Investigating the Loss of Wicking Properties Due to Hard Washing of the Fabric Used for the Top Layer of the Period Underwear

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Keywords—period underwear, wicking, hard washing, feminine hygiene management, sustainability

I. Introduction

A period panty consists of three layers, a moisture wicking layer to transfer liquid away from the skin, absorbent layer to absorb liquid, and a protective layer to prevent leaking or staining [1]. The moisture wicking layer is made from a French terry material which has high wicking properties with a one-way transfer structure, allowing it to absorb the liquid and prevent it from returning to the surface. However, it has been observed that this wicking layer tends to lose its wicking properties after two LTD 30 hard washes. (One LTD 30 wash is approximately equal to twenty-five washes defined in AATCC 135 standard) When wicking properties of the top layer are lost, the liquid does not pass through to the absorbent layer, instead the liquid remains on the fabric surface. This will impair the functionality of the product and significantly reduce the comfortability of the wearer. Therefore, it is vital to find a solution to this issue to increase the durability of the product and to meet the requirements of the customer.

In this research, the root cause for this problem is investigated and methods to retain the wicking properties are suggested.

A. Aims and Objectives

Aim: Investigate the loss of wicking properties due to hard washing of the fabric used for the top layer of the period underwear.

Objectives:
1. Investigate the impact of hard washing on the fabric structure and finishes.
2. Identify the root causes for loss of wicking properties after a few hard washes.
3. Recommend methods to retain the wicking properties of the fabric after hard washes.

II. LITERTURE REVIEW

A. Menstruation and Feminine Hygiene Products

During menstruation, the female body sheds the uterine lining, involving blood, endometrial tissue, mucus, white blood cells, and bacteria. There are two main types of hygiene products: disposable and reusable [1]. Period underwear, is a type of reusable menstrual product providing an additional layer of protection against leakage and often including moisture-wicking and odour-control features [2].

B. The Usage of French Terry Fabric

French terry is a type of knit fabric that has a looped pile on one side and a smooth surface on the other. The loops on the pile side of the fabric are typically longer and more widely spaced than those on regular terry cloth [3]. Due to its exceptional moisture absorbance properties, it is used for a wide range of applications such as towels, sweaters, etc.

C. The Effect on Sustainability

Disposable menstrual products contribute to environmental issues due to non-biodegradable materials, prompting the need for increased awareness and research on sustainable alternatives to balance women's health and ecological concerns [4].

D. Moisture Transmission Techniques

There are two main methods for liquid moisture transfer: wicking and wetting [5]. Wicking and wetting are interconnected, with wetting being a prerequisite for wicking [6]. Wicking involves liquid moving along fibers, driven by interactions and pore structures. Wettability refers to initial liquid-substrate interactions. Wetting depends on surface tension, solid energy, and roughness, measured by the contact angle. High surface tension leads to droplet formation. Moisture-wicking relies on fabrics quickly moving moisture from skin to underlying layers, affected by fabric, fit, and activity. Capillary action, driven by adhesive forces exceeding cohesive forces, underlies moisture-wicking.

This research centers on the wicking properties of the top layer of period panties, crucial for wearer comfort. While cotton is conventionally comfortable, it is unsuitable due to low durability and bacterial growth concerns. Manufacturers opt for 100% Polyester due to its widespread use and synthetic nature. Polyester's molecular structure limits wettability, but its moisture transportation is effective [7]. The study highlights the French Terry fabric structure's role in improving wettability through capillarity. While studies explore moisture management in Polyester fabrics, fabric structure manipulation is the primary approach for enhancing wicking.

III. MATERIALS AND METHODS

A. Identifying and Confirming the Problem

1) Contact angle measurement test

Contact angles were determined on washed and non-washed fabric samples using water and a liquid with similar kinematic viscosity (2.9184 mm²/seconds at 37°C) to blood according to BS EN 13726-1:2002 standard. The contact angle was calculated using ImageJ image analysis tool after photographing the droplets on the fabric.

2) Moisture Management Test

The moisture management properties of the fabric before and after washing were evaluated using an SDL Atlas Moisture Management Tester (MMT) following the AATCC 195 test method.

B. Analyzing the Effect of Finishes

1) Fourier Transfer Infrared (FTIR) Analysis

The FTIR spectroscopy was conducted on untreated and treated samples using a Bruker FTIR machine in the 4000cm^{-1} to 400cm^{-1} range. This was done to analyze any changes caused by finishes to the polyester structure.

2) Scanning Electron Microscopy (SEM) with Energy Dispersive X-Ray Analysis (EDX)

To investigate the fabric's elemental composition at high magnification, SEM EDX analysis was done using the Zeiss SEM.

C. Studying the Changes of Fabric Structure and Properties

1) Pilling and Fuzzing

The surface of the treated-washed sample was observed for pilling or fuzzing using the BS EN ISO 12945 – 2 test standard.

2) Nature of the Surface

SEM images of the treated and non-treated samples before and after washing were taken. The magnification was adjusted to 70x to see wales and courses of the fabric clearly.

A vhx-5000 digital microscope was used to observe and analyze the morphology of the treated and non-treated, washed and non-washed samples.

3) Nature of the Yarn Surface

To observe the surface of the yarn, an MT optical microscope was used at 50x magnification level. Both ground yarn and pile yarn were observed.

D. Identifying the Root Cause

By analyzing the results and observations, the root cause was identified with the support of literature.

E. Suggesting and Experimenting a Potential Solution

According to the identified root cause, potential solutions were explored, and the following method was experimented.

A hydrophilic finish (Permalose AQUA) was applied to the washed fabric which had lost its wicking properties significantly. 16 ml of Permalose AQUA was added to a beaker and topped off with water to get a final volume of 400ml. 4-5 drops of acetic acid were added to make the medium acidic. Fabric was finished using the pot dyeing machine at around 70°C initially. The samples were kept in the machine for 30 minutes until the temperature reached 85°C. Then the temperature was again reduced to 70°C and the samples were taken out and air dried. A water drop test was conducted to check the wettability of the finished sample.

IV. RESULTS AND DISCUSSION

A. Contact Angle Measurement Test

TABLE I. RESULTS OF CONTACT ANGLE MEASREMENT TEST

Sample	Angle of water	Angle of viscous solution
Before washing	0	0
After washing (LTD 30*2)	131.71°	135.36°

The loss of wicking properties of the treated- washed sample was confirmed since both contact angles were more than 90°.

B. Moisture Management Test

The treated-washed sample exhibits poor wicking efficiency and extended wetting time, indicating reduced effectiveness in its role as a transport layer for period underwear. The study confirms a loss of wicking ability after undergoing two hard wash cycles.

C. FTIR Analysis

The FTIR spectra of untreated and treated samples reveal characteristic peaks associated with polyester fabric, such as the C=O vibration at 1707 cm^{-1} and the stable aromatic ring at 1404 cm^{-1}. Peaks at 1337 cm^{-1} and 1012 cm^{-1} suggest the presence of carboxylic ester or anhydride, with the latter indicating O=C–O–C or secondary alcohol. Despite minor variations, the FTIR spectra of the treated sample resemble those of polyester, implying that the finishing chemicals share similar chemical groups. This suggests the absence of distinct moisture-absorbent finishes or alterations to the fabric's surface wettability, potentially due to deep embedding or structural interaction of the finishing chemicals within the fabric.

D. SEM EDX

The presence Al, Ag, Cu, and Zn confirms the presence of anti-microbial and anti-odour finishes. A small amount of finishes have been washed off during hard washing. However, considering the small weight percentages, the contribution of the nano-level roughness created by finishing chemicals on loss of wicking properties of the fabric can be neglected.

E. Pilling and Fuzzing

Pilling was absent on both treated-washed and treated-non washed fabric surfaces. However, the treated-washed sample exhibited notable fuzziness, potentially hindering wetting due to air entrapments among protruding fiber fuzziness, which in turn could diminish wicking properties.

F. *Nature of the Fabric Surface*

TABLE II. SEM IMAGES OF FABRIC SAMPLES

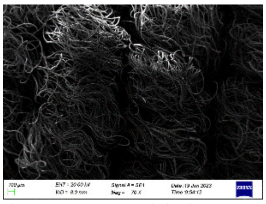
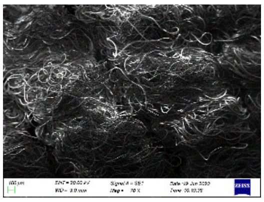
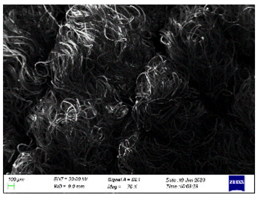
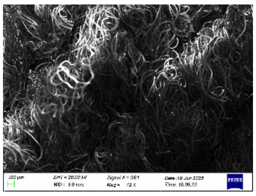
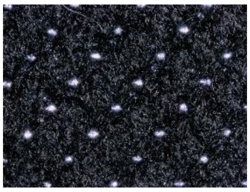
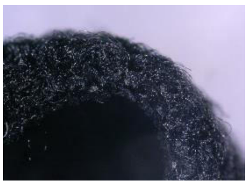
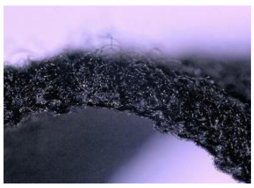
	Before Washing	After Washing (LTD 30*2)
Non-treated	 Fig. 1. Non-treated, before wash	 Fig. 2. Non-treated,after wash
Treated	 Fig. 3. Treated, before wash	 Fig. 4. Treated, after wash

TABLE III. DIGITAL MICROSCOPE IMAGES OF FABRIC SAMPLES

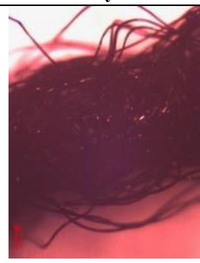
View	Before Washing	After Washing (LTD 30*2)
Front (50x)	 Fig. 5. Front, before wash	 Fig. 6. Front, after wash
Edge cut (50x)	 Fig. 7. Edge, before wash	 Fig. 8. Edge, after wash

The images reveal significant disruptions in the fabric structure following 2 hard washes, particularly evident in the edge cut where protruding fibers contrast with the smooth surface of the non-washed sample. This confirms the presence of increased surface voids in washed samples, potentially leading to trapped air and impeding liquid penetration.

G. *Nature of the Yarn Surface*

From the below table it can be observed that the yarns were significantly distorted after washing. These distortions further confirms voids in the washed fabric.

TABLE IV. OPTICAL MICROSCOPE IMAGES OF YARNS

Stage	Ground yarn	Pile yarn
Before washing	 Fig. 9. Ground yarn, before wash	 Fig. 10. Pile yarn, before wash
After washing (LTD30*2)	 Fig. 11. Ground yarn, after wash	 Fig. 12. Pile yarn, after wash

H. *Identifying the Root Cause*

According to the above results, there are more void spaces on the fabric surface. When a drop of liquid is placed, there is a higher possibility of forming air pockets between the liquid and the fabric, preventing the wetting of the surface. This can be further explained by the Cassie-Baxter equation for contact angles. [8]

$$\cos\theta_{CB} = r.f_{sl}.\cos\theta_E + f_{sl} - 1 \quad (1)$$

$\cos\theta_{CB}$ - Cassie-Baxter contact angle
$\cos\theta_E$ - Equilibrium contact angle
r – roughness factor
f_{sl} - areal fraction of solid-liquid

According to (1), when air pockets increase, f_{sl} decreases and contact angle increases.

This can occur in any application of French terry where rigorous washing processes are involved.

I. *Applying a Hydrophilic Finish*

The water drop test indicated successful wicking retention in the fabric treated with Permalose AQUA, as the water was quickly absorbed without beading. However, to ensure its effectiveness even after hard washes, the finish should be applied prior to washing with subsequent assessment like SEM, FTIR, or SEM XRD. Compatibility with other finishes, such as anti-microbial and anti-odour, should also be considered in future research.

V. CONCLUSION

No moisture-management finishes were present in the fabric. Consequently, the impact on wicking properties can be attributed solely to the fabric's surface structural changes. Microscopic images reveal a distorted fabric structure with increased protruding fibers due to rigorous washing, resulting in increased void spaces on the surface, capable of trapping air pockets. This trapped air disrupts the water-fiber contact angle, hindering surface wetting and wettability, thereby causing the loss of wicking properties. The wicking properties can be retained using a hydrophilic finish such as Permalose AQUA.

VI. RECOMMENDATIONS

If the hydrophilic finish is not durable when applied in fabric level, applying the finish at the yarn level before knitting is recommended.

In future research, it is recommended to use the mechanical model of wicking to derive relationships for capillary and other related forces.

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