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# A COMPREHENSIVE PERFORMANCE EVALUATION OF RECYCLED COTTON AND BAMBOO VISCOSE BLENDS AS PILE YARN IN SUSTAINABLE TERRY FABRIC

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**Abstract**

The conventional textile industry, particularly the water- and resource-intensive production of terry fabrics, faces immense pressure to transition towards circular and sustainable models. The incorporation of recycled fibers and rapidly renewable alternatives into high-consumption products like towels represents a significant opportunity for reducing environmental impact. This research aimed to critically assess the technical feasibility and performance of using blended yarns from post-industrial recycled cotton and bamboo viscose as pile materials in terry fabric, providing a direct comparison to conventional virgin cotton across key functional properties. Three terry fabric samples were manufactured on a controlled loom setting with an identical 3-pick structure and pile height. The sole variable was the pile warp yarn: 1) 100% virgin cotton (control), 2) 50/50 recycled cotton/virgin cotton, and 3) 50/50 bamboo viscose/virgin cotton. The fabrics underwent rigorous testing for water absorption capacity and rate (AATCC 79), fabric softness (Handle-O-Meter, ASTM D6828), bursting strength (ASTM D3786), and abrasion resistance (ASTM D4966). The bamboo viscose blend demonstrated exceptional performance in comfort-oriented properties, exhibiting a 40% higher water absorption capacity and a 15% improvement in softness (lower bending length) compared to the virgin cotton control. In contrast, the recycled cotton blend showed water absorption comparable to the control but suffered a significant 20% reduction in both bursting strength and abrasion resistance. The bamboo blend's mechanical durability was intermediate, slightly lower than virgin cotton but substantially better than the recycled blend. Bamboo viscose is identified as a superior sustainable alternative for terry pile yarn, offering enhanced absorbency and a luxurious soft hand, making it ideal for premium products. Recycled cotton presents a viable pathway for reducing virgin material use but necessitates application in less demanding products due to its compromised durability. This study provides a scientific basis for material selection in the sustainable design of terry textiles.

**Keywords**: Sustainable Terry Fabric, Recycled Cotton, Bamboo Viscose, Circular Economy, Water Absorption, Bursting Strength, Abrasion Resistance.

## Introduction

The global textile industry is one of the largest polluters worldwide, with conventional cotton cultivation being a primary contributor due to its extensive water consumption, pesticide use, and land degradation [1]. Terry fabric, a staple in households and the hospitality sector, is particularly resource-intensive, relying heavily on virgin cotton to achieve its signature absorbency and softness. In this context, the principles of the circular economy—which emphasize waste reduction, resource efficiency, and the cycling of materials—present a transformative framework for the industry [2]. Integrating recycled fibers from post-industrial waste and alternative fibers from rapidly renewable sources into core products like terry fabric is no longer a niche trend but a critical imperative for environmental sustainability and long-term economic resilience.

Despite growing market interest and regulatory pressures, the adoption of recycled and alternative fibers in technically demanding applications like terry pile yarn remains cautious. The pile structure in terry fabric is subjected to significant mechanical stress during weaving, daily use, and repeated laundering. Its performance is paramount to the product's functionality and lifespan. Key concerns from manufacturers include:

* Whether recycled cotton, with its inherently shortened and weakened fibers, can provide adequate strength and durability in the looped pile structure.
* How bamboo viscose, known for its softness and absorbency but perceived lack of resilience, withstands abrasion and maintains loop integrity over time.

A significant gap exists in peer-reviewed, scientifically rigorous studies that quantitatively document the performance of these sustainable materials specifically in the terry pile application, comparing them directly to the industry standard of virgin cotton.

Existing literature provides insights into the general properties of these fibers but lacks specificity for terry pile applications. Studies on recycled cotton consistently report a reduction in mean fiber length and a higher short fiber content due to the mechanical and chemical stresses of the recycling process [3]. This directly translates to lower yarn tenacity and potential issues with pilling and abrasion resistance [4]. On the other hand, bamboo viscose is celebrated for its high moisture regain (approximately 13%, compared to 8% for cotton), exceptional softness, and natural luster, attributed to its micro-grooved structure and high porosity [5]. However, its wet strength and resistance to abrasive forces are generally lower than those of cotton [6].

While these studies lay a foundation, they predominantly focus on the fibers or yarns in isolation or in simple knit or woven structures. The performance of these materials when engineered into the complex, looped architecture of a terry pile, where properties like loop cohesion, three-dimensional absorbency, and multi-directional durability are critical, is not well-documented. This study builds upon this existing knowledge by applying it to a specific, high-value application.

The primary objective of this research is to conduct a comprehensive, comparative evaluation of the performance of terry fabrics produced using recycled cotton and bamboo viscose blend pile yarns against a conventional virgin cotton benchmark. The performance is assessed



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through key metrics of absorbency, tactile comfort (softness), and mechanical durability (bursting strength and abrasion resistance).
Based on the literature, we hypothesize that:
1. The **bamboo viscose blend** will outperform virgin cotton in terms of **water absorption capacity and fabric softness** due to its superior hydrophilicity and fiber smoothness.
2. The **recycled cotton blend** will exhibit **comparable absorbency** to virgin cotton but will demonstrate **inferior mechanical durability** (lower bursting strength and abrasion resistance) due to the compromised fiber length and strength from the recycling process.

## METHODS

The selection of materials was critical to ensure a fair and meaningful comparison. To isolate the effect of the pile yarn material, all other components were standardized.
* **Pile Warp Yarns (Variable):** All pile yarns had a final linear density of Ne 16/2 (2-ply) to ensure consistent fabric geometry.
  * **Sample VC (Control):** 100% virgin cotton. This represents the industry standard.
  * **Sample RC:** 50/50 blend of post-industrial recycled cotton and virgin cotton. The virgin cotton was blended to ensure spinnability and provide a baseline of strength.
  * **Sample BV:** 50/50 blend of bamboo viscose and virgin cotton. The virgin cotton was blended to mitigate the low wet strength and abrasion issues of pure bamboo viscose.
* **Ground Yarns (Constant):** Both the ground warp and the weft were made from 100% virgin cotton yarn of Ne 20/1. This ensured a consistent and stable ground structure for all samples, upon which the different pile yarns could be evaluated.
All three fabric samples were produced on the same automated shuttle loom to minimize machine-based variations. The loom was equipped with a positive let-off motion for precise pile warp control.
* **Weave Structure:** A standard 3-pick terry weave was used for all samples. This structure involves two picks locked into the ground fabric and a third pick that forms the loop when the loose pile warp is beaten up.
* **Constant Parameters:** To ensure that any differences in the final fabric properties were attributable solely to the pile yarn material, the following parameters were held constant:
  * Pile Height: 3 mm
  * Ends per Inch (EPI): 42
  * Picks per Inch (PPI): 68
  * Loom Speed and Tension Settings: Carefully calibrated and maintained.
All fabric samples were conditioned for 24 hours at 20°C ± 2°C and 65% ± 2% relative humidity (ASTM D1776) prior to testing. The following tests were conducted:
* **Water Absorption Capacity:** Two tests were employed:
  1. **Absorbency Rate (AATCC 79):** The time (in seconds) for a single drop of water to be fully absorbed by the fabric was measured. Ten measurements were taken per sample.
  2. **Total Water Holding Capacity:** A 10x10 cm fabric sample was weighed dry (W<sub>dry</sub>), fully immersed in water for one minute, hung vertically for 10 minutes

to drain, and then re-weighed (W<sub>wet</sub>). The water holding capacity was calculated as `[(W<sub>wet</sub> - W<sub>dry</sub>) / W<sub>dry</sub>] * 100%`.
* **Fabric Softness (Stiffness):** Measured using a **Handle-O-Meter** (ASTM D6828 - Standard Test Method for Stiffness of Fabric). The bending length (in cm) of a fabric strip was measured in the warp direction. A shorter bending length indicates a softer, more pliable fabric (i.e., better softness). Five specimens were tested for each sample.
* **Bursting Strength:** Determined using a hydraulic diaphragm bursting strength tester according to **ASTM D3786**. This test is particularly relevant for terry fabrics as it applies force multidirectionally, simulating the stress on the fabric from within the looped structure. The result is reported in kilopascals (kPa). Five tests were performed per sample.
* **Abrasion Resistance:** Conducted on a **Martindale abrasion tester** (ASTM D4966 - Standard Test Method for Abrasion Resistance of Textile Fabrics). The test was continued until the first sign of pile thread breakage or noticeable wear was observed. The number of cycles endured was recorded. A higher cycle count indicates better abrasion resistance.

**RESULTS**

The data collected from all tests were statistically analyzed, and the mean values for each property are reported below. The results clearly delineate the performance profiles of the three pile yarn materials.

The results for water absorption revealed significant differences between the samples, confirming the first part of our hypothesis.
* **Total Water Holding Capacity:** The **bamboo viscose blend (Sample BV)** demonstrated a remarkable water holding capacity of **35%**, meaning it could absorb 35% of its dry weight in water. This was substantially higher than the **virgin cotton control (Sample VC)**, which held **25%**. The **recycled cotton blend (Sample RC)** performed similarly to the control, with a capacity of **24%**.
* **Absorbency Rate:** The **AATCC 79 drop test** showed that Sample BV also had the fastest absorption rate, with water droplets being absorbed in an average of **1.5 seconds**. Sample VC and Sample RC were slower, with average absorption times of **2.1 seconds** and **2.3 seconds**, respectively.

These results position the bamboo viscose blend as the superior material for applications where high and fast absorbency is the primary requirement.

The Handle-O-Meter test provided quantitative evidence for the perceived softness of the fabrics.
* The **bamboo viscose blend (Sample BV)** was the softest, exhibiting the shortest average **bending length of 2.1 cm**.
* The **virgin cotton control (Sample VC)** was measurably stiffer, with a bending length of **2.5 cm**.
* The **recycled cotton blend (Sample RC)** was the stiffest of the three, with a bending length of **2.7 cm**.

This represents a **15% improvement in softness for BV over VC**, and an **8% reduction in softness for RC compared to VC**. The smooth, round filament-like structure of bamboo viscose fibers contributes directly to this luxurious hand-feel.
The tests for mechanical durability revealed a critical trade-off, confirming the second part of our hypothesis.
* **Bursting Strength:** The **virgin cotton control (Sample VC)** showed the highest resistance to bursting, with an average strength of **450 kPa**. The **bamboo viscose blend (Sample BV)** showed a moderate reduction, with a strength of **410 kPa** (a 9% decrease). In contrast, the **recycled cotton blend (Sample RC)** exhibited a significantly lower bursting strength of **360 kPa**, representing a **20% reduction** compared to the control.
* **Abrasion Resistance:** A similar trend was observed in the Martindale test. Sample VC withstood **25,000 cycles** before noticeable pile wear. Sample BV performed reasonably well, enduring **22,000 cycles** (a 12% reduction). Sample RC failed much earlier, showing wear after only **15,000 cycles** (a 40% reduction compared to Sample VC and a 32% reduction compared to the hypothesis).
These findings highlight the durability challenges associated with recycled cotton, while suggesting that the bamboo viscose blend, when reinforced with virgin cotton, offers acceptable durability for most end-uses.

## DISCUSSION

The results can be directly explained by the intrinsic properties of the constituent fibers.
The **superior absorbency of the bamboo viscose blend** is a direct function of its fiber morphology. Bamboo viscose fibers have a high degree of crystallinity and a micro-porous structure, which creates a large internal surface area for water molecules to occupy [7]. Furthermore, the amorphous regions within the cellulose structure of bamboo contain abundant hydrophilic groups (-OH), leading to a higher moisture regain than cotton. This combination of micro-porosity and high hydrophilicity facilitates rapid wicking and greater water retention [8]. The **enhanced softness** is attributed to the smooth, round cross-section and the long, fine filaments of the bamboo viscose, which reduce interfiber friction and create a pliable, silky hand.
The **significantly reduced mechanical durability of the recycled cotton blend** is a classic consequence of fiber damage during the recycling process. Mechanical shredding of pre-consumer or post-industrial cotton waste severely reduces the average staple length and weakens the individual fibers [3]. When spun into yarn, these shorter, damaged fibers result in a lower fiber-to-fiber cohesion and a higher propensity for fiber slippage under stress. This manifests as lower yarn tenacity, which directly translates to reduced bursting strength and poor resistance to abrasive forces, as the piles are more easily pulled out or broken [4].
The **intermediate durability of the bamboo viscose blend** can be explained by its lower abrasion resistance in pure form. However, by blending it 50/50 with strong virgin cotton fibers, the resulting yarn gains enough structural integrity to perform adequately. The virgin

cotton fibers act as a reinforcing scaffold, mitigating the inherent weakness of the bamboo viscose.

Our findings are in strong agreement with the general body of knowledge on these fibers. The work of [4] on recycled cotton yarn strength and [6] on the abrasion resistance of bamboo fibers is consistent with our quantitative results. The novelty of this study lies in contextualizing these properties within the specific performance requirements of a terry fabric pile. We have moved from general fiber properties to applied fabric performance, providing data that is directly actionable for product developers. The finding that a 50/50 bamboo-virgin cotton blend can achieve a balance of high comfort and acceptable durability in this application is a key contribution, addressing a common concern among manufacturers.

This study provides a robust initial assessment, but it is subject to certain limitations. Firstly, the research was confined to a single blend ratio (50/50). The performance landscape could shift significantly with different proportions (e.g., 30/70 or 70/30). Secondly, the study evaluated the fabrics in their "as-woven" state. The impact of repeated home laundering—which involves mechanical action, chemicals, and heat—on the absorbency, softness, and durability of these sustainable blends is unknown and critical for assessing long-term value. Finally, the recycled cotton was sourced from post-industrial waste; the properties of yarns from post-consumer waste streams might differ.

The implications of this research are clear for the terry fabric industry. **Bamboo viscose blends** are highly recommended for the **premium product segment** (e.g., luxury bathrobes, high-end towels) where superlative absorbency and a soft, silken hand are the primary marketing and functional attributes. **Recycled cotton blends** offer a viable route to **reduce the environmental footprint** and can be successfully deployed in products where extreme durability is not the main concern, such as light-duty kitchen towels, decorative towels, or hotel spa wear that is frequently replaced.

Future research should build upon these findings by:

1. **Optimizing Blend Ratios:** Systematically investigating a range of blend percentages for both recycled cotton and bamboo viscose to identify the optimal balance between sustainability, cost, and performance.
2. **Laundering Studies:** Conducting accelerated laundering tests to understand the durability of these sustainable piles over their lifecycle and their resistance to pilling and fuzzing.
3. **Life Cycle Assessment (LCA):** Conducting a cradle-to-gate or cradle-to-grave LCA to quantitatively compare the environmental benefits of these alternative piles against virgin cotton, providing a holistic view of their sustainability claim.

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