Characterizing Wettability Dynamics in High Performance Fabrics Made of Multicellulosic Fibers (Cotton, Flax, Modal, Bamboo, and Lyocell)

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Abstract:
This study investigates at the properties of high-performance fabrics manufactured using multiple cellulose fibers (cotton, flax, modal, bamboo, and lyocell) with different blending ratios. The primary goal is to compare the absorption capabilities of various cellulose fibers in water and dyes. The purpose of this research is to gain an understanding of how different cellulose fiber ratios interact with one another, taking into consideration their unique characteristics, presence in the fabric, and influence on absorption and dyeability. A total of 15 samples were produced with weft atlas 12 weave structures. The warp yarn were 100% polyester, while the weft yarns were made up of a variety of cellulose components. In order to evaluate the approach, we obtained five samples of only one type of cellulose fiber: cotton, flax, modal, bamboo, and lyocell, in a regular order. An extra ten samples were also collected. Each sample combines two distinct cellulose fibers, such as cotton and flax, cotton and modal, cotton and bamboo, etc. We estimated the proportion of each mineral in the combination, as indicated in the study, and used the immersion test to conduct the wet test on 15 samples. The immersion test findings, measured in seconds, reflect the rate at which liquid samples are absorbed, with shorter durations suggesting higher lubricant velocity. Statistical study revealed that sample 4, which only contained bamboo cellulose fiber, had the shortest time per second for vasectomy. This shows that bamboo fibers have a high capacity for absorption. Sample number five, which is primarily composed of lyocell cellulose fiber, exhibits quick absorption and a high moisture content, similar to the results of sample number four. The results show that sample 12, which had 27% flax and 14% lyocell, sample 13, which contained 19% modal and 19% bamboo, and sample 14, which contained 16% lyocell and 16% modal, were the most beneficial in speeding up the vasectomy operation. **The research problem** is as follows: The research problem is the need to characterize the wettability properties of high-performance woven fabrics made from different blend ratios of cotton, flax, modal, bamboo, and lyocell. The study aims to examine the effects of various yarn ratios on the absorption characteristics of cellulosic fibers in water and dyes. **Research Objectives**: Understanding the influence of the polymer structure of cellulosic fibers on the speed at which they absorb liquid is essential for maximizing their effectiveness in the manufacturing of high-performance fabrics. **Research Hypotheses**: 1. The difference in polymer content of cellulosic fibers influences wettability speed, dyeability, and color strength. 2. Cellulosic fibers with higher cellulose content have faster wettability and better dye absorption than fibers with lower cellulose content. Furthermore, the presence of hemicellulose and lignin in cellulosic fibers might affect their color strength and overall performance during dyeing operations. The difference in mixing ratio of cellulosic fibers also impacts wettability and dyeability. **Research Limits**: The research focuses on five cellouse fiber materials: cotton, flax, modal, bamboo, and lyocell. **Research Methodology**: This study combines an experimental and analytical methodology.

Keywords:
Wettability, Cellouse fibers, Dyeing, High Performance Fabrics

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Introduction:
The diverse properties of textile materials are intricately linked to the choice of fibers and the manufacturing and finishing processes employed in fabric production. Beyond functionality, the aesthetics of fabrics play a pivotal role in determining their suitability for various products. Cotton, a ubiquitous fibre in the textile industry, is predominantly dyed using reactive dyes [Abdur Rehman et al., 2018, BK et al., 2019, and Latif et

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al., 2018]. In contrast, linen, modal, bamboo, hemp, and lyocell offer versatility in dyeing and are compatible with both reactive dyes and direct dyes [Kavita, 2021].

The strength and extensibility of natural fibres vary significantly. Linen emerges as the strongest among them, followed by hemp, cotton, and banana fiber. linen exhibits low extensibility, while cotton stands out for its high extensibility, contributing significantly to mechanical comfort [BK et al., 2019].

Regenerated cellulosic fibres, although sharing similar chemical compositions, differ in density, molecular mass, degree of polymerization, supermolecular arrangement, crystallinity, and orientation. [Ryürek& Kılıç, 2018]. Bamboo fabric, characterised by its enhanced extensibility compared to cotton fabric, presents micro-gaps and holes in its cross-section, contributing to superior moisture absorption. [Subramanian, 2016] On the other hand, the water wicking of fabrics depends on the raw material used and is therefore related to the chemical structure of fibres and capillary forces. [Ozdemir, 2017].

Tencel, also known as Lyocell, represents another durable cellulosic fibre derived from eucalyptus wood [Badr et al., 2016]. The surface of Tencel fibres is remarkably smooth, with water absorption occurring exclusively in the capillaries between fibrils as the fibrils themselves do not absorb water [Çeven & Günaydın.2021]. The fabrics may be regarded as structures in which there is a spread of molecular order, ranging from highly ordered crystalline domains to disordered amorphous regions. [Abdur Rehman et al., 2018] The strength originates in the crystalline material, while the amorphous material provides flexibility. Therefore, the fabric properties, including dyeing properties, vary depending upon the relative degrees of order and disorder in the structure (often described as the crystalline/amorphous ratio) and also molecular alignment (degree of orientation), i.e., lower orientation and crystalline mean a higher rate of dye diffusion with these fabrics. [Kavita, 2021] Bamboo fibre has a crystallite size similar to that of ramie but larger than that of flax and cotton fibers. The cross-section of bamboo fibre is covered with various microspaces. [Simair et al., 2018] modal fibres, a special viscose fibre derived from beech wood. The cross section of modal is smoother than that of viscose, and the molecular weight is higher than that of viscose [Ozdemir, 2017].

The overall properties of a textile fabric structure are determined by a series of constructive parameters built in at different levels of material design. For example, the wetting behaviour and the final water uptake of a fabric will be determined by: [Jeon, 2012].

- Type of fiber material and fiber properties [Sekerden,2012]
- Technical construction of the yarn, e.g., spinning process, turns per metre, yarn count
- Fabric construction, e.g., plain weave. [Jeon,2012]

In addition to these structural considerations, the fabric's ability to absorb moisture through capillary action away from the skin is paramount. [Sekerden, 2012] This moisture transport and quick drying behaviour are largely dependent on the capillary capability and moisture absorbency of the fibres comprising the fabric. [Bait et al., 2019].

The phenomenon of swelling within porous regions of fibres plays a crucial role in fabric behavior. This swelling disrupts hydrogen bonds connecting crystalline units, leading to fibrillation, wherein external crystalline regions break and peel away from the fiber, resulting in fibrils. Leveraging this fibrillation effect can enhance fabric aesthetics and tactile qualities, often referred to as the "peach skin effect." [Badr et al., 2016].

Lyocell fabrics have wicking height values due to their high percentage of fibrillar structure. [Ozdemir, 2017] Tencel has a circular cross-section [Badr et al., 2016], so it leads to less surface area as compared to grooved structures. Bamboo fibre absorbs more than it spreads due to its grooved structure. Modal has small pores and very large pores toward the center. Tencel has a homogeneous distribution of pores in its whole structure [Badr et al., 2016], which makes it able to absorb and wick moisture well and is hence highly air permeable as water does not trap in pores and does not cause hindrance for air. [Latif et al., 2018] Tencel fibre is composed of structural subunits (fibrils) in the micro- and nanometer range. Different porous zones could be distinguished, partly confirming the crystallization model. The very first zones of the skin surface have a high porosity. A porous fibre middle zone is characterised by a gradual increase in porosity. Pores and cellulose domains are presumably surrounding the cellulose bodies. It also ends gradually towards the compact fibre centre, where the pores become tighter and the overall structure becomes more compact. [BK et al., 2019] Moreover, bamboo fabrics exhibit remarkable dyeing characteristics, requiring less dyestuff than cotton fabrics while showcasing superior colour absorption and retention. [Sekerden, 2012]

Experimental Work

This study used fabric with a, 66 ends, 33 picks per square centimeter, and an approximate area density of 300 g/m²., and the fabric was commercially colored.

A total of 15 samples were produced with weft atlas 12 weave structures. The warp yarn were 100% polyester, while the weft yarns were made up of a variety of cellulose components. In order to evaluate the approach, we obtained five samples of only one type of cellulose fiber: cotton, flax, modal, bamboo, and lyocell, in a regular order. An extra ten samples were also collected. Each sample combines two distinct cellulose fibers, such as cotton and flax, cotton and modal, cotton and bamboo, etc. We estimated the proportion of each mineral in the combination, as indicated in the study, and used the immersion test to conduct the wet test on 15 samples.

Methods:

For this investigation, we utilized five types of cellulosic yarns sourced from same manufacturer to serve as weft materials. These raw materials comprised cotton yarn (30/2Ne), flax yarn (16/1Ne), modal yarn (24/1Ne), bamboo yarn (30/1Ne), and lyocell (Tencel) yarn (30/1Ne). Employing a weaving machine equipped with a satin 12 weave structure and consistent picks per centimeter, we wove these cellulosic yarns. The warp yarns, constituting 100% polyester with a yarn count of 150 denier, were utilized consistently across all samples. In total, we produced 15 samples, varying in material composition and percentage.

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Wettability Test

The mechanism of wetting a fabric surface can be explained as follows: when a liquid droplet is placed on a solid surface, it forms a contact angle denoted by 'α' at the interface between the liquid and solid (see Figure 1). [19].

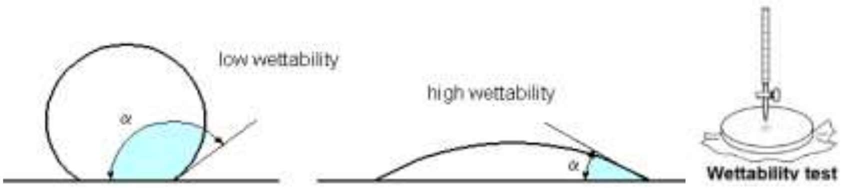

Figure (1) the contact angle on fabric

The tangent to both the liquid-vapor and slid liquid interfaces determines the angle in the liquid at the solid-liquid-air (vapor) interface.

The magnitude of the contact angle measures fabric wettability, while the equilibrium contact angle indicates the solid surface's wettability for liquid.

If the contact angle is less than 90 degrees, the liquid will wet the solid; if the angle is greater than 90 degrees, the solid surface will not be wettable.

The wetting process of a cloth in an aqueous medium lying on its surface predominantly involves wicking movement due to capillary forces, which comprises the following stages:

1- Spreading and penetration of the fibers below.
2- Radial spread is assisted by the liquid's absorption and adsorption into the substrate via capillary forces.

   The research found that all 15 samples had contact angles less than 90 degrees.

   The fabrics were tested to determine their absorption properties, namely in dyeing processes such as wetting (sinking method), vertical wicking (BS 3424), transverse wicking, and moisture vapor transfer (ASTM E 96 cup method).

   We evaluated fifteen samples for each criterion and compared their average values.

   An analysis of variance statistical method was used to investigate the effect.

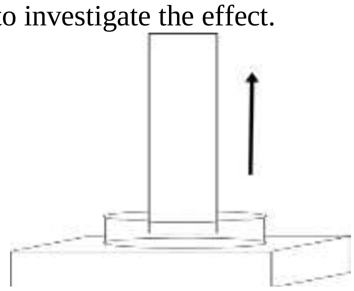

Figure (2) the fabric sinking in beaker.

We evaluated the fabric's wetting properties by measuring the time it took for a piece of fabric to sink completely from the surface layer of distilled water in a beaker.

We dropped each 3 cm × 3 cm fabric sample from a standard height and measured how long it took for the specimen to sink entirely in water.

Yarns produced from natural fibers had highly uneven capillary characteristics. [19]

Fabric Specifications andTest Results (Table 2) Samples specification and wettability Test Results

No.	Density /cm	Warp yarn rate in fabric %	Picks /cm Finished	Weft yarn rate in fabric %					Wettability, time, seconds (Sinking Method)
				Cotton 30/2 Ne	Flax 16/1 Ne	Modal 24/1Ne	Bamboo 30/1Ne	Lyocell 30/1 Ne	
1	72	49	35	51	---	---	---	---	2.26
2	68	47	34	---	53	---	---	---	3.03
3	68	61	34	---	---	39	---	---	1.83
4	72	69	35	---	---	---	31	---	1.59
5	72	65	33	---	---	---	---	35	1.6
6	71	48	33	26	26	---	---	---	2.63
7	72	55	34	29	---	16	---	---	2.3
8	72	59	32	27	---	---	---	14	2.4
9	72	61	34	26	---	---	13	---	2.5
10	72	55	34	---	30	15	---	---	2.64
11	72	56	32	---	29	---	15	---	1.99
12	72	59	32	---	27	---	---	14	1.7
13	72	62	34	---	---	19	19	---	1.83
14	73	68	34	---	---	16	---	16	1.8
15	72	66	34	---	---	---	17	17	1.83

Results and Discussions:

We tested and studied the fabric's ability to be completely submerged in water. As shown in Figure 3, fabrics containing lyocell yarns in the weft had faster sinking periods than those with cotton and flax yarns. Specifically, increasing the amount of cotton and flax yarns led to longer sinking periods for the materials.

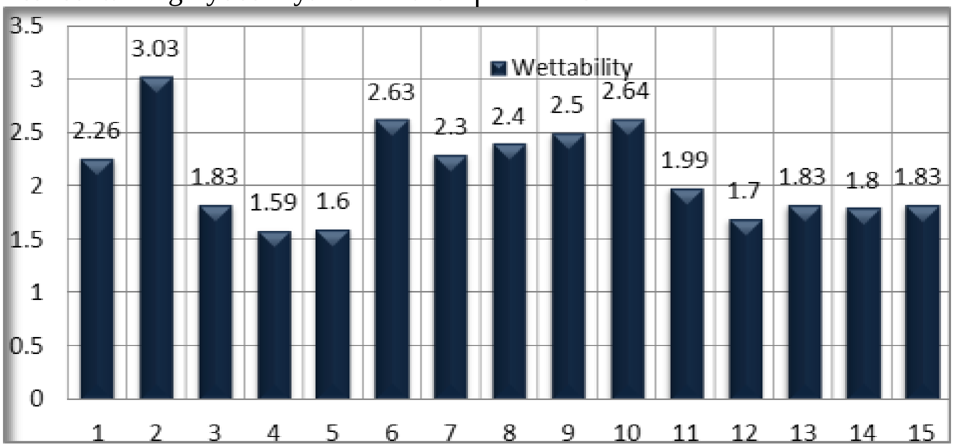

Figure (3). Reflect Wettability Test Results

Among the tested fabrics, Sample No. 5, which had lyocell yarns in the weft, performed the best in the wetting tests. Fabric No. 2, which had flax strands in the weft, had the least acceptable wetting qualities of the fabrics tested. Sample number one, with cotton yarns in the weft (51%) using 30/2 Ne yarn, was compared to sample number six, which included a blend of cotton yarns (26%) and flax yarns (26%), using 16/1 Ne. Cotton has a central lumen that remains after the cell wall collapses during fiber development. This lumen promotes water absorption and wicking by capillary action, making cotton a pleasant material. Cotton, on the other hand, has far lower wicking characteristics than regenerated fibers.

In sample No. 4, wettability times of 1.59 and 1.6 seconds were achieved. Samples 4 and 5 are made of bamboo and lyocell, respectively, but the other cellulosic materials had a higher wettability speed.

It is well understood that the wettability and absorption properties of cellulosic fibers are determined by their hydroxyl groups and crystalline regions.

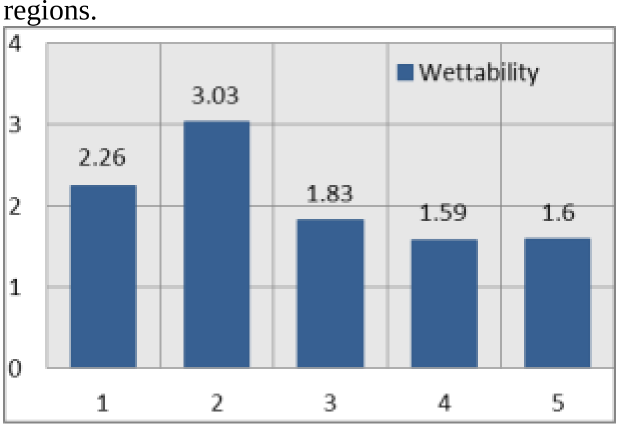

Figure (4) Reflect Wettability Test Results for sample 1 : 5

Natural bamboo fibers range in diameter from 14 to 27 µm, with an average of 20 µm. Natural bamboo fibers have less crystallinity than cotton and flax, which are similar to jute. Bamboo fibers are predominantly composed of cellulose (57-63%), with α-cellulose content ranging from 36% to 41%, lignin (22-26%), and pentosan (16-21%). Fabrics with more bamboo content in the weft direction have the highest absorption rates. Higher bamboo content causes water to spread faster. However, as the bamboo percentage grows, the fabric's total moisture management performance decreases.

The hydrophilic property of Tencel and bamboo fibers allows them to absorb some test liquid, which then permeates the fiber structure, resulting in less moisture spreading along the fabric. The dyeing rate of cellulose fibers varies depending on their supramolecular structures. These variances in dyeing rates, caused by variables in physical structure, have practical implications. Crystallites in cellulose fibers normally align parallel to the fiber axis. There are also lower-order regions and gaps between crystals. The typical size of crystallites and the quantitative ratio of crystallites to lower order regions vary depending on the fabric.

Figure (5) Figure (4) Reflect Wettability Test Results for sample 6 : 15

- From Figure 5, Samples 12-15 displayed a shorter wettability time, indicating a high ability to absorb liquid molecules and dyes. The presence of lyocell material in the wefts of samples 12-14-15, as well as bamboo material in samples 12-15, allows us to estimate this behavior. This confirms what was previously stated: the polymer system of bamboo and lyocell fibers allows for a higher absorption rate than cotton, flax, and modal.
- According to Figure 5, the highest time is attai ned in samples 6-10, where sample 6 contains cotton and linen a nd sample 10 contains flax and modal, indicati ng that cotton and flax are the cellulosic materi als with the lowest wettability.

Conclusion:

Based on our findings, we observed that incorporating bamboo and lyocell yarns into fabrics significantly improves their wettability. Fabrics constructed of 100% lyocell and 100% bamboo yarn had good wetting attributes and a high dye absorption capability. This can be attributable to both the fibers' inherent qualities and the fabric's structure.

Lyocell yarn-based fabrics produced deep and dazzling colors, with bamboo yarn coming as a close second in terms of color depth. Better yarn properties were obtained by increasing the amount of modal, bamboo, and lyocell in the fabric blend. This was in compared to the results obtained using cotton and flax yarn. Based on this information, it appears that these alternative fibers outperform ordinary cotton and flax in terms of fabric performance properties.

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