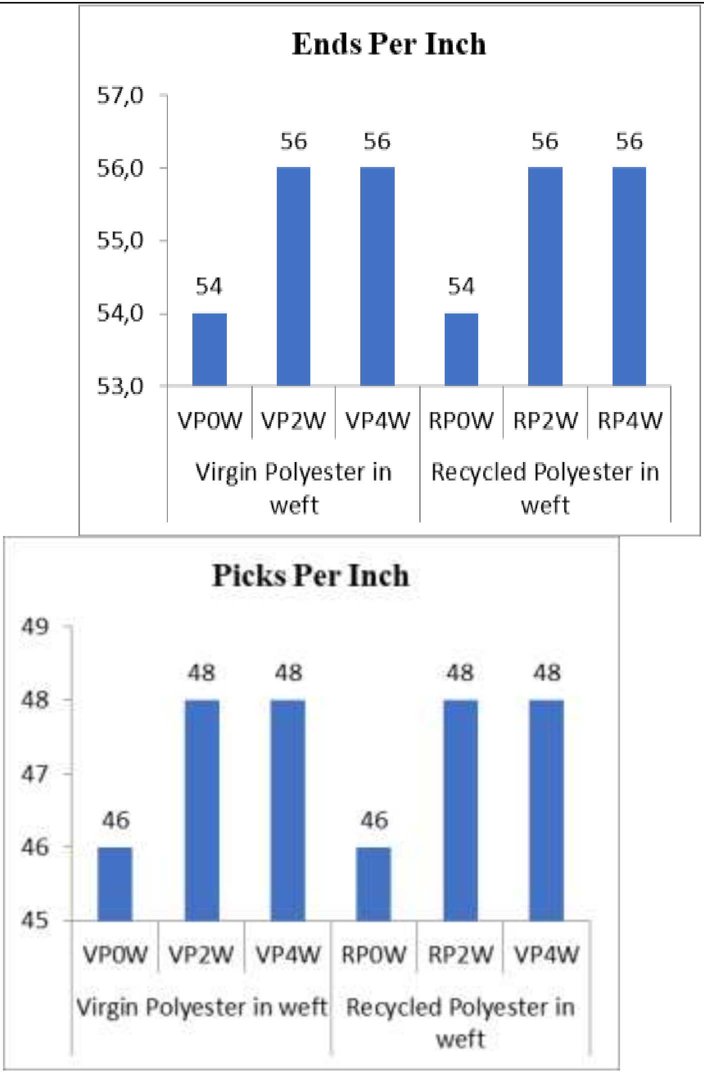
3.9. Air permeability

The air permeability of the fabric samples was tested according to ASTM D737. The test was performed using an TTSAir Permeability Tester, model TTS AirMASTER. Each sample was clamped securely in the test head, ensuring there were no wrinkles or leaks. A standard test pressure, 125 Pa, was applied across a test area of 38 cm^2, and the rate of air flow through the fabric was recorded in units of **$cm^3/cm^2/s$**.Five readings were taken from different sections of each sample, and the average air permeability was calculated.

4. Result and Discussion

4.1 Ends per inch and picks per inch

At 0- wash samples, ends per inch (EPI) and picks per inch (PPI) were found same in both virgin and recycled polyester fabrics i.e. EPI: 54 and PPI :46. After 2-wash and 4-wash cycles, both EPI and PPI increased slightly to 56 and 48 respectively. The change in EPI and PPI was observed because of first 2- washes, thereafter no change was seen which means minor fabric shrinkage or yarn relaxation due to first 2-washing. Importantly, the values were identical across polyester types, suggesting that fabric construction remained structurally consistent irrespective of the polyester types(virgin and recycled). Figure 3(a-b) shown the details of EPI and PPI of fabric in 0-washed, 2-washed and 4-washed conditions.



(a) (b)

Figure 3 (a-b): Effect of washing on fabric EPI and PPI

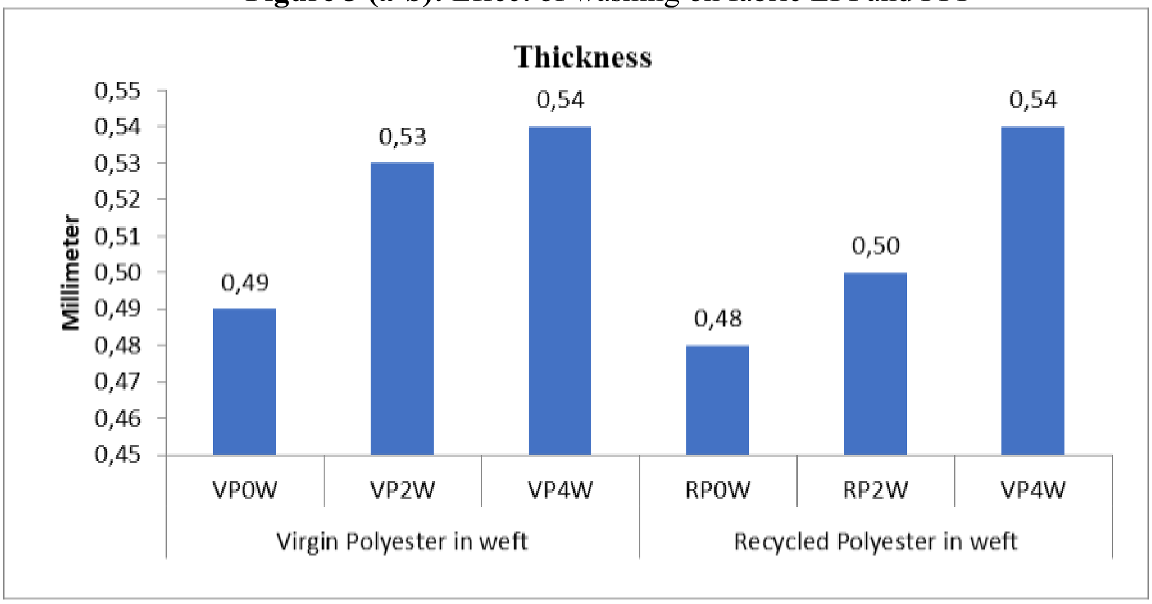


Figure 4: Effect of washing on fabric thickness

4.2 Fabric thickness

Virgin polyester fabric thickness increased from **0.48 mm (0-wash)** to **0.50 mm after two washes,** and then increased at **0.54 mm after four washes. Recycled polyester** showed a similar pattern, starting at **0.49 mm**, increased to **0.53 mm after two washes,** and then increased to 0.54 mm after four washes. Thickness increase maybe due to yarn swelling during washing.

The minimal increase and subsequent stabilization in thickness for both fabric types indicate **good dimensional stability** under repeated laundering. Overall, the thickness values remained**within acceptable limits** for both virgin and recycled polyester fabrics, as reflected in **Figure 4.**

4.3 Fabric weight

The fabric weight (GSM) of both fabric types **increase gradually after repeated washing. Virgin polyester increased from 226 GSM to 235.5 GSM** after two washing, and then after it increased to 237 GSM after four washing and **recycled polyester increased from 229 GSM to 235.7 GSM** after two washing then after it increased to 238 GSM after four washing cycles (refer **Figure 5**). This increasein GSM reflects **relaxation in yarn, in recycled polyester it is little higher due to more relaxation than virgin polyester after washing.**

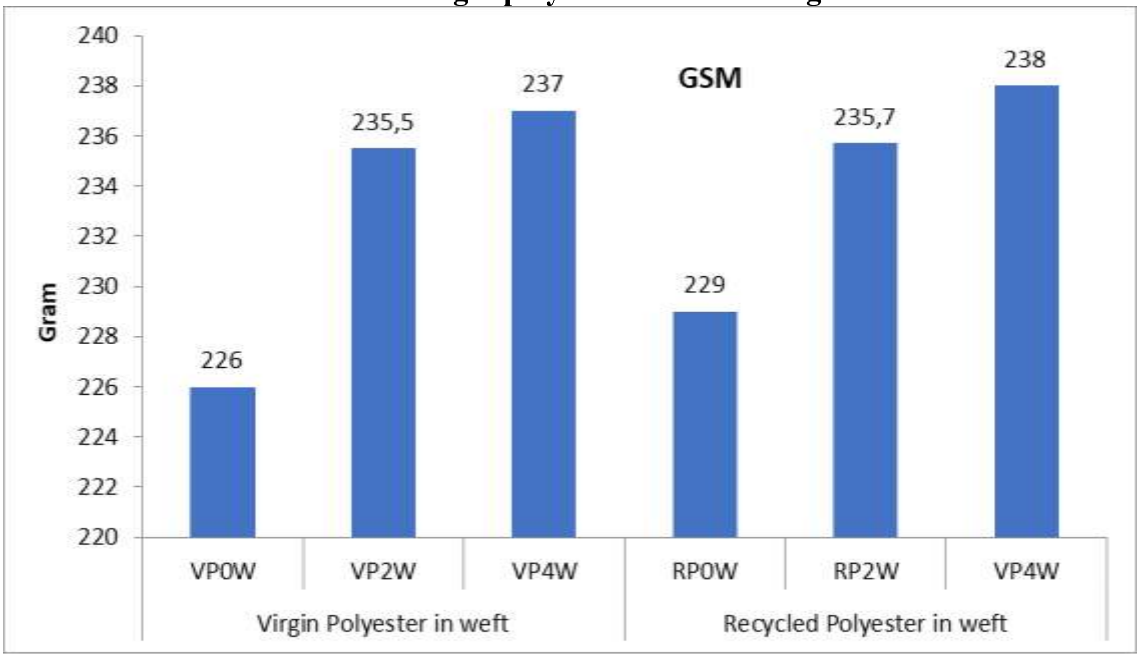


Figure 5: Effect of washing on GSM of fabric

4.4 Moisture content in fabric

Moisture content, in both cases (virgin and recycled polyester) increase progressively, in virgin polyester from 1.15% (0-washed) to 1.15% (after 2- washes), and then after it becomes 1.22% (after 4- washes).And in case of recycled polyester 1.55% (at unwashed condition) to 1.85% (after 2- washes),and then after it becomes 1.98% (after 4- washes) refer Figure 6. Increase in moisture content in case of recycled polyester is higher to virgin polyester fabric.

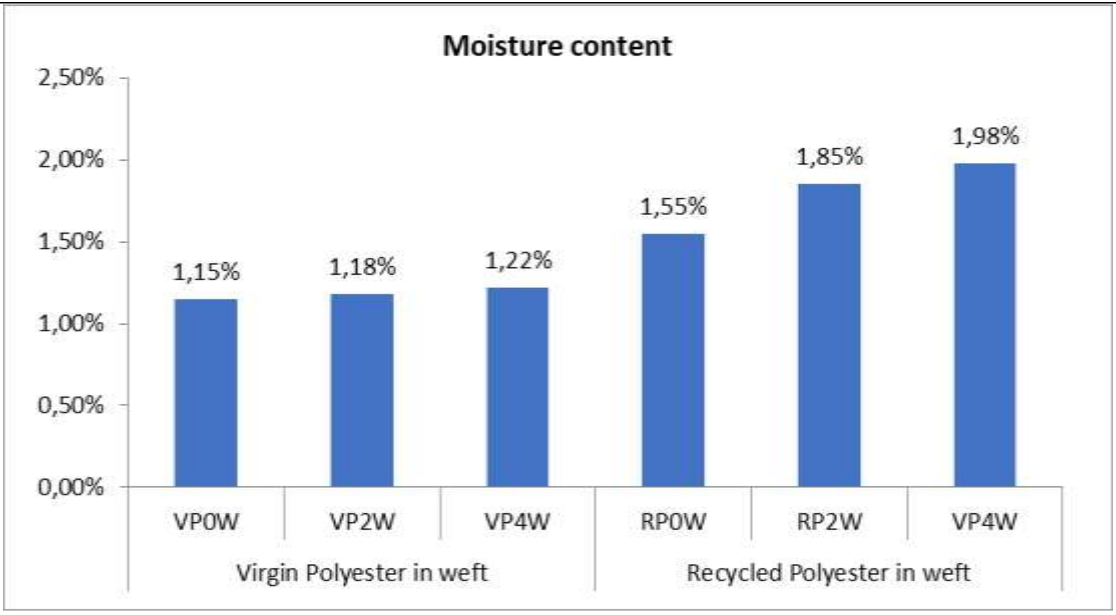
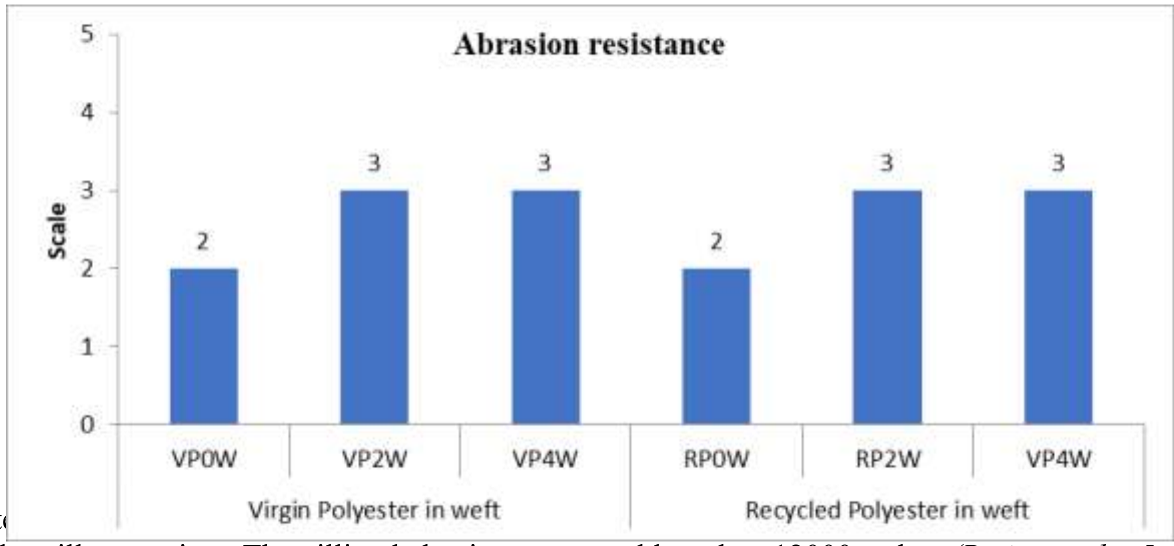


Figure 6: Effect of washing on Moisture content of fabric

4.5 Abrasion resistance

Both fabrics achieved consistent abrasion resistance ratings of 2 to 3 across washing cycles, with no significant difference between virgin and recycled polyester (refer Figure 7). This suggests that recycled yarns can withstand surface wear just as effectively as virgin ones. The moderate ratings indicate durability suitable for general apparel and upholstery usage after multiple washes.*(Rating scale: 5 = no pilling, 1 = severe pilling).*



3 to 2 aft[...]orm similar pills over time. The pilling behavior was tested less than 12000cycles. *(Rating scale: 5 = no pilling, 1 = severe pilling).*

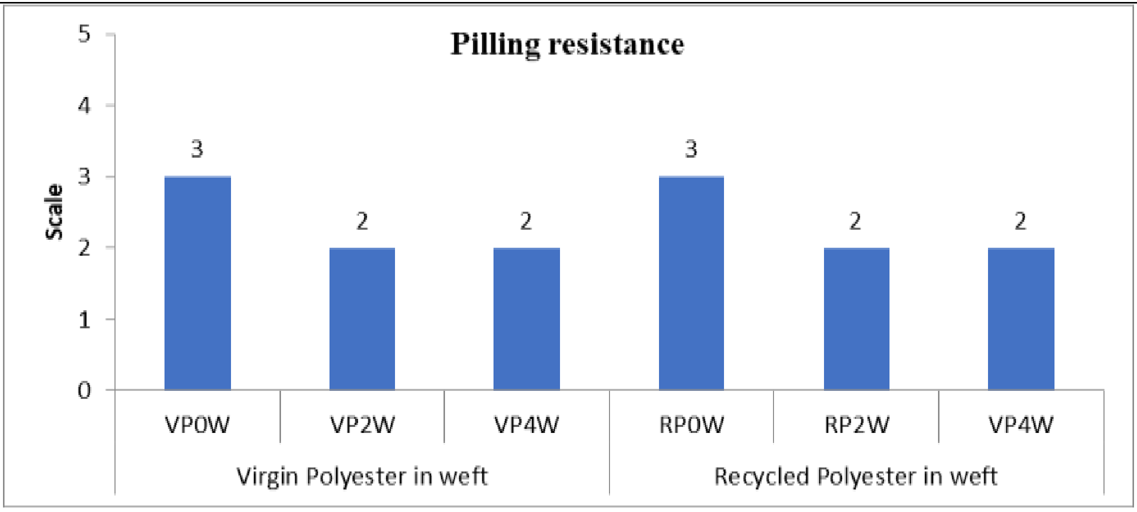


Figure 8: Effect of washing on Pilling Resistance of fabric

4.7 Crease recovery of fabric

Crease recovery angle is a critical parameter that indicates a fabric's ability to resist and recover from wrinkling or creasing. A higher crease recovery angle signifies better wrinkle resistance and fabric resilience, which is essential for maintaining the garment's appearance and ease of maintenance during wear and after laundering. This property is especially important in applications where aesthetic appeal and low-ironing requirements are desired.

Virgin polyester had superior crease recovery in the unwashed state in both the directions (80° warp, 75° weft) compared to recycled polyester fabric (76° warp, 72° weft). After washing, both fabric types shown decrease in their crease recovery angle (refer Figure 9).This is may be due to loss of surface finish, change in crystalinity.

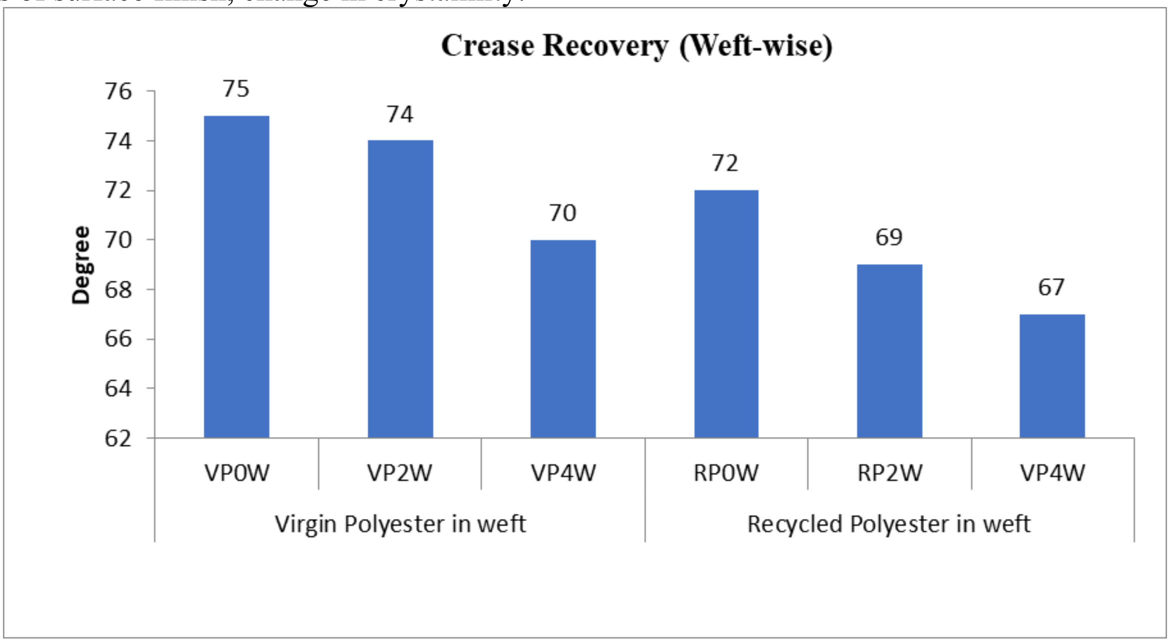


Figure 9: Effect of washing on Crease Recovery of fabric

4.8. Drape of fabric

Recycled polyester initially had a higher drape coefficient (64.75) than virgin (57.75), suggesting a stiffer fall. After four washes, both fabrics exhibited reduced drape coefficients, improving fluidity (refer Figure 10). Virgin polyester showed greater drape improvement, making it more suitable for applications where better drape and fall are desired after repeated usage (Figure 10).

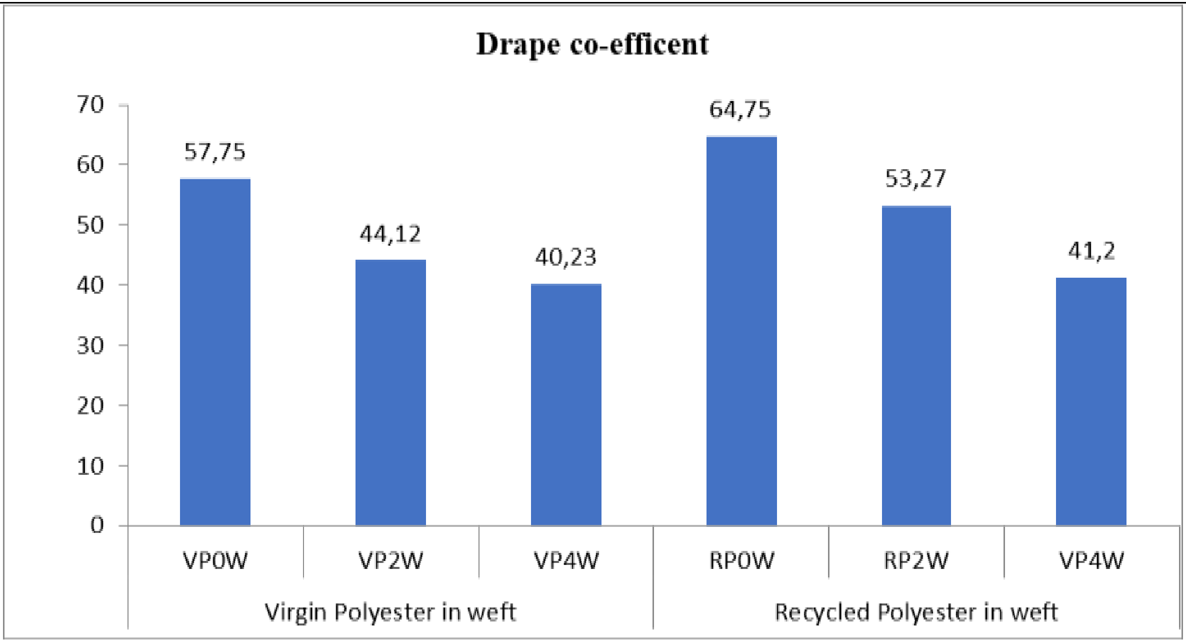


Figure 10: Effect of washing on drape of fabric

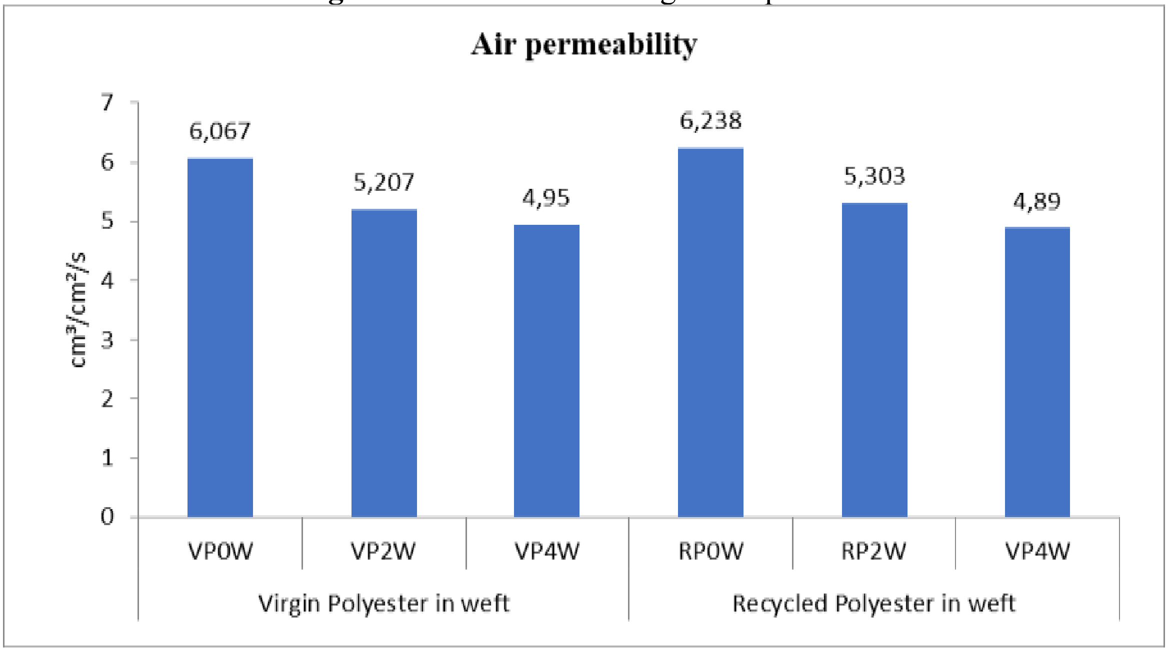


Figure 11: Effect of washing on air permeability of fabric

4.9 Air permeability

Recycled polyester consistently exhibited slightly better air permeability than virgin polyester across all three wash conditions. Both fabrics showed a decrease after washing, with values ranging from about 6.2 to about4.9 CFM (refer Figure 11). This decline is attributed to fabric compaction and yarn swelling. The higher permeability of recycled polyester indicates greater wearer comfort and breathability.

5. Conclusion

This study compared the influence of washing cycles on virgin and recycled polyester fabrics. Both fabric types showed similar trends across four washing cycles for most properties. Construction parameters (EPI/PPI) and GSM consistently increased after two washes, while thickness and tensile strength decreased. The main research findings of the study are as follows:

- The results reveal that the construction parameters such as EPI and PPI slightly increased after two washing cycle and thereafter, no any change was seen. The trend for both fiber types (virgin and recycled) was remained same after four wash cycle.

- The analysis of fabric thickness shown similar behavior between virgin and recycled polyester fabrics across different washing cycles. Initially, in the unwashed state, the **virgin polyester fabric exhibited a thickness** slightly greater than that of the **recycled polyester fabric.** After the first two washing cycles, **both fabric types demonstrated a reduction in thickness**, and this value remained **unchanged after the fourwash.**
- The analysis of fabric weight, expressed as **Grams Per Square Meter (GSM),** at the**unwashed staterecycled polyester fabric exhibited a slightly higher GSM**compared to the **unwashed virgin polyester fabric**. A consistent trend of **increase GSM** was observed for both fabric types after two and four washing cycles.
- The analysis of moisture content reveals, for the unwashed samples, recycled polyester exhibited higher moisture content compared to virgin polyester. A general trend of increase moisture content was observed for both types of polyester. Virgin polyester fabric showed aminor increase after two washes and further after four washes. Similarly, recycled polyester's moisture content increase after two washes and after four washes but the increase is higher in recycled polyester.
- At the analysis of abrasion resistance, in the unwashed state, both virgin and recycled polyester fabrics exhibited same abrasion resistance rating .After two washes, the rating for both virgin and recycled polyester fabrics improved, the study reveals that there is no significant difference in abrasion resistance between virgin polyester and recycled polyester fabrics across all washing conditions.
- Pilling resistances, at the unwashed state, both virgin polyester and recycled polyester fabric had a same pilling resistance rating. After washing (2-wash and 4- wash cycle) the pilling resistance of both fabric types showed similar behavior.
- Crease recovery, at the unwashed state, virgin polyester generally demonstrated superior crease recovery in both warp and weft directions compared to recycled polyester. The impact of washing cycles on crease recovery was higher in recycled polyester and found decrease in crease recovery angle.
- Drape, at the unwashed state, recycled polyester exhibited a higher drape coefficient compared to virgin polyester, indicating that the recycled fabric was initially stiffer and less drapable. However, a consistent and substantial improvement in drape (decrease in drape coefficient) was observed for both fabric types with increasing washing cycles.
- The analysis of air permeability reveals, at the unwashed state, the virgin polyester fabric demonstrated higher air permeability compared to the recycled polyester fabric. This initial finding suggests that the virgin polyester fabric is inherently more breathable .A consistent trend of decreasing air permeability was observed for both fabric types with an increasing number of washing cycles.

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