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Analysis of moisture management behaviour of sanitary napkins

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This study aims to develop an exceptionally absorbent and comfortable feminine hygiene product. This involves crafting a surface layer exclusively composed of bamboo spun-laced material. The core layer incorporates varied blends of bamboo, flax, and hemp fibres combined in specific ratios to maximise comfort and absorbency. Enhanced absorbency is achieved by incorporating a super absorbent polymer (SAP) in the middle layer, swiftly locking in menstrual fluids. Fabrication involves mechanical extraction and processing of bamboo fibres for the top layer, while the core layers are formed using wet-laying techniques. Comprehensive testing evaluates moisture management performance, with wetting time measurements revealing superior absorption rates and spreading speeds in Sample S3, attributed to its optimal material composition. Additionally, Quantitative indices such as the Accumulative One-Way Transport Index (AOTI) and Overall Moisture Management Capacity (OMMC) further confirm Sample S3 as the top performer in efficiently absorbing and distributing moisture, ultimately ensuring user comfort and satisfaction. This detailed approach underscores the importance of material selection and structural design in producing high-quality sanitary napkins, emphasising the potential for sustainable and effective menstrual hygiene products.

Keywords: Bamboo, Moisture management, Sanitary napkin, Super absorbent layer

1 Introduction

In recent years, consumers are increasingly demonstrating heightened environmental awareness and engaging in eco-friendly consumer behaviours. The apparel industry is responding by prioritising environmental sustainability within its brand strategies, recognising the potential for both ethical practices and financial gains[1]. This shift in focus has driven demand for improving the environmental footprint of apparel products through measures such as recycling waste materials[2]. Sustainability, as defined by Frankel[3] and Elkington and Rowlands[4], encompasses the balance between economic, environmental, and social considerations. Green products are characterised by their use of recycled materials[5], and it's crucial that the finished products and their manufacturing processes are conducted with care to avoid environmental harm[6].

Within textile research, moisture management is a critical area of study, particularly concerning wearer comfort and product performance. Moisture management refers to the capacity of a textile material to absorb, transport, and evaporate moisture—both in liquid and vapour form—generated by the body. The human body produces heat throughout various activities, which can raise the body temperature above 37 °C and cause more perspiration. Fabrics act as a barrier between the body and its surroundings, regulating body temperature and transferring moisture from the body to the atmosphere. The process involves key parameters such as wetting, wicking, and moisture vapour transmission. Wicking describes the capillary movement of moisture across the fabric structure, while vapour transmission includes both diffusion across inter-yarn spaces and through individual fibres. Fibre properties, such as hydrophilicity or hydrophobicity, and structural features like porosity, thickness, and surface area collectively influence these mechanisms[7].

Several studies have explored the moisture transport properties of textile materials composed of natural and synthetic fibres. Süpüren *et al.*[8] discovered that fabrics with cotton exteriors and polypropylene interiors had superior moisturising qualities. Wardiningsih and Troynikov[9] reported that a higher cover factor lowers the material's overall ability for water management. Namlıgöz *et al.*[10] demonstrated that liquid transport of mixes of cellulose and polyester performs better than liquid transport of 100 % polyester and 100 % cotton. The moisture absorption characteristics of two-layer knits composed of polyester, bamboo, wool, mixes of polyester and wool, and wool were investigated by Troynikov and Wardiningsh[11].

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Moisture management plays a crucial role in determining how comfortable clothing is for the wearer by selecting the fabric's capacity to transfer water away from the body's surface. There are multiple steps in this process. Wetting precedes wicking and refers to the initial interaction between a liquid and a solid surface, replacing the solid-air interface with a solid-liquid one. Wicking enables moisture to spread across the fabric via capillary action, while moisture vapour transmission occurs through three primary pathways: diffusion through inter-yarn spaces, capillary transfer across fibre bundles, and diffusion through individual fibres. Each of these routes is influenced by the fibre’s physical and chemical properties, the structure of yarns and fabrics, and environmental conditions.

Capillary action in fabrics and yarns allows water to move across the surface more quickly, hastening the process of evaporation and drying. Fabrics can absorb moisture more easily because of the increased capillary action caused by the smaller gaps between fibres in textile structures. Higher surface area also plays a role in improved capillary action. The chemical makeup of the fibre's exposed surface greatly influences the surface energy of a textile construction[12].

Given the increasing demand for sustainable and high-performance hygiene products, this study focuses on developing a sanitary napkin composed of natural, biodegradable fibres—specifically bamboo, flax, and hemp—structured to maximise moisture management capabilities.

2 Materials and Methods

Sanitary napkins are necessary feminine hygiene products, offering comfort and protection and absorption during menstruation. This study aims to develop a sustainable and high-performance sanitary napkin with a top layer that is 100 % bamboo spun stitched for a smooth, skin-friendly surface, a middle layer of super absorbent polymer (SAP) and a core layer designed using three different proportions of hemp, flax, and/or bamboo fibres to enhance absorbency.

2.1 Materials

2.1.1 Surface Layer

100 % Bamboo Spun-laced Material: Bamboo fibres possess inherent softness, hypoallergenic properties, and biodegradability. Through the spun-lacing process, these fibres are transformed into a non-woven fabric with a web-like structure, ensuring a gentle and smooth surface against the skin.

2.1.2 Intermediate Layer

Super Absorbent Polymer (SAP): SAP is a highly absorbent substance capable of retaining liquid many times its own weight. Frequently utilised in sanitary napkins, it swiftly absorbs and locks in menstrual fluids, enhancing the product's effectiveness.

2.1.3 Core Layer: Bamboo Fibre

This material contributes to the core layer's softness and overall comfort, promoting a pleasant experience for the user. Flax Fibre: Adding to the core's absorbency and durability, flax fibre provides additional strength to the sanitary napkin. Hemp Fibre: Recognised for its absorbent properties and eco-friendliness, hemp fibre further enhances the absorbency of the core layer while aligning with sustainable practices.

2.2 Methods

2.2.1 Fabrication of Top Layer (Bamboo Spun-laced Material)

Bamboo fibres undergo mechanical extraction and subsequent processing into pulp. This pulp is combined with water to form a slurry. The slurry is then deposited onto a conveyor belt, where excess water is drained, forming a wet web. High-pressure water jets entangle the fibres, creating a spun-laced, non-woven fabric. Following this, the fabric undergoes drying, rolling, and cutting processes to achieve the desired dimensions for the top layer of the sanitary napkin.

2.2.2 Preparation of Middle Layer (Super Absorbent Polymer)

The selected SAP is acquired in granular form. These granules are uniformly dispersed onto the bamboo spun-laced top layer utilising a dispersion technique. To ensure even distribution and prevent clumping of SAP particles, the middle layer undergoes compression.

2.2.3 Formulation of Core Layer Combinations

Three distinct core layer combinations are developed:

Sample 1 (Bamboo 40 %: Flax 60 %): Bamboo and flax fibres are mechanically processed into pulps and blended in the specified ratio for a homogeneous mixture. This blend is then transformed into a core layer via a wet-laying process.

Sample 2 (Bamboo 40 %: Hemp 60 %): Bamboo and hemp fibres are subjected to mechanical extraction and pulp processing. These pulps are combined in the designated proportion to create a uniform blend, forming a core layer using the wet-laying technique.

Sample 3 (Bamboo 40 %: Flax 30 % + Hemp 30 %): Bamboo, flax, and hemp fibres undergo mechanical extraction and pulp processing. The resulting pulps are blended to achieve the desired composition, forming a core layer via wet-laying process.

Final Assembly: The SAP middle layer is interposed between the bamboo spun-laced top and core layers. These layers are securely bonded together using heat and pressure to ensure a leak-proof structure. The finished napkin is then trimmed to the appropriate shape and size and individually wrapped for hygiene and convenience (Fig. 1).

2.3 Quality Testing

The moisture management performance of the fabricated sanitary napkins is evaluated using the SDL Atlas Moisture Management Tester, following the AATCC 195–2009 standard. These tests are conducted to verify compliance with safety and efficacy standards. Fabric samples are conditioned before testing to ensure consistency. Key metrics such as wetting time, absorption rate, and spreading speed are recorded to assess the moisture handling efficiency of each sample.

Fig. 1 — Developed sanitary napkin

3 Results and Discussion

3.1 Wetting Time

The moisture management performance of the three developed sanitary napkins (S1, S2, and S3) is assessed by measuring wetting time on both top and bottom surfaces (Fig. 2). Wetting time indicates the speed at which moisture penetrates the napkin layers. Lower values reflect faster absorption and distribution, suggesting superior performance.

The data obtained from the wetting time measurements is analysed to evaluate the effectiveness of moisture management in the tested sanitary napkins. Among the tested sanitary napkins, sample S3 exhibits the shortest wetting time for the top surface at 2.98 s, followed by S1 (6.42 s) and S2 (9.37 s). This indicates that S3 absorbs moisture most rapidly, followed by S1 and S2. The differences in wetting times between the napkins suggest variations in their ability to absorb and distribute moisture effectively.

A similar trend is observed for the bottom surface, where sample S3 again demonstrates the shortest wetting time (4.01 s), followed by S1 (7.63 s), and S2 (9.91 s). The results imply that Napkin S3 facilitates rapid moisture penetration through both surfaces, enhancing user comfort. The differences in wetting times observed among the tested sanitary napkins can be attributed to variations in material composition and structural design. Napkin S3, with its superior moisture management performance, may have a more optimal combination of materials and construction methods that facilitate rapid moisture absorption and distribution. The disparities in wetting times also highlight differences in the permeability and absorbency properties of the materials used in each napkin. These findings underscore the importance of optimising material composition and structural design

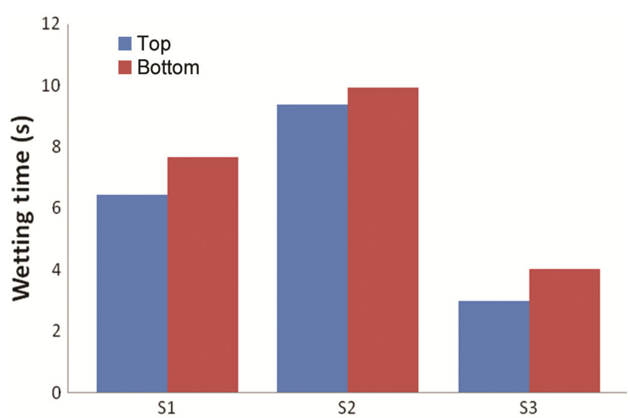

Fig. 2 — Wetting time of the developed sanitary napkins

to enhance moisture management performance in sanitary napkins, ultimately improving user comfort and satisfaction.

3.2 Absorption Rate

Analysing the absorption rates of the developed sanitary napkins, as measured on both the top and bottom surfaces, provides crucial insights into their effectiveness in managing moisture, a vital aspect of their performance and user satisfaction (Fig. 3). Sample S1 demonstrates an absorption rate of 34.39 % on the top surface and 29.32 % on the bottom surface. Sample S2 exhibits lower absorption rates, with 21.79 % on the top surface and 18.18 % on the bottom. Conversely, Sample S3 boasts the highest absorption rates among the three samples, registering 41.39 % on the top surface and 36.52 % on the bottom. Sample S3 emerges as the top performer, followed by S1 and S2.

Effective moisture management is essential for sanitary napkins to ensure user comfort, prevent leakage, and maintain overall hygiene. A higher absorption rate signifies that the napkin can quickly absorb and retain moisture, keeping the user dry and comfortable throughout their menstrual cycle. Sample S3, with its superior absorption rates, may offer excellent moisture management, making it a promising choice for users seeking reliable protection and comfort. Conversely, Sample S2's lower absorption rates indicate potential limitations in moisture management, which could lead to discomfort or the need for more frequent changes for users. In all cases, the absorption rate is higher on the top surface, directly interacting with the body and receiving most of the menstrual flow. This pattern is expected as the top layer needs to efficiently absorb and distribute moisture to the inner layers of the napkin. However, the differences between the top and bottom surface absorption rates vary among the samples. Sample S3 exhibits a relatively smaller difference between the two surfaces than Samples S1 and S2. This suggests that Sample S3's design may facilitate better transfer of moisture from the top to the bottom surface, ensuring more uniform absorption and reducing the risk of leakage or discomfort. On the other hand, Samples S1 and S2 show more significant differences between the absorption rates of the top and bottom surfaces. This could imply that these samples might have limitations in transferring moisture effectively through their layers, potentially leading to uneven absorption or leakage issues. In conclusion, the

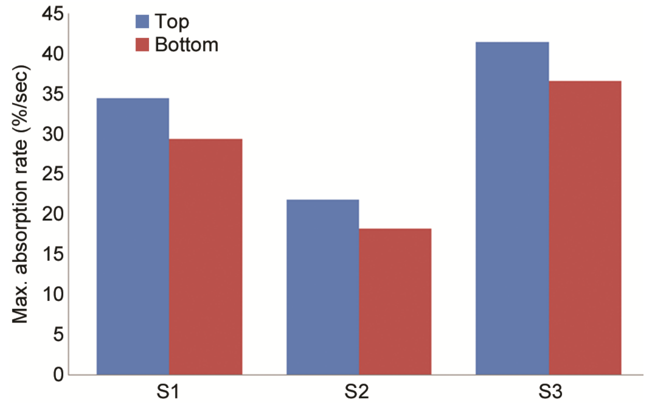

Fig. 3 — Absorption rate of the developed sanitary napkins

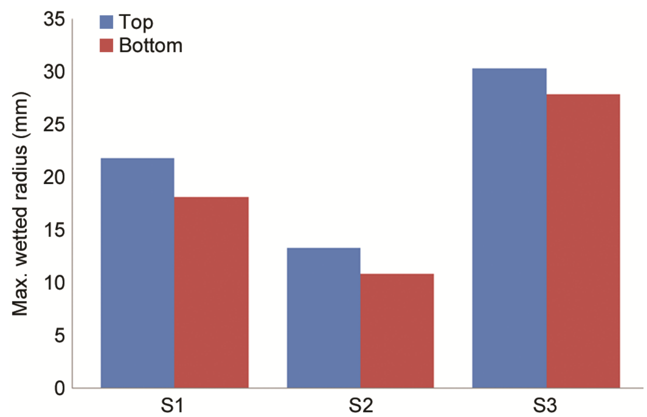

Fig. 4 — Maximum wetted radius of the developed sanitary napkins

absorption rates of sanitary napkins, as measured on both the top and bottom surfaces, play a critical role in determining their effectiveness in managing moisture and ensuring user comfort and protection.

3.3 Maximum Wetted Radius (MWR)

MWR reflects the extent of moisture spread across the napkin surface on both the top and bottom surfaces during the moisture management test (Fig. 4). Sample S3 again leads, with the top and bottom MWR values of 30.25 mm and 27.83 mm, respectively. This suggests that S3 has a greater capacity to spread and absorb moisture, potentially offering enhanced protection against leakage and keeping users feeling dry and comfortable. In contrast, S2 shows the lowest MWR values (13.31 mm top and 10.89 mm bottom). These lower values indicate that S2 may have limitations in effectively managing moisture, which could result in a higher risk of leakage or discomfort for users, especially during heavier flow days.

Sample S1 falls between S2 and S3 with MWR values of 21.78 mm on the top surface and 18.15 mm on the bottom. While not as high as S3, S1 demonstrates a moderate ability to spread and absorb moisture, suggesting satisfactory performance in moisture management. Examining the differences between the top and bottom surface MWR values within each sample provides valuable insights. In all cases, the MWR values are higher on the top than the bottom surface. This is expected, as the top surface of the napkin directly interacts with menstrual flow and requires greater moisture management capabilities.

3.4 Spreading Speed

Spreading speed quantifies the rate of moisture dispersion across the napkin surfaces, which is crucial for ensuring efficient absorption and preventing leakage. Figure 5 shows variations in the spreading speeds for both the top and bottom surfaces. Sample S3 demonstrates the highest spreading speeds of 5.967 mm/s (top surface) and 4.360 mm/s (bottom surface). This suggests that Sample S3 can spread moisture faster, indicating superior moisture management capabilities compared to S1 and S2. Sample S2 exhibits lower spreading speeds (3.259 mm/s on the top surface and 1.942 mm/s on the bottom). It indicates that S2 may have limitations in spreading moisture efficiently, which could lead to slower absorption and potentially increase the risk of leakage or discomfort for users.

S1 shows a moderate spreading speed of 3.634 mm/s (top) and 3.525 mm/s (bottom), indicating satisfactory performance in moisture management. In all cases, the spreading speeds are higher on the top surface than bottom. Faster spreading allows quicker fluid movement into absorbent layers, reducing surface wetness. S3's performance underscores its capacity to keep the surface dry and prevent leakage. The higher top surface speeds across all samples reflect their design focus on immediate contact areas.

3.5 Accumulative One-Way Transport Index

The Accumulative One-Way Transport Index provides a comprehensive measure of the moisture management capabilities of developed sanitary napkins. Sample S3 demonstrates the highest index value of 311.67, indicating superior performance in transporting moisture away from the body and through the napkin's layers (Fig. 6). Sample S3 is highly effective in keeping users dry and comfortable by efficiently absorbing and distributing moisture. In contrast, S2 exhibits a lower index value of 130.15, indicating comparatively lower moisture management capabilities. This suggests that Sample S2 may have limitations in transporting moisture effectively, potentially leading to dampness or discomfort for users. Sample S1 records a moderate value (252.44), revealing a satisfactory performance in transporting moisture, indicating effective absorption and distribution throughout the napkin's layers[13].

3.6 Overall Moisture Management Capacity (OMMC)

OMMC serves as a comprehensive measure of a sanitary napkin's ability to absorb, distribute, and transport moisture effectively (Fig. 7). Sample S3 exhibits the highest OMMC (0.611), indicating superior performance in maintaining dryness and comfort for users. This suggests that Sample S3 offers excellent absorption and moisture distribution

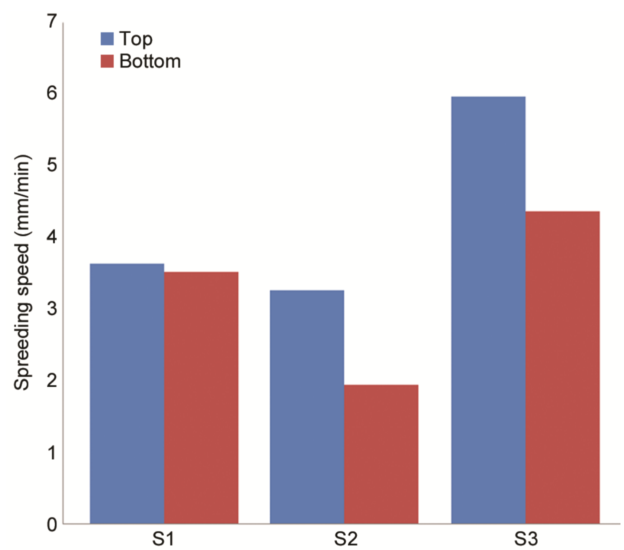

Fig. 5 — Spreading speed of the developed napkins

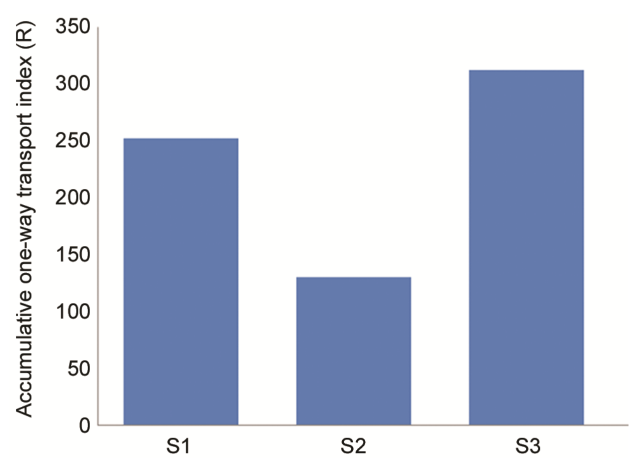

Fig. 6 — Accumulative one-way transport index of the developed sanitary napkins

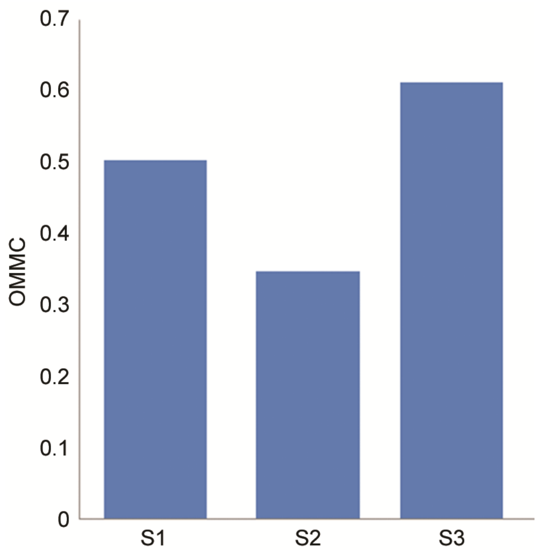

Fig. 7 — Overall Moisture management capacity of the developed napkins

capabilities, making it a promising choice for individuals seeking reliable protection[14].

In contrast, S2 demonstrates a lower OMMC (0.348), suggesting comparatively weaker moisture management capabilities. This indicates that Sample S2 may be less effective in absorbing and distributing moisture, potentially leading to discomfort or a higher risk of leakage for users. S1 shows moderate performance (0.503). Overall, the OMMC provides valuable insights into the sanitary napkins' overall moisture management capabilities, helping users make informed decisions based on their preferences for comfort and protection[15].

4 Conclusion

This study comprehensively evaluates the moisture management performance of three developed sanitary napkins (S1, S2, and S3) through a series of key parameters, including wetting time, absorption rate, maximum wetted radius, spreading speed, accumulative one-way transport index, and overall moisture management capacity. Among the tested samples, napkin S3 consistently demonstrates superior performance across all metrics, indicating enhanced fluid absorption, rapid moisture distribution, efficient one-way transport, and greater surface dryness. These findings underscore the critical role of material composition and structural design in optimising sanitary napkin performance. While S1 exhibits moderate efficiency suitable for average flow, S2 reveals limitations in moisture handling, suggesting the need for further material and structural enhancements. The results provide valuable insights for designing and developing of next-generation sanitary products that prioritise comfort, hygiene, and user satisfaction. By prioritising effective moisture management, manufacturers can enhance the performance of their products, ensuring superior comfort and protection for users throughout their menstrual cycle.

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